Wearable Sensors Detect Movement Differences in the Portable Warrior Test of Tactical Agility After mTBI in Service Members

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ABSTRACT

Introduction:

Assessment of functional recovery of service members following a concussion is central to their return to duty. Practical military-relevant performance-based tests are needed for identifying those who might need specialized rehabilitation, for evaluating the progress of recovery, and for making return-to-duty determinations. One such recently developed test is the 'Portable Warrior Test of Tactical Agility' (POWAR-TOTAL) assessment designed for use following concussion in an active duty population. This agility task involves maneuvers used in military training, such as rapid stand-to-prone and prone-to-stand transitions, combat rolls, and forward and backward running. The effect of concussion on the performance of such maneuvers has not been established.

Materials and Methods:

The Institutional Review Board–approved study was conducted at Ft. Bragg, North Carolina, on 57 healthy control (HC) service members (SMs) and 42 well-matched SMs who were diagnosed with concussion and were referred for physical therapy with the intent to return to duty. Each study participant performed five consecutive trials of the POWAR-TOTAL task at full exertion while wearing inertial sensors, which were used to identify the constituent task maneuvers, or phases, and measure their durations. Statistical analyses were performed on durations of three main phases: (1) rising from prone and running, (2) lowering from vertical to prone, and (3) combat rolls.

Results:

None of the three phases showed significant correlation with age (range 18-45 years) in either group. Gradual improvement in all three phase durations across five trials was observed in the HC group, but not in the concussed group. On average, control subjects performed significantly faster ($P < .004$ or less) than concussed subjects in all trials in the lowering and rolling phases, but less so in the rising/running phase. Membership in the concussed group had a strong effect on the lowering phase (Cohen's $d = 1.05$), medium effect on the rolling phase ($d = 0.72$), and small effect on the rising/running phase ($d = 0.49$). Individuals in the HC group who had a history of prior concussions were intermediate between the concussed group and the never-concussed group in the lowering and rolling phases. Duration of transitional movements (lowering from standing to prone and combat rolls) was better at differentiating individuals' performance by group (receiver operating characteristic area under the curve [AUC] = 0.83) than the duration of the entire POWAR-TOTAL task (AUC = 0.71).

Conclusions:

Inertial sensor analysis reveals that rapid transitional movements (such as lowering from vertical to prone position and combat rolls) are particularly discriminative between SMs recovering from concussion and their concussion-free peers. This analysis supports the validity of POWAR-TOTAL as a useful tool for therapists who serve military SMs.

INTRODUCTION

The risk of traumatic brain injury (TBI) is an occupational hazard faced by active duty service members (ADSMs). While around 80% of such injuries are classified as mild TBI (mTBI), even these injuries can significantly impair an injured individual's functionality. Acutely mTBI can produce headaches, dizziness, poor concentration, slowed reaction time and thinking, memory problems, and other disturbances. These symptoms can undermine operational performance and thus, ultimately, impact unit and mission readiness.[1] For the majority of SMs, mTBI symptoms resolve in 7-30 days, but up to 30% of cases demonstrate functional impairments lasting longer than 3 months.[2]

While a carefully managed progressive return to activity is recognized to be the best approach to post-concussion recovery,[3,4] specialized rehabilitation may be necessary.

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Preliminary data from this project were presented as a poster at AMSUS-The Society of Health Professionals conference in 2019.

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doi:https://doi.org/10.1093/milmed/usab361

Determination of readiness for return to duty (RTD) remains a clinical challenge. Patient's self-report of symptoms is important but is subject to over- or under-reporting. The development of functional assessment tools, recommended by most published concussion practice guidelines, is needed. Existing performance-based tests are not very discriminative in a high-performing population due to ceiling effects and are not attuned to the combined sensory, cognitive, and physical demands of complex military tasks performed by ADSM. Practical military-relevant performance-based tests are needed to aid in the identification of individuals that may need rehabilitation, to aid in evaluating the progress of recovery, and to aid in the clinical RTD decision-making process.

To address these needs, we tested a military-relevant tactical agility assessment (the 'Portable Warrior Test of Tactical Agility' or POWAR-TOTAL) designed for use following mTBI in ADSMs. This performance-based assessment was developed from elements of an earlier multifaceted testing approach, the 'Assessment of Military Multitask Performance'[5,6] and the Run-Roll-Aim task[7] in particular. The POWAR-TOTAL task involves familiar maneuvers used in military training, such as rapid movement transitions while running and carrying a simulated weapon. This task was designed to stress known functional vulnerabilities associated with mTBI that might be inconsistent with successful RTD by challenging dynamic stability in both a single-task and dual-task format. Cecchini et al.[8] reported significant differences in timed POWAR-TOTAL performance between healthy control (HC) SMs and those who were diagnosed with mTBI and were referred for physical therapy with the intent to RTD. Single- and dual-task cognitive performance was also significantly different.[8]

The POWAR-TOTAL task was also evaluated through the use of wearable inertial sensors that collected movement data. Utility of wearable sensors for concussion assessment is increasingly described in the literature,[9–13] including applications focused on postural control in standing under different conditions during dynamic balance tests,[9] and for examining spatiotemporal gait parameters or gait variability.[9] The use of inertial sensors for analyzing dynamic movement in sports is also growing, including running[10] and sport-specific complex movement patterns.[11] While military wearable sensor studies have focused on physiological monitoring related to environmental conditions, alertness, musculoskeletal limits, and neuropsychological status,[12] the use of sensors for specific movement assessment has additional relevance for clinicians who serve the military population. Johnston et al. suggest that serial monitoring with inertial sensors may be the future of post-concussion assessment, offering benefits over conventional observational tests of motor function.[13]

Use of inertial sensors allowed for more detailed movement analysis of the distinct movement components of the POWAR-TOTAL task to detect whether some phases of the motor task were more sensitive to mTBI than other phases, as these movement components engage different functional elements of the sensorimotor system throughout the task. In this article, we used inertial sensor data to identify and measure the duration of individual motor phases in each trial.

METHODS

The POWAR-TOTAL study was conducted at Ft. Bragg, North Carolina, and at Joint Base Lewis McChord, Washington. The study was approved by the Regional Health Command-Atlantic Institutional Review Board (IRB) and by the Madigan Army Medical Center IRB. All participants provided informed consent. A description of the participants and the protocol methods are comprehensively described by Cecchini et al.[8] Here we provide a streamlined summary.

Participants

Two groups of SMs were recruited into the study: (1) HC SMs who were fully eligible for deployment and had no current concussion complaints and (2) SMs who had been diagnosed with mTBI within the past 2 years and were beginning outpatient physical therapy services for their persistent symptoms at an Intrepid Spirit Clinic. Participants were screened after informed consent and before initiating study procedures to ensure that they had the medical clearance and the ability to perform the study activities. Participants were excluded if they had a history of moderate, severe, or penetrating brain injury; major psychiatric disorder; or had visual or hearing deficits that prevented participation in testing.

All HC SMs ($n = 60$) were enrolled in this study at Ft. Bragg. One of them, however, was excluded from the analysis because of self-reported symptom burden, extensive concussion history, and post-study referral to the Intrepid Spirit Center for TBI-related treatment. Two other HC participants did not contribute to the study because of technical failures to record their inertial sensor data. To match this HC sample and testing experience, the inertial sensor data analysis in this study was confined to concussed SMs ($n = 50$) who were also enrolled at Ft. Bragg and were tested under the same conditions by the same study personnel. Of these 50 participants, seven were not able to complete the full set of five POWAR-TOTAL task trials (four developed dizziness and three stopped trials because of pain) were excluded from the analysis. Furthermore, due to technical problems, no inertial sensor data were obtained from another concussed participant. As a result, the study included 57 HCs and 42 individuals with mTBI.

POWAR-TOTAL Procedure

The task was performed while carrying a simulated standard service weapon (Bluegun M4), starting with the subject lying in a prone position. To start, the subject stood and ran diagonally forward 3 m, transitioned to prone on a floor mat and performed a clockwise combat roll, stood and ran backward to the start, side shuffled several feet to the left, ran diagonally forward again to the mat, performed a counterclockwise combat roll, and ran backward to the start. The subjects were asked to perform the task as quickly as they could and to carry the weapon as they typically would.

Each subject repeated the task five times, with a brief rest between trials. The first trial was used to familiarize the subject with the task. Next, one single-task test trial and three 'dual-task' trials were completed as quickly as possible. For dual-task trials, the subject was verbally provided an 8-character grid coordinate to remember while performing the task. After the task, the SM recited recalled items. Each trial included a new grid coordinate. Results of the cognitive task performance are reported elsewhere.[8]

Inertial Sensor Data Collection

During POWAR-TOTAL trials, motor activity was continuously collected using inertial sensors in two Samsung Galaxy S6 smartphones (weighing 138 g) that were secured with neoprene athletic straps to the back of the head and the lumbar area. The use of smartphones was determined by (1) their comparable performance to laboratory-grade high-quality inertial sensors and (2) use of inexpensive readily available technology to make POWAR-TOTAL more practical for end users. Readings of triaxial accelerometer, gravity, and gyroscope sensors in each smartphone were recorded at 100 Hz.

Inertial Data Processing

The raw triaxial recordings from the accelerometer, gravity, and gyroscope sensors are complex, and different phases of a POWAR-TOTAL trial are not readily distinguishable (Fig. 1). However, each phase generates a distinctive pattern of activities when viewed *in toto* in the 9-dimensional space defined by all the axes of the accelerometer, gravity, and gyroscope. The complex mix of body movements executed during a POWAR-TOTAL trial, combined with individuals' idiosyncrasies, make it necessary to use machine learning pattern recognition to distinguish these patterns. As there are no class-labeled training datasets for such patterns, supervised learning methods cannot be applied. Instead, we used self-organizing networks of radial basis function (RBF) units, which are known for their efficient time-series prediction and classification.[14] We used the Decorrelated Hebbian Learning algorithm of Deco and Obradovic[15] to train RBF units on the POWAR-TOTAL data. The full description of the RBF network and its training procedures is provided in Supplemental Materials section.

RESULTS

Discrimination of Constituent POWAR-TOTAL Motor Actions with RBF Networks

In the course of training, RBF units become selectively tuned to particular patterns of activity in the inertial sensors generated by different motor actions performed in a POWAR-TOTAL trial. To explore the repertoire of motor actions that RBF units select during training, we trained multiple RBF networks, varying RBF parameters, numbers of RBF units, starting states, and sets of randomly picked activity patterns used in training. We found this repertoire to be highly constrained: with very little variation, RBF networks consistently selected the same set of motor actions. In every network, one RBF unit tunes to the subject lying prone at the start of the trial and also briefly right before and after combat rolls; four RBF units tune to the first or second half of the clockwise or counterclockwise combat rolls, respectively; four RBF units tune to running, producing sinusoidal oscillations shifted by 90°, 180°, or 270° in the stride cycle relative to each other; and one RBF unit tunes to transitioning from the vertical to prone position. At least one and usually two RBF units tune to rising up from the prone position; and in a majority of networks, one RBF unit is active when the subject is vertical and either standing (at the end of the trial) or finishing a running distance. Remaining RBF units never become active. Motor actions of rising up and running forward were partially overlapping, since most individuals start running while still getting up.

As an illustration, in Figure 2 we developed 15 RBF networks. All networks had the same number of RBF units ($n = 15$) and parameters (0.5 s time window, $\sigma^2 = 6$), but were trained starting from different random states and using different random sets of activity patterns. Once all 15 networks were trained, their responses to 2,000 test activity patterns were used to evaluate—using hierarchical clustering—the emergent diversity and common themes in tunings among the 225 RBF units. Figure 2A shows the resultant dendrogram, revealing very distinct clusters of highly correlated RBF units. In Figure 2B, time courses of the response of all the RBF units belonging to the same cluster during an exemplary POWAR-TOTAL trial are plotted superimposed to show their high similarities.

Because RBF units in action-specific clusters are very consistent with each other, we randomly chose five RBF networks with units tuned to every motor action and used their averaged activities as consensus 'indicators' of each motor action employed in POWAR-TOTAL trials (Fig. 1). We used activities of such action indicators to partition each POWAR-TOTAL trial in our dataset precisely into nine phases: (1) waiting to start in prone position; (2) rising up and running forward; (3) lowering to prone position; (4) rolling clockwise; (5) rising up, running backward, shuffling sideway, and running forward; (6) lowering to prone position; (7) rolling counterclockwise; (8) rising up and running backward; and (9) standing still at the trial end.

Such phase partitioning of POWAR-TOTAL trials allows exploration of phase attributes and their sensitivity to mTBI. In this article, we analyzed phase durations, specifically duration metrics of three main combined phases, which capture three distinct groups of motor actions:

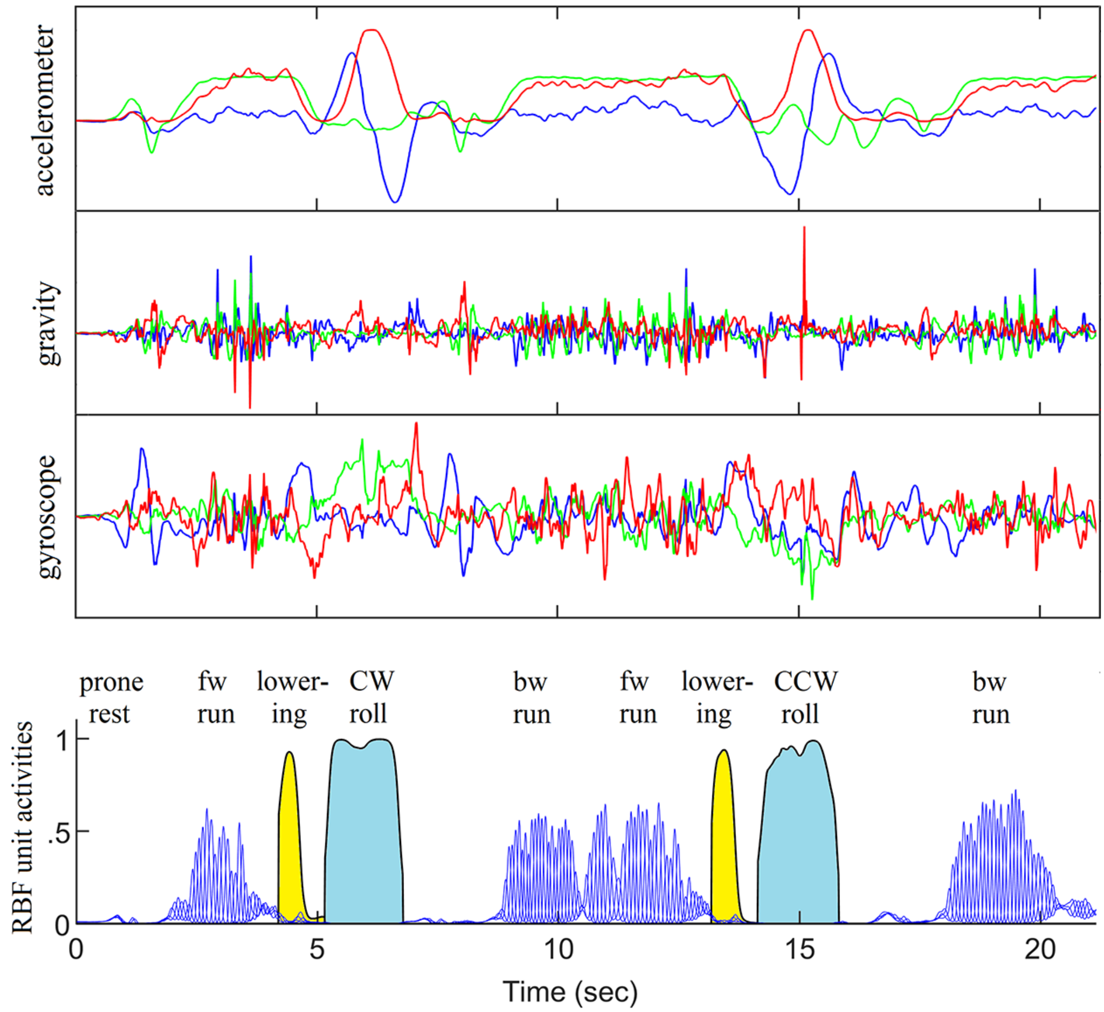

Figure 1. Inertial sensor recordings during an exemplary Portable Warrior Test of Tactical Agility (POWAR-TOTAL) trial. Red, green, and blue curves in the top three panels show the time courses of activities recorded along the *x*, *y*, and *z* axes of the accelerometer, gravity, and gyroscope. The bottom panel shows the time courses of activities of nine radial basis function (RBF) units: one RBF unit active during lowering to prone position (yellow); four RBF units, each active during either the first or second half of either the clockwise or counterclockwise roll (cyan); and four RBF units active during either the first, second, third, or fourth quarter of running stride cycle (blue). Abbreviations: fw—forward, bw—backward, CW—clockwise, CCW—counterclockwise.

(1) "Lowering" metric—total amount of time during a trial lowering from vertical to prone;
(2) "Rolling" metric—total amount of time spent during a trial rolling clockwise and counterclockwise;
(3) "Rising & Running" metric—the rest of a trial period, which is dominated by rising and running, but also includes brief transitional periods of standing or lying.

Analysis of POWAR-TOTAL Phase Durations

The POWAR-TOTAL assessment of a subject included five trials. Trial 1 was a task familiarization trial; therefore, data from trial 1 were not included in the analysis. For trials 2, 3, 4, and 5, the average durations of the three main phases are plotted in Figure 3A. Several notable phase duration differences can be seen in these plots.

Trial 2 is a motor single-task trial. Trials 3-5, on the other hand, are dual-task trials, with a working memory task (grid coordinate memorization) added to the motor task. This extra demand did not appear to interfere with motor task performance, as no significant increase in phase duration is observed between trials 2 and 3 in either HC or mTBI groups. The subjects appeared to prioritize motor performance over cognitive performance, as dual-task decrements in average cognitive score were observed.[8]

The HC plots in Figure 3A show a gradual decline of phase durations across trials. According to the paired *t*-test, the overall decline from trial 2 to trial 5 is statistically significant for all three phases (Table IA). This gradual improvement in motor performance of HC subjects on successive trials is likely due to learning effects with continued practice of the task; however, no such improvement can be seen in Figure 3 in mTBI plots.

Figure 3A shows HC subjects performed faster than mTBI subjects in all phases and in all trials. According to Welch's

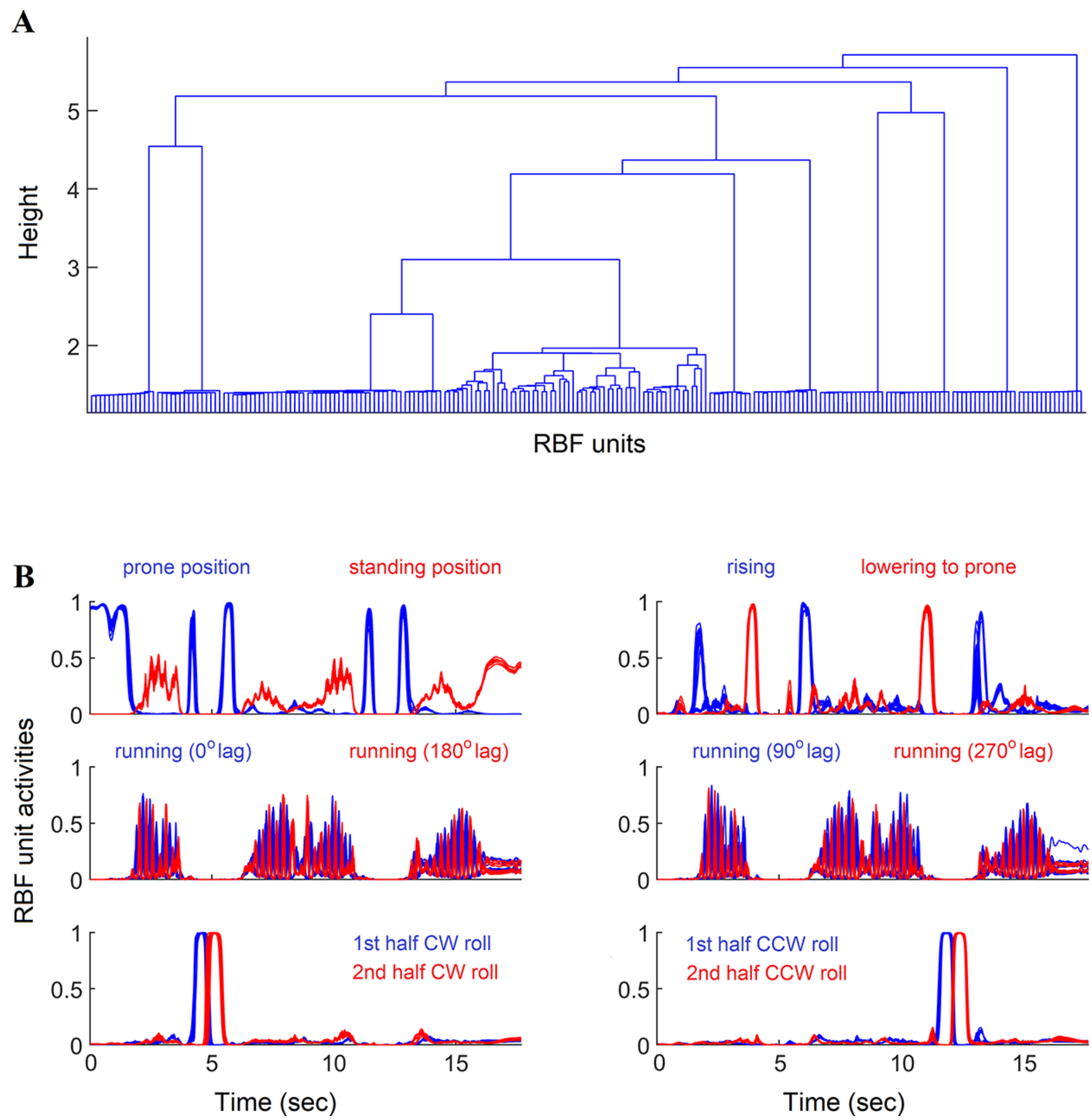

Figure 2. Clustering of radial basis function (RBF) units by their feature selectivities. (A) Dendrogram generated by hierarchical clustering of 225 RBF units from 15 independently developed RBF networks based on their responses to 2,000 sensor activity patterns. (B) Superimposed time courses of RBF units' activities during an exemplary Portable Warrior Test of Tactical Agility (POWAR-TOTAL) trial. All RBF units belonging to the same cluster are plotted together in a panel in the same color. Two clusters are plotted in each of the six panels, with the motor action to which these clusters respond indicated in each panel.

t-test of the difference of the means, these differences are statistically significant for all conditions except rising and running phase of trials 2 and 3 (Table IB). Effect size, calculated using Cohen's *d* (Table IC), indicates that the later trials are more sensitive to group status than earlier trials and the lowering phase is the most sensitive in all trials, the rolling phase becomes increasingly more sensitive across trials, and the rising and running phase is the least sensitive.

The HC and mTBI samples were closely matched by age ($P = .42$ on the *t*-test of the means). The age of HC subjects ranged between 18 and 45 years (29.7 ± 6.7 mean/SD). The age of TBI subjects ranged between 20 and 44 years (29.4 ± 6.5 mean/SD). To test whether age affected their performance on the POWAR-TOTAL task, Pearson's correlation coefficient was computed for the duration of each phase in trial 5 and the subject's age (Table ID). None of the phases showed a significant correlation with age in either group.

While age did not significantly affect POWAR-TOTAL performance in our study sample, prior history of concussion did have a notable impact. Among 57 HC participants, 23 had no prior concussion history, while 34 had at least one prior lifetime concussion (up to 20, 5.1 ± 5.7 mean/SD). None of the HC participants had sustained a concussion in the prior 2 years and none were receiving any services for their previous injuries. The average phase durations of the subjects in the HC group with prior history of concussions are plotted

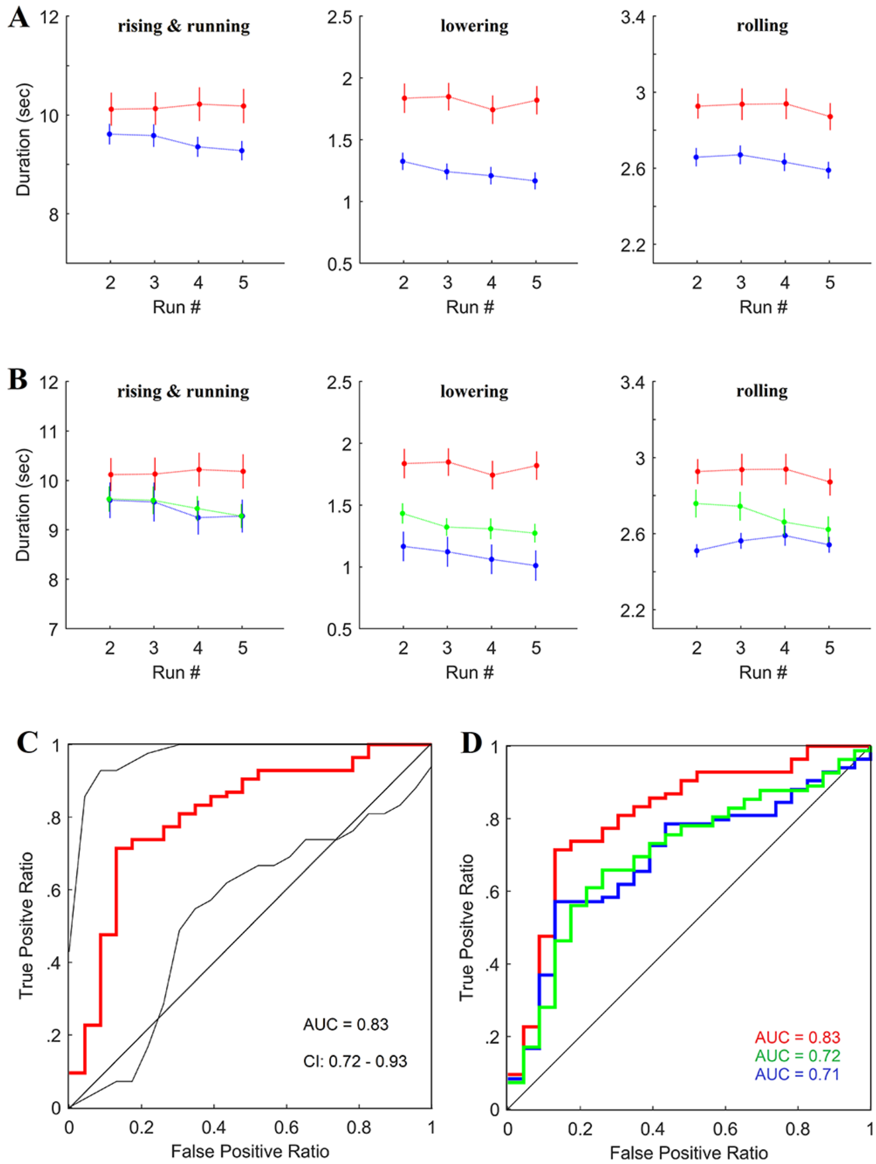

Figure 3. Average durations of the three main phases in trials 2-5 and receiver operating characteristic (ROC) analysis of phase durations of the mTBI subjects vs. healthy control (HC) subjects with no history of concussions. (A) The averages computed for the HC subjects (blue) and the mTBI subjects (red) are plotted. (B) The averages computed for the HC subjects with no prior history of concussive events (blue), for the previously concussed HC subjects (green), and for the mTBI subjects (red) are plotted. Vertical bars represent SEM. (C) ROC curve (red) of the sum of all the lowering and rolling phases and its 95% confidence interval (black). (D) Superimposed ROC curves plotted for (1) sum of all the lowering and rolling phases (red); (2) total trial duration based on inertial sensor recordings (blue); and (3) total trial duration measured with a stopwatch (green).

in Figure 3B separately from the average phase durations of the never-concussed subjects. The plots reveal that the previously concussed HC group occupies an intermediate position between the mTBI group and the never-concussed group in the lowering and rolling phases, but not the rising and running phase.

As Cohen's *d* effect size in Table IC shows, group status had the largest effect on the final trial for all phases. Also, lowering and rolling phases had a larger effect size than rising and running phases. Therefore, we combined lowering and rolling phase durations in the fifth run and performed receiver operating characteristic (ROC) analysis on this metric. We excluded previously concussed HC subjects from our analysis, since according to Figure 3B they perform somewhat differently than the never-concussed HC subjects. The ROC curve plot is shown in Figure 3C. The area under the curve (AUC) = 0.83 (0.72-0.93 95% confidence interval), which indicates a high degree of discriminability for this metric.

In addition to inertial sensors, the total duration of trials was measured with a stopwatch. The stopwatch and sensor

TABLE I. Statistics of Comparisons of the Healthy Control (HC) and Mild Traumatic Brain Injury (mTBI) Samples

Statistical test	Group or trial #	Trial phase: Rising and running	Lowering	Rolling
(A) paired t-test of the in-subject difference of the phase durations between trials 2 and 5 (P value)	HC group	0.0033	0.0004	0.0080
	mTBI group	0.68	0.82	0.20
(B) t-test of the difference of the means of phase durations between HC and mTBI samples (P value)	trial 2	0.1032	0.0002	0.0007
	trial 3	0.0899	<0.0001	0.0038
	trial 4	0.0167	0.0001	0.0009
	trial 5	0.0133	<0.0001	0.0006
(C) effect size Cohen's d for HC and mTBI samples	trial 2	0.27	0.79	0.68
	trial 3	0.28	1.01	0.59
	trial 4	0.47	0.84	0.70
	trial 5	0.49	1.05	0.72
(D) correlation of phase durations with subject's age (r^2/p)	HC group	0.0008/0.84	0.0024/0.73	0.0092/0.49
	mTBI group	0.0024/0.77	0.0753/0.09	0.0154/0.45

For Cohen's d: blue—small effects; green—medium effects; red—large effects.

estimates of trial durations match closely—the squared correlation coefficient between the two is 0.95. From the practical point of view, using a stopwatch is a more readily available option than using inertial sensors. However, as our analyses above show, the rising and running phase of trials—which is the longest phase—is the phase that is the least sensitive to mTBI status. If we focus just on the lowering and rolling phases, discrimination between HC and mTBI subjects improves (Fig. 3D). In addition to showing the curve for the lowering + rolling phases, this plot also shows two curves for the total trial duration as measured manually and with inertial sensors. These two estimates of total trial duration generate practically identical curves, but relying on just lowering + rolling duration raises the AUC from 0.71 to 0.83. The difference between lowering + rolling and total trial duration ROC curves is highly statistically significant ($P = .0053$).[16]

DISCUSSION

The results of inertial sensor analysis of POWAR demonstrate significant performance differences in those who have begun a course of physical therapy for mTBI complaints from their healthy peers, with the greatest difference in performance for transitional movements (lowering from standing to prone and combat rolls). Medium to large effect sizes were obtained for these transitional movement phases, with larger effect sizes observed in later trials. Concussion history appears to have also affected task performance as noted in the sub-analysis of control group participants with and without a concussion history.

Across-trial improvement in movement time was observed for HC subjects, but not for those with mTBI. This finding is similar to that of Prim et al. in an earlier iteration of the task, Run-Roll-Aim, that was theorized as a possible reduced learning or increased fatigue effect.[7] Our cross-sectional assessment targeted individuals with mTBI at the start of a course of physical therapy. These individuals may not have been engaged in the routine level of physical activity typical of ADSM. As a result of relative deconditioning, fatigue with repetition of the POWAR maneuvers could have influenced their ability during later trials. Exacerbation of concussion-related symptoms due to the provocative nature of the task may also have influenced continued improvement across trials, or interaction between cognitive and motor performance required for trials 3-5 may have resulted in sufficient interference to minimize improvements in motor performance.

Efforts to devise means for clinicians to assess ADSM RTD capability have increasingly combined cognitive and motor skills[5,6,17–20] or simulated tasks that are commonly used in military training.[7,17,20] Impairments following mTBI are varied and as an individual recovers, performance changes may be subtle and difficult to observe using conventional means. Sensor-based measurements are appealing as a means to capture decrements in performance that are otherwise hard to detect, yet the use of such technology often requires complex analysis that makes it difficult to use in clinical practice.[21] In this application, sensors detected specific movement phases that differentiated between those recovering from injury and those without injury, which would not be detected with observational testing.

After mTBI, physical impairments are common, although no consistent pattern is observed across all patients. Vulnerabilities that are targets for physical assessment and intervention include the vestibular system, musculoskeletal–cervical function, exercise tolerance, and higher-level functional mobility and balance tasks that may include simultaneous cognitive/motor performance.[22] Traumatic brain injury in the military population is associated with complaints of dizziness and vestibular dysfunction.[23] These complaints could stem from peripheral or central vestibular impairments, cervical dysfunction, difficulty with integration of sensory information required for balance, or any combination of these factors.[24] The motor component of POWAR-TOTAL was designed to challenge individuals who may have vestibular impairment. As one moves from prone to stand and reverse, rapid non-rotational head position change occurs, triggering otolith organ activity. The performance of combat rolls requires rapid rotation in each direction that stimulates semicircular canal activity. Given that these transitional movements are the components of the POWAR-TOTAL task that demonstrate the largest group differences, vestibular impairment is a plausible factor in these performance decrements, but causality cannot be inferred. There are additional factors that could contribute to performance decrements.

Some individuals following mTBI have exercise intolerance tied to autonomic dysfunction, with an inability to appropriately regulate blood pressure and circulation to meet ongoing body demands.[25] These issues are detected using orthostasis testing or heart rate variability analysis during exercise.[26] Service members need to be able to make rapid physical changes, often under dynamic conditions that may challenge the autonomic nervous system. The rapid transitions from prone to stand and the reverse may induce challenges similar to orthostasis testing requiring rapid blood pressure regulation, which may have contributed to the observed group differences. This is not an area that was examined in this study, so we are unable to determine the presence of this physiologic condition or its correlation with task performance.

The job of an ADSM is physically demanding, with constant physical challenges and risk of injury that over time may result in musculoskeletal conditions that induce pain. Rapid movement transitions may also be more difficult for individuals experiencing cervical or other forms of pain (headache, lower extremity, and back) that similarly could contribute to the differences observed between the groups. The HC subjects who had a history of concussion were on average older and had significantly higher self-reported complaints of pain, self-reported symptom, and post-traumatic stress.[8]

The inertial sensor measures of the transitional movements were better at differentiating individuals' performance by group (ROC AUC = 0.83) than were observational[8] and inertial sensor measures of the duration of the entire POWAR task (AUC = 0.71). Further machine-learning exploration of different phases of the POWAR-TOTAL task—going beyond their durations and characterizing their temporal patterns of inertial sensor activities—has a potential to further enhance POWAR-TOTAL sensitivity and specificity with regard to various aspects of mTBI.

While robust group differences are illustrated in the performance of the POWAR task that are most significant during the transitional movement components, it is not possible to determine why these occur for each individual, although future analyses will correlate key impairments to performance. The TBI group had significantly greater complaints of pain, post-traumatic stress, and higher self-reported symptoms on the Neurobehavioral Symptom Inventory (NSI).[8] There may be 'multiple reasons' for group differences to occur, including effects of the mTBI (vestibular, exertional intolerance, and cognitive challenge during dual task), pain, increased symptom complaints, or post-traumatic stress or any combination of these factors. Medication use, which at least some individuals in the mTBI group might have been taking for post-concussion symptoms, also could have affected their cognitive or physical performance and was not controlled for in this study. Nevertheless, one could argue that the reason(s) why mTBI physical performance differs from HC matters less than the fact that there is a decrement in performance at all. The rehabilitation process is focused on improving function to a level that is consistent with the considerable demands of active duty.

Whether the group differences detected in POWAR-TOTAL that are statistically significant are truly functionally significant is an important question that is difficult to answer and will require additional study. Study of successful RTD is exceptionally difficult to do, as the definition of RTD varies and access to service records is not typically feasible. Even once an SM returns to duty, the quality of their work is not easily discernable, and the nature of active duty service involves risk that sometimes results in injury or mortality for individuals with no prior injury.[27] In this study we report group differences that show promise. Longitudinal study of performance measures using proxies for successful RTD is still needed.

In clinical practice, there is a need for performance-based tests with reference values of typical performance that approximate the challenging physical demands of active duty. Having tools with real-time movement sensor data and interpretation guidance may increase the confidence therapists have in judging whether an individual is physically ready to RTD. Sensor-based information could also identify possible areas to target during intervention. There is still work to be done to make such measures ready for clinical use, but the results from study of POWAR-TOTAL suggest that it may be a useful tool for therapists who serve military service members.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

FUNDING

Congressionally Directed Medical Research Program through the FY16 Joint Program Committee 8/Clinical and Rehabilitative Medicine Research Program, Psychological Health/Traumatic Brain Injury Research Program, and Complex Traumatic Brain Injury Rehabilitation Research Award (award no: W81XWH-17-2-0046). The project described was supported by the National Center for Advancing Translational Sciences (NCATS), National Institutes of Health, through Grant Award Number UL1TR002489. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest or disclosures to report.

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