Measuring Soldier Performance During the Patrol-Exertion Multitask: Preliminary Validation of a Postconcussive Functional Return-to-Duty Metric

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Abstract:

Objective

To assess the discriminant validity of the Patrol-Exertion Multitask (PEMT), a novel, multidomain, functional return-to-duty clinical assessment for active duty military personnel.

Design

Measurement development study.

Setting

Nonclinical indoor testing facility.

Participants

Participants (N=84) were healthy control (HC) service members (SMs; n=51) and military personnel (n=33) with persistent postconcussive symptoms receiving rehabilitation (mild traumatic brain injury [mTBI]).

Interventions

Not applicable.

Main Outcome Measures

Known-groups discriminant validity was evaluated by comparing performance on the PEMT in 2 groups of active duty SMs: HCs and personnel with mTBI residual symptoms. Participant PEMT performance was based on responses in 4 subtasks during a 12-minute patrolling scenario: (1) accuracy in identifying virtual improvised explosive device (IED) markers and responses to scenario-derived questions from a computer-simulated foot patrol; (2) auditory reaction time responses; (3) rating of perceived exertion during stepping; and (4) self-reported visual clarity (ie, gaze stability) during vertical head-in-space translation while stepping.

Results

Significant between-group differences for the PEMT were observed in 2 of 4 performance domains. Postpatrol IED identification task/question responses (P=.179) and rating of perceived exertion (P=.133) did not discriminate between groups. Participant self-report of visual clarity during stepping revealed significant (P<.001) between-group differences. SM reaction time responses to scenario-based auditory cues were significantly delayed in the mTBI group in both the early (P=.013) and late (P=.002) stages of the PEMT.

Conclusions

Findings from this study support the use of a naturalistic, multidomain, complex clinical assessment to discriminate between healthy SMs and personnel with mTBI residual symptoms. Based on this preliminary study, additional research to further refine the PEMT and extend its application to return-to-work outcomes in military and civilian environments is warranted.

Keywords: Brain concussion, Mild traumatic brain injury, Military personnel, Multitask, Outcome measures, Performance-based assessment, Rehabilitation, Return to duty, Return to work, Validation

List of abbreviations

AMMP: Assessment of Military Multitasking Performance
HC: healthy control
IED: improvised explosive device
mTBI: mild traumatic brain injury
PEMT: Patrol-Exertion Multitask
RPE: rating of perceived exertion
RT: reaction time
RTD: return to duty
SM: service member
SRT: simple reaction time
TBI: traumatic brain injury

Service members (SMs) are at significant risk for mild traumatic brain injury (mTBI) given inherent vocational hazards associated with military training and warfighting. Since 2000, over 344,000 Department of Defense SMs have sustained TBI, with 82.3% of these cases classified as mTBI or concussion.1 Postconcussive neurocognitive, sensorimotor, or somatic sequelae can limit the ability of an SM to perform duty-related activities, resulting in degraded individual and unit readiness.2 In 1 report3 characterizing the impact of TBI on a deployed army brigade combat team, 92% of injured SMs endorsed somatic or neuropsychiatric symptoms acutely after mTBI, with 38.9% experiencing persistent postconcussive sequelae. While most postconcussive symptoms resolve within 7 to 10 days after injury,4, 5 the impact of persistent cognitive and sensorimotor deficits on complex, duty-relevant task performance has not been reported.

In deployed settings, mission success is contingent on the ability of SMs to execute timely, coordinated actions under conditions that are physically, cognitively, and psychologically demanding. Commanders must often make difficult decisions about whether an SM is capable of returning to duty (RTD) after mTBI, with limited prognostic resources.6 To date, RTD decision-making within the Department of Defense has been influenced largely by best practices described in the sports concussion literature, including reliance on patient-reported symptom severity at rest and during exertion,7, 8 instrumented or clinical measures of gaze9 or postural10 stability, and various neurocognitive testing approaches.2, 3, 7, 11

While return-to-play standards provide a reasonable starting point for readiness determinations within the Department of Defense, vocational demand distinctions between civilian and military personnel and known limitations in existing, impairment-level metrics suggest a need for more sophisticated and ecologically valid RTD metrics.2 Exclusive reliance on patient self-report of symptoms in the absence of appropriate and complementary objective measures may be of limited value to decision makers, given a tendency among SMs to downplay or “underreport” symptoms to expedite return to their unit when injured on deployment.12 Impairment-level outcome measures to guide RTD decision making may be similarly problematic among war fighters. Many lack sensitivity to high-level functional deficits, revealing ceiling effects when used to assess a highly conditioned warrior population. Existing clinical measures typically lack normative values in the age and activity range of the SM, and few have been validated in military populations. Use of standard clinical rehabilitation measures are further complicated by the absence of face validity among injured SMs and their leaders because it is unclear how substandard performance on an isolated body structure–based or function-based task relates to performance in their role as combatants.2

This discontinuity between existing RTD testing and its utility to evaluate real-world performance accentuates the importance of integrating ecologic validity into RTD assessments.13 There is growing support for ecologically valid testing methods to inform RTD decision making within the military.2, 13, 14, 15 Virtual reality applications have increasingly emerged as tools to assist military decision makers in assessing post-mTBI RTD readiness, given their versatility in replicating complex, real-world scenarios of vocational relevance to SMs.2, 14, 15

Military rehabilitation providers are exploring the utility of complex, dual-task, and multitask assessments to more appropriately gauge SM readiness.2, 7 Complex tasks are well suited for RTD assessment because, like real-world demands, attention must be allocated appropriately to perform multiple efforts successfully. Laboratory studies using complex task methodologies have revealed slower reaction times (RTs) and decreased task accuracy after concussion.16, 17 In recent years, a multidisciplinary group of military and civilian clinician-scientists has leveraged this approach to develop a battery of novel dual tasks and multitasks that integrate warfighter competencies to challenge known mTBI-related vulnerabilities.18 The Assessment of Military Multitasking Performance (AMMP) is composed of 3 dual tasks and 3 multitasks, and was designed to assess performance by concurrently tasking finite cognitive processing resources with physical and sensorimotor challenges.

One of these tasks, the Patrol-Exertion Multitask (PEMT), was developed to concurrently probe for symptoms of postconcussive exercise intolerance8 using an exertional task while engaged in a virtual reality patrol task to replicate the experiences of a deployed, dismounted warfighter.2 While technically a “multitask” given the need to engage in “multiple activities at the same time with serial switching of attentional priorities between activities,”19 the PEMT diverges from the traditional clinical definition of multitasking characterized by “discrete, interleaving tasks typically punctuated by interruptions as means to identify executive dysfunction.”20 The PEMT scenario requires engagement of cognitive resources, including situational awareness, memory, and decision making under conditions of moderate exertion. During the 12-minute assessment, participants view a custom-developed virtual patrolling scenario on a large computer monitor while responding to intermittent and unpredictable RT cues, reporting visual clarity and perceived exertion while stepping on and off a platform, similar to an exercise step test. The PEMT demonstrates excellent interrater reliability for the assessment of cognitive (intraclass correlation coefficient =.97), visual (intraclass correlation coefficient =.99) and exertional (intraclass correlation coefficient =.98) measurement metrics.21

The purpose of this report is to describe preliminary validation results for the PEMT. Discriminant validity was evaluated by comparing PEMT outcomes between known groups of SMs with residual mTBI sequelae and healthy SMs considered to be “duty ready.” Convergent validity was evaluated by correlating PEMT metrics of cognitive functioning and RT with standard neurocognitive tests of attention and simple reaction time (SRT). We hypothesized that PEMT outcomes in patient participants recovering from mTBI would differ significantly from those who were healthy, and that convergent validity measures would achieve moderate correlations.

Methods

Design and facilities

This measurement development study was conducted in a nonclinical testing facility at Fort Bragg, North Carolina. The PEMT was 1 of 6 functional assessment measures approved in a larger research protocol by the Womack Army Medical Center Institutional Review Board. All participants provided informed consent.

Participants

Active duty healthy control (HC) SMs between the ages of 18 and 42 years were recruited among volunteers at installation briefings or in response to recruitment flyers. HC participants were excluded if they reported a concussion within the 12 months preceding enrollment. Those with a remote history of concussion were required to be asymptomatic, deployable, and not currently receiving rehabilitation services. Participants with mTBI were recruited from a clinical population receiving outpatient rehabilitation services at the Womack Army Medical Center TBI Clinic for management of persistent postconcussive symptoms. Personnel recovering from mTBI sustained 2 weeks to 2 years before testing were eligible to enroll. Potential participants were excluded if current duty status was restricted with a military medical profile that prevented continuous activity for up to 30 minutes; if there was a history of psychiatric disorder, moderate, severe, or penetrating TBI; or if uncorrected hearing or visual deficits prevented functional hearing or vision.

In accordance with calculations22 to achieve a power of 80% to detect between-group differences, a sample of 51 “duty ready” HCs and 33 subjects with mTBI were enrolled in the study (table 1). One SM was excluded for lack of effort on the Test of Memory and Malingering, a test of exaggerated or deliberately faked memory impairment.23

Table 1. Participant demographics

Characteristic	HCs (n=51)	mTBI (n=33)	*P* (α=.05)
Age (y)	30 (19–42)	25 (19–42)	.001*
Sex: women	9 (17.6)	2 (6.1)	.188
Race: white	26 (51.0)	22 (66.7)	.181
College degree or higher	24 (47.1)	4 (12.1)	.002*
Service time (y)	8.0 (0.3–23.3)	3.6 (1.2–18.3)	.005*
Ready to deploy combat zone within 72h? (yes/no)	47 (92.2)	18 (54.5)	<.001*

Characteristic	HCs (n=51)	mTBI (n=33)	*P* (α=.05)
WRAT reading (standardized)	101 (80–134)	96 (70–119)	.050*

NOTE. Values are mean (range), n (%), or as otherwise indicated.

Abbreviation: WRAT, Wide Range Achievement Test.

* Statistical significance at $P<.05$.

Measures and procedures

Patrol-Exertion Multitask

The PEMT was designed to place functional demands on divided and alternating attention, prospective memory, visual attention, gaze stability, and auditory and visual processing in conjunction with simultaneous exertion. During this task, participants were challenged to gather information from a 12-minute virtual reality scenario depicting a first-person patrol in Afghanistan (Virtual Afghanistana) while reporting observed improvised explosive device (IED) markers. The scenario included 4 “tactical pause” stops for IED marker identification with a total of 13 targets observed during the scenario. After completion of the task, participants were asked 11 postpatrol questions related to their patrol experience (eg, grid coordinates, clothing colors, time, date, enemy vehicles, presence of IED components, and weapons) to functionally assess their attention and memory. Participants were asked to continuously step on a 6-in exercise step to simulate the demands of a patrol (fig 1) and maintain a heart rate between 65% and 85% of their age-predicted maximum heart rate.

Fig 1. PEMT setup. Participant performing continuous step ups on 6-in exercise platform at 65% to 85% of age-predicted maximum heart rate while monitoring virtual patrol scenario on computer.

Participants wore an army combat helmet, clear eye protection, and held a simulated M-4 weapon (Bluegunb) fitted with an instrumented trigger switch and audio cue transmitter. At 12 time points during the scenario, an audible tone cue was emitted from a speaker mounted on the top of the mock weapon. These tones were deliberately generated during periods of both minimal distractions (patrolling in a quiet environment) and during periods with multiple visual and auditory distractions. Participants were instructed to press the grip-mounted trigger switch as quickly as possible after each tone. RT was measured in milliseconds as the delay from the audible cue to when the trigger was activated and recorded via Bluetooth on the examiner's laptop.

To standardize the test exertion requirement, all participants wore a chest-mounted, sports-type heart rate monitor (Polar FT1c) with wrist watch display, allowing heart rate monitoring by the examiner. Age predicted maximum heart rate was calculated using the formula 220-Age. The 65% “lower” exertion threshold was calculated by 0.65 × (220-age) and the 85% “upper” exertion threshold was calculated by 0.85 × (220-age). Verbal cues were provided to increase participant stepping cadence if the participant's heart rate dropped below the 65% threshold. This moderate exertion was intended to simulate functional cardiovascular demands under submaximal patrolling conditions and as a possible trigger for exertional symptoms associated with mTBI. Participants were asked at baseline (standing still) and during the initial and the final 15 seconds of stepping to rate how hard they were working on a scale of 6 to 20 using a standard rating of perceived exertion (RPE) scale.24

Participants verbally rated their visual clarity on a scale of 0 (normal, clear and stable vision) to 10 (extremely blurry or jumpy vision, “the worst it could be”) at baseline standing still, during the first 15 seconds of stepping, and again at the end of the patrolling scenario during the final 15 seconds of stepping. Primary metrics included (1) IED marker/postpatrol question responses; (2) self-reported visual clarity; (3) self-reported RPE; and (4) instrumented RT responses.

Testing procedures

Testing for the battery of AMMP tasks, including the PEMT, an intake questionnaire, and a series of neurocognitive tests, was collected in a 1-time session lasting up to 3 hours. Intake information for the larger study included demographic information, military history, symptom report questionnaires, injury and behavioral health history, and a question about perceived readiness to be deployed to a combat zone in 72 hours. Standard neurocognitive tests administered included the Comprehensive Trail-Making Test,25 Test of Memory Malingering,23, 26 SRT,27 and Wide Range Achievement Test Version 4–Reading Test28 as an estimate of intelligence. The Comprehensive Trail-Making Test and Test of Memory and Malingering results were extracted from the medical record for mTBI participants. All other cognitive tests for HC and mTBI subjects were administered at the time they were tested on the AMMP.

Statistical analysis

Data were entered and verified using an online Research Electronic Data Capture (REDCap)29 database. Descriptive analyses were performed on demographic and military history characteristics. Convergent validity was assessed using Pearson correlation coefficients that included PEMT metrics and cognitive assessments. These included correlations between the IED marker/postpatrol questions and the Comprehensive Trail-Making Test as well as the correlations between SRT and the “early” and “late” RT responses. “Early” RT responses were characterized as the mean response to the initial 6 of 12 tone cues (measured in milliseconds) and “late” RT responses were characterized as the final 6 of 12 tone cues provided. Correlation coefficients included 95% confidence intervals and a P value as a measure of the difference from zero. R Statisticsd was used for analysis of correlations. A sample size of 80 total participants provided 80% power to detect a correlation for expected convergence at a minimum of .30 assuming an alpha level of .05.

Discriminant validity between HC and mTBI cohorts was assessed using the nonparametric Mann-Whitney U test due to nonnormal distribution of the data based on the Kolmogorov-Smirnov test. This analysis reports the significance of between-group median differences when data are not normally distributed. Alpha was established at .05 for significance. Sample sizes of 50 and 30 in the HC and mTBI groups, respectively, provided 80% power to detect a medium effect size (0.3) using a 2-tailed analysis. Effect size22 for the Mann-Whitney U test was calculated as the z score divided by the square root of N (total observations), where the median is defined as >0.3 and <0.5. Mann-Whitney U and chi-square tests were used to evaluate group differences of continuous and dichotomous demographic characteristics. SPSS version 22e was used for these analyses.

Results

Between-group analyses revealed significant differences between HC and mTBI cohorts in 2 of 4 measures (table 2). Visual clarity symptoms reported during initial baseline stepping (P=.002) and during the final phase of the exertional protocol (P<.001) were significantly different. RT responses in HC and mTBI groups were different during both early (P=.013) and late (P=.002) portions of the PEMT protocol, with increased response latencies identified in the mTBI cohort. Total correct responses to identify IED markers and postpatrol questions did not distinguish between groups. Similarly, the median group report of RPE did not discriminate groups.

Table 2. PEMT HC and mTBI known-groups analysis

Task Component (Score Range, Anchor if Applicable)	HC Sample (n=51)	mTBI Sample (n=33)	*P*	Effect Size (Interpretation)
IED/patrol questions correct (0–24)	18.2±2.6 19.0 (11–22)	17.5±2.8 18.0 (10–22)	.179	NS
Baseline visual clarity (0–10, where 0=completely clear)	0.13±0.4 0 (0–2) n=45	0.79±2.3 0 (0–5) n=25	.002*	.38 (medium)
Posttest visual clarity	0.4±0.9 0 (0–4)	1.6±2.0 1 (0–8)	<.001*	.39 (medium)
Posttest RPE, Borg scale (6–20)	11.2±2.0 11 (7–15)	12.1±2.3 12 (7–17)	.133	NS
Early RT responses for stimuli 1–6 (ms)	590.4±224.1 538.8 (297.5–1305) n=48	681.6±216.9 640.0 (370–1400) n=32	.013*	.28 (small)
Late RT responses for stimuli 7–12 (ms)	547.1±209.7 535.2 (334–930) n=48	674.1±209.7 602.0 (471–1400)	.002*	.34 (medium)

NOTE. Values are mean ± SD, median (range), or as otherwise indicated. Effect size interpretation based on Cohen's[30] *d* values: *d*=0.1–.29 (small); *d*=0.3–.49 (medium); *d*=0.5 (large).
Abbreviation: NS, not significant (no effect size calculation for nonsignificant findings).

* Statistical significance at *P*<.05.

Correlation between total correct IED markers identification/postpatrol questions and the Comprehensive Trail-Making Test as a measure of attention and cognitive flexibility demonstrated no statistically significant relationship (n=77, r=0.2 [95% confidence interval, −.03 to .41], P=.082). SRT was tested before and after the full 6-task AMMP battery was administered. The prebattery SRT demonstrated significant (P=.018) but low correlation with RT during the PEMT (r=.26), while the postbattery SRT demonstrated moderate correlation with RT during the PEMT (r=.45, P<.001) (table 3).

Table 3. Pearson correlation coefficients for early and late patrol task RT and pre/post ANAM SRT

Test Phase (Early vs Late)	SRT (ANAM) Pre-AMMP Testing	SRT (ANAM) Post-AMMP Testing
Early patrol RT responses (mean RT for stimuli 1–6)	*r*=.18 95% CI: −.04 to .39 n=81, *P*=.104	*r*=.31 95% CI: .09 to 0.5 n=77, *P*=.006*

Test Phase (Early vs Late)	SRT (ANAM) Pre-AMMP Testing	SRT (ANAM) Post-AMMP Testing
Late patrol RT responses (mean RT for stimuli 7–11)	*r*=.26 95% CI: .05 to .45 n=81, *P*=.018[*]	*r*=.45 95% CI: .26 to .61 n=77, *P*<.001[*]

Abbreviations: ANAM, Automated Neuropsychological Assessment Metrics; CI, confidence interval; n, pooled sample size.

* Statistical significance at *P*<.05.

Discussion

As a component of the AMMP battery, the PEMT represents a novel approach to multitask development concurrently challenging multiple mTBI-susceptible domains.2 In addition to assessing facets of cognition (attention, memory, executive function, RT), the PEMT probes exertional tolerance and gaze stability under conditions of moderate exertion in a standardized, reliable,21 low-cost, and clinically feasible test to simulate vocational demands and improve the objectivity of RTD testing. The PEMT and other AMMP tasks were designed to challenge integrated functional performance and reveal residual deficits that become evident when limited and shareable brain resources are deliberately stressed,31 but are neither diagnostic nor mechanistic. Multiple studies32, 33, 34, 35, 36 have shown that postconcussive dual-task deficits in gait, obstacle clearance, and balance, measured in laboratory settings, persist over much longer time frames than cognitive deficits observed in single-task conditions. This type of concurrent multiple-domain testing is intended to reveal deficits in SMs that are not always evident from single-domain assessments.31, 37, 38

Study findings revealed between-group difference (P<.001) for self-reported visual clarity during 12 minutes of stepping. Blurred vision during head movement, known clinically as oscillopsia, is commonly attributed to excessive retinal slip on the fovea during head movement, and is pathognomonic for angular vestibulo-ocular reflex dysfunction. In 1 study39 characterizing a population of blast-exposed SMs with TBI, investigators reported between-group differences in pitch plane visual clarity during treadmill running using a visual analog scale for oscillopsia. Findings in that study distinguished between symptomatic (dizzy) and asymptomatic personnel. The functional significance of degraded visual clarity among previously concussed SMs in these data is uncertain however, given the absence of a concurrent dizziness self-report measure. While visual analog scale reporting of visual blurring during horizontal head movement has been reported in the literature,40, 41 a verbal symptom severity scale in response to vertical head movement has not yet been reported, and clinical change indices are not yet available. Of some anecdotal clinical interest was a finding in 1 participant who reported a postassessment visual clarity severity of 8 out of 10. From a screening perspective, a finding of oscillopsia on a functional RTD metric could be a valuable indicator for further assessment.

Scenario-based RT responses with concurrent physical and cognitive loads proved sensitive to group assignment for both the early ($P=.01$) and late ($P=.002$) portions of the patrol video (see table 2). It is possible that fatigue contributed to elevated mean response latencies among the mTBI group, with a 19% mean between-group latency difference for the late RT relative to a 14% differential for the early RT. Correlations of mean RT measures (early and late) during the PEMT with the baseline seated Automated Neuropsychological Assessment Metrics SRT (see table 3) were significant, although lower than anticipated, given the considerable variance associated with performance testing in cohorts with neurologic dysfunction. These findings align with emerging evidence in the concussion literature42 that demonstrates that integration of RT into multimodal assessment strategies increases the sensitivity of testing in civilian athletes.

Identification of IED markers and postpatrol questions ($P=.179$) did not distinguish groups. While the median of mTBI responses was slightly lower than that of the HCs (see table 2), it is likely that the cognitive tasks of the PEMT simply lacked the difficulty for experienced SMs of either group. Deficits were apparent in the concurrent RT measure, indicating that the combination of cognitive and exertional challenge did stress cognitive resources. Complex and ecologically valid assessment techniques that use dual-task,32, 33, 34, 35, 36, 43, 44 multitask, including virtual reality,15, 45 and novel military-specific assessment tasks46 are being developed to assist decision-making related to RTD assessment after concussion. It appears likely that the memory and recognition challenges embedded in the virtual patrolling scenario did not exceed finite and sharable intellectual resources in cognitive domains stressed by the PEMT. Recent findings suggest that physical tasks that require movement planning, such as climbing or the use of a footwork ladder,44 are more disruptive to concurrent cognitive task performance. Similarly promising is the use of interactive virtual reality avatar platforms to identify executive dysfunction between healthy SMs and those with mTBI residuals.15 Military personnel and athletes may prioritize physical components of a dual-task or multitask over the cognitive either because of an innate cultural bias of excellence in physical performance or because of an internal recognition that failure of the movement task could result in injury.43, 44

Symptom report after 2 minutes of exertion is 1 component of a standard RTD protocol46, 47; however, most military tasks require sustained exertion. While TBI has been shown to affect RPE during treadmill testing (especially acutely),48 stepping was selected as the physical challenge for the PEMT to enhance clinical feasibility and given its similarity to dismounted patrolling. In military deployment or clinics with limited space, clinician access to exercise equipment may be limited, making the PEMT more feasible. During the PEMT, the HC group demonstrated a slightly lower RPE than did those with mTBI (see table 2); however, the difference was not significant ($P=.133$). Examiners observed that participants of both groups required frequent cueing to maintain the minimum 65% age-predicted maximum heart rate threshold, potentially causing an exertion ceiling effect. It is not clear whether this behavior was related to fatigue, distraction, requirements for auditory or visual clarity, or perhaps a more deliberate strategy of reducing physical activity to allow for allocation of resources to the cognitive demands of the patrolling scenario. Youth and elevated physical fitness levels in SMs may have superseded the relatively easy stepping challenge for the groups. Another potential explanation for this finding related to video gaming and exertion49 could be that for both groups, the perception of exercise intensity (RPE) while watching the virtual patrol is lower than the perception of exercise intensity (RPE) during exercise alone.

An important argument for multitask assessment is its enhanced ecologic validity and presumed likelihood that findings would more closely predict real-world functioning.14, 18 Traditional multitasking characterized by interleaving, prospective memory tasks, and adherence to multiple rules has demonstrated great utility in the naturalistic assessment of persons with executive dysfunction.50 These assessments have not traditionally measured performance relevant to physically demanding and risk-susceptible professions such as the military, law enforcement, or firefighting. By integrating structured exertional testing, symptom reporting, and sensorimotor assessment with neurocognitive challenges, the PEMT represents a first attempt to provide a novel, lower-cost approach to readiness assessment that could be tailored to meet the vocational demands of civilian or military patients recovering from concussion.

Study limitations

Study findings revealed significant between-group differences for years of education, military service, and Wide Range Achievement Test scores (used as a measure of intelligence). These group differences may have contributed to bias in study findings, limiting interpretation of results. Additionally, the integrated and functional nature of PEMT performance in cognitive, exertional, and gaze stability domains limits investigator inference related to underlying mechanisms in the study.

Conclusions

The PEMT represents a novel approach to multitask performance testing with the potential to inform RTD or return-to-work decision making in operational vocations. This measure demonstrated selective discriminant validity between HCs and SMs rehabilitating from concussion. Research to further refine the PEMT and extend its application to return-to-work outcomes in military and civilian environments is warranted.

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d. R Statistics; R Foundation for Statistical Computing. Available at: https://www.r-project.org.
e. SPSS version 22; IBM Corp.

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References (Endnotes)

1 Defense and Veterans Brain Injury Center**DoD worldwide numbers for TBI worldwide totals.** Available at: http://dvbic.dcoe.mil/dod-worldwide-numbers-tbi. Accessed January 1, 2017

2 M.R. Scherer, M.W. Weightman, M.V. Radomski, L. Davidson, K.L. McCulloch. **Returning service members to duty following mild traumatic brain injury: exploring the use of dual-task and multitask assessment methods.** Phys Ther, 93 (2013), pp. 1-14

3 H. Terrio, L. Brenner, B.J. Ivins, *et al.***Traumatic brain injury screening: preliminary findings in a US Army Brigade combat team.** J Head Trauma Rehabil, 24 (2009), pp. 14-23

4 P. McCrory, W. Meeuwisse, M. Aubry, *et al.***Consensus statement on concussion in sport—the 4th International Conference on Concussion in Sport held in Zurich, November 2012.** Clin J Sport Med, 23 (2013), pp. 89-117

5 H.G. Belanger, G. Curtiss, J.A. Demery, B.K. Lebowitz, R.D. Vanderploeg**Factors moderating neuropsychological outcomes following mild traumatic brain injury: a meta-analysis.** J Int Neuropsychol Soc, 11 (2005), pp. 215-227

6 Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury**Concussion management in deployed settings version 4.0.** Available at: http://www.dcoe.health.mil/Content/Navigation/Documents/DCoE_Concussion_Management_Algorithm_Cards.pdf (2012). Accessed January 1, 2017

7 K.L. McCulloch, S. Goldman, L. Lowe, *et al.***Development of clinical recommendations for progressive return to activity after military mild traumatic brain injury: guidance for rehabilitation providers.** J Head Trauma Rehabil, 30 (2015), pp. 56-67

8 J.J. Leddy, J.G. Baker, B. Willer**Active rehabilitation of concussion and post-concussion syndrome.** Phys Med Rehabil Clin N Am, 27 (2016), pp. 437-454

9 K.R. Gottshall, M.E. Hoffer**Tracking recovery of vestibular function in individuals with blast-induced head trauma using vestibular-visual-cognitive interaction tests.** J Neurol Phys Ther, 34 (2010), pp. 94-97

10 L.A. King, F.B. Horak, M. Mancini, *et al.***Instrumenting the Balance Error Scoring System for use with patients reporting persistent balance problems after mild traumatic brain injury.** Arch Phys Med Rehabil, 95 (2014), pp. 353-359

11 L. French, M. McCrea, M. Baggett**The Military Acute Concussion Evaluation (MACE).** J Spec Oper Med, 8 (2008), pp. 68-77

12 T. Hettich, E. Whitfield, K. Kratz, C. Frament**Case report: use of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT) to assist with return to**

duty determination of special operations soldiers who sustained mild traumatic brain injury. J Spec Oper Med, 10 (2010), pp. 48-55

13 N. Chaytor, M. Schmitter-Edgecombe**The ecological validity of neuropsychological tests: a review of the literature on everyday cognitive skills.** Neuropsychol Rev, 13 (2003), pp. 181-197

14 J. Edwards, J. Vess, G. Reger, *et al.***The use of virtual reality in the military's assessment of service members with traumatic brain injury: recent developments and emerging opportunities.** Appl Neuropsychol Adult, 21 (2014), pp. 220-230

15 Robitaille N, Jackson PL, Hébert LJ, et al. A Virtual Reality avatar interaction (VRai) platform to assess residual executive dysfunction in active military personnel with previous mild traumatic brain injury: proof of concept. Disabil Rehabil Assist Technol. 2016 Sep 28. [Epub ahead of print].

16 P. Van Donkelaar, L. Osternig, L.S. Chou**Attentional and biomechanical deficits interact after mild traumatic brain injury.** Exerc Sport Sci Rev, 34 (2006), pp. 77-82

17 K.C. Siu, L.S. Chou, U. Mayr, *et al.***Attentional mechanisms contributing to balance constraints during gait: the effects of balance impairments.** Brain Res, 1248 (2009), pp. 59-67

18 M.V. Radomski, M.M. Weightman, L.F. Davidson, *et al.***Development of a measure to inform return-to-duty decision making after mild traumatic brain injury.** Mil Med, 178 (2013), pp. 246-253

19 Editors of the American Heritage Dictionaries**The American heritage dictionary of the English language.** (5th ed.), Houghton Mifflin Harcourt, Boston (2011)

20 P.W. Burgess**Strategy application disorder: the role of the frontal lobes in human multitasking.** Psychol Res, 63 (2000), pp. 279-288

21 M.M. Weightman, K.L. McCulloch, M.V. Radomski, *et al.***Further development of the assessment of military multitasking performance: iterative reliability testing.** PLoS One, 12 (2017), p. e0169104

22 C.O. Fritz, P.E. Morris, J.J. Richler**Effect size estimates: current use, calculations, and interpretation.** J Exp Psychol Gen, 141 (2012), pp. 2-18

23 T.N. Tombaugh**Test of Memory Malingering (TOMM).** Multi-Health Systems, New York (1996)

24 G.A. Borg**Psychophysical bases of perceived exertion.** Med Sci Sports Exerc, 14 (1982), pp. 377-381

25 C.R. Reynolds**Comprehensive Trail Making Test (CTMT).** Pro-Ed, Austin (2002)

26 A. Jones**Test of memory malingering: cutoff scores for psychometrically defined malingering groups in a military sample.** Clin Neuropsychol, 27 (2013), pp. 1043-1059

27 R.L. Kane, T. Roebuck-Spencer, P. Short, M. Kabat, J. Wilken**Identifying and monitoring cognitive deficits in clinical populations using Automated Neuropsychological Assessment Metrics (ANAM) tests.** Arch Clin Neuropsychol, 22 (2007), pp. 115-126

28 G.S. Wilkinson, G. Robertson**Wide Range Achievement Test (WRAT4).** Psychological Assessment Resources, Lutz (2006)

29 P.A. Harris, R. Taylor, R. Thielke, J. Payne, N. Gonzalez, J.G. Conde**Research Electronic Data Capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support.** J Biomed Inform, 42 (2009), pp. 377-381

30 H. Coolican**Research methods and statistics in psychology.** (5th ed.), Routledge, London (2009)

31 A. Tapper, D. Gonzalez, E. Roy, E. Niechwiej-Szwedo**Executive function deficits in team sport athletes with a history of concussion revealed by a visual-auditory dual task paradigm.** J Sports Sci, 35 (2017), pp. 231-240

32 T.M. Parker, L.R. Osternig, H.J. Lee, P. Donkelaar, L.S. Chou**The effect of divided attention on gait stability following concussion.** Clin Biomech (Bristol, Avon), 20 (2005), pp. 389-395

33 T.M. Parker, L.R. Osternig, P. van Donkelaar, L.S. Chou**Gait stability following concussion.** Med Sci Sports Exerc, 38 (2006), pp. 1032-1040

34 P. Fait, B.J. McFadyen, B. Swaine, J.F. Cantin**Alterations to locomotor navigation in a complex environment at 7 and 30 days following a concussion in an elite athlete.** Brain Inj, 23 (2009), pp. 362-369

35 E.F. Teel, J.K. Register-Mihalik, J. Troy Blackburn, K.M. Guskiewicz**Balance and cognitive performance during a dual-task: preliminary implications for use in concussion assessment.** J Sci Med Sport, 16 (2013), pp. 190-194

36 C.S. Baker, M.E. Cinelli**Visuomotor deficits during locomotion in previously concussed athletes 30 or more days following return to play.** Physiol Rep, 2 (2014), p. e12252

37 L.C. Henry, R.J. Elbin, M.W. Collins, G. Marchetti, A.P. Kontos**Examining recovery trajectories after sport-related concussion with a multimodal clinical assessment approach.** Neurosurgery, 78 (2016), pp. 232-241

38 J.K. Register-Mihalik, A.C. Littleton, K.M. Guskiewicz**Are divided attention tasks useful in the assessment and management of sport-related concussion?** Neuropsychol Rev, 23 (2013), pp. 300-313

39 M. Scherer, M. Shelhamer, M. Schubert**Characterizing high-velocity angular vestibulo-ocular reflex function in service members post-blast exposure.** Exp Brain Res, 208 (2011), pp. 399-410

40 S. Herdman, M.C. Schubert, V.E. Das, R.J. Tusa**Recovery of dynamic visual acuity in unilateral vestibular hypofunction.** Arch Otolaryngol Head Neck Surg, 129 (2003), pp. 819-824

41 C.D. Hall, S.J. Herdman**Reliability of clinical measures used to assess patients with peripheral vestibular disorders.** J Neurol Phys Ther, 30 (2006), pp. 74-81

42 K. Bigsby, R. Mangine, J. Clark, *et al.***Effects of postural control manipulation on visuomotor training performance: comparative data in healthy athletes.** Int J Sports Phys Ther, 9 (2014), pp. 436-446

43 K.A. Darling, W.S. Helton**Dual-task interference between climbing and a simulated communication task.** Exp Brain Res, 232 (2014), pp. 1367-1377

44 S.L. Epling, M.J. Blakely, P.N. Russell, W.S. Helton**Free recall and outdoor running: cognitive and physical demand interference.** Exp Brain Res, 234 (2016), pp. 2979-2987

45 L.B. Smith, M.V. Radomski, L.F. Davidson, *et al.***Development and preliminary reliability of a multitasking assessment for executive functioning after concussion.** Am J Occup Ther, 68 (2014), pp. 439-443

46 A.M. Kelley, B.M. Ranes, A. Estrada, C.M. Grandizio**Evaluation of the Military Functional Assessment Program: preliminary assessment of the construct validity using an archived database of clinical data.** J Head Trauma Rehabil, 30 (2015), pp. 11-20

47 Defense and Veterans Brain Injury Center**Concussion management algorithm pocket cards (v. 4.2).** Defense and Veterans Brain Injury Center, Silver Spring (2015). Available at: http://dvbic.dcoe.mil/files/resources/DVBIC_Concussion-Management-Algorithm_Pocket-Cards_Version-4.2_April-2015.pdf. Accessed January 16, 2017

48 A. Hinds, J. Leddy, M. Freitas, N. Czuczman, B. Willer**The effect of exertion on heart rate and rating of perceived exertion in acutely concussed individuals.** J Neurol Neurophysiol, 7 (2016), p. 388

49 J.F. Guzman, J. Lopez-Garcia**Acute effects of exercise and active video games on adults' reaction time and perceived exertion.** Eur J Sports Sci, 16 (2016), pp. 1197-1203

50 T. Shallice, P.W. Burgess**Deficits in strategy application following frontal lobe damage in man.** Brain, 114 (1991), pp. 727-741