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TITLE: POrtable WARrior Test Of Tactical AgiLity: POWAR-TOTAL

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14. ABSTRACT The goals of this project were to establish project infrastructure and regulatory approvals, compare POWAR-TOTAL performance in healthy controls (n=60) to those with concussion (n=100) recruiting from Fort Bragg and Madigan Army Medical Center (MAMC), and examine how POWAR-TOTAL scores change with rehabilitation recovery for those with concussion. As of September 2020 we had collected data on 60/60 healthy control participants and 75/100 individuals with mTBI using the POWAR-TOTAL, (50 pre- post-test). During the 2020-21 year we published two papers sharing the primary findings of our study, supporting the value of the POWAR-TOTAL test in differentiating motor and cognitive task performance of those with mTBI compared to healthy control peers. An additional paper on the responsiveness and validity of the measure has been submitted to Physical Therapy Journal, and a fourth paper that uses machine learning approaches is being drafted to submit to Journal of Neurotrauma. We have shared our ongoing					
15. SUBJECT TERMS mTBI, concussion, return to duty					
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1. INTRODUCTION:

This project translated components of the Assessment of Military Multitask Performance (AMMP) to a clinic-ready test providing real-time feedback about high-level mobility and dual task performance with the use of smartphone based sensor technology. Similar tasks from the AMMP project empirically demonstrated that service members with persistent symptoms after mTBI have movement characteristics that are not clearly discernible to the naked eye but that differ from healthy active duty service members. Expensive laboratory equipment and analyses were used in the AMMP proof-of-concept project to document these subtle movement differences. This project combined the most sensitive elements of two AMMP tasks in a clinical test that is time efficient, uses inexpensive wearable sensors, is more clinically feasible, and has the ability to provide immediate performance feedback to the clinician. This dual-task assessment is innovative as it is the first and currently only military post-concussion standardized, externally valid multi-domain functional assessment that is time, space, and cost efficient for clinic use. The data collection and analysis is innovative, as data collection will be done via smartphone and immediately following collection, uploaded to a computer that uses healthy control data to compare performance. Our ability to provide immediate feedback from movement sensors data is still in development as we continue use of the POWAR task as part of a 3 task test battery in our Complex Assessment of Military Performance study. We were surprised to find that the simple observational measures of timing and cognitive task scoring proved to discriminate between those with concussion and their healthy control peers, increasing the clinical utility of the test. It is feasible to use the POWAR task without the movement sensors and still have data that is useful clinically. These additional data points for evaluating abilities are clearly related to functional demands associated with warfighting and can aid the clinician in verifying that a SM is not only symptom-free but duty ready.

2. KEYWORDS:

Mild traumatic brain injury, mTBI, concussion, military, vestibular, functional assessment, return to duty, movement analysis, dual-ta

3. ACCOMPLISHMENTS:

✦ What were the major goals of the project?

	Project month	Percent completed
Major Task 1: Establish infrastructure, procedures		
Coordinate with Sites for CRADA submission	1-3	100%
Refine eligibility criteria, exclusion criteria, screening protocol	1-3	100%
Finalize consent form & human subjects protocol	1-3	100%
Coordinate with Sites for IRB protocol submission, ISC-FB first, UNC to rely on WAMC. Obtain ORP/HRPO review for ISC-FB.	1-3	100%
Pilot test with 3-5 healthy controls and 2-3 patients with concussion to confirm planned methods are appropriate.	4-5	100%
Coordinate activities for healthy control recruitment with DVBIC Education Outreach coordinator.	3-6	100%
Initiate MAMC IRB approval process, obtain ORP HRPO approval	3-5	100%*
<i>Milestone: IRB and HRPO approval at all sites.</i>	1-6	100%
Submit amendments, adverse events and protocol deviations	PRN	ongoing
Coordinate annual IRB report for continuing review	annually	ongoing
Create manual of procedures, finalize instruments for use in study, build RedCap database.	1-3	100%
Clarify return to duty indicators in common use across sites, and indicators unique to ISC-FB or MAMC.	2-4	100%
Advertise and interview for project related staff (Ft Bragg hire first, then MAMC hire once IRB is in process there)	3-6	100%
Coordinate for space allocation, credentialing, and training necessary to obtain access to MTF and patients.	1-6	100%
RedCap database ready for use by project staff	4-6	100%
Conduct training with ISC-FB RA, revise training procedures and manual as necessary.	4-6	100%
Conduct training with MAMC RA (RA to travel to ISC-FB)	5-7	100%
Coordinate with Sites for flow chart for all study steps, web data collection and database requirements	4-7	100%
<i>Milestone Achieved: Research staff trained</i>	4-8	100%
Major Task 2: Compare POWAR-TOTAL scores between		
Subtask 1: Data collection initiated at both sites (ISC-FB first,	5-9	100%
Complete healthy control data collection	4-15	100%
Complete post-intervention assessments after completion of	6-24	100%
Subtask 2: Preliminary accelerometry data analysis with first	9-15	100%
Confirm custom algorithm is functioning as expected.	9-10	100%
Assess 10 concussion patients for change in POWAR-TOTAL response post-intervention.	12-13	100%

Determine need to repeat test healthy control subjects based on post-intervention testing.	13-14	100%
If necessary, test additional healthy control subjects 2 nd time.	14-18	100%
Tested additional healthy control subjects 2 nd time (n=10)		100%
Major Task 3: Planning for translation		
In conjunction with T2 collaborators/consultants, develop a plan for transition of technology use toward clinical practice.	3-6	75%
Seek feedback from clinicians about the test procedure, interface,	3-24	ongoing
Seek feedback from patients tested about the test process and feedback screens.	8-24	ongoing
Develop plans to translate the test and application to practice, as appropriate	18-24	100%
Major Task 4: Data analysis		
Coordinate with Sites & database manager for monitoring data collection rates and data quality	4-24	100%
Perform all analyses according to specifications, share output and findings with all investigators	12-24	95%
Dissemination and reporting of findings (abstracts, presentation, publications, DOD)	12-24	75%

✦ **What was accomplished under these goals?**

We met our data collection goal at Fort Bragg, testing 50 individuals with TBI, with 32 of those post-tested. At JBLM, we were only able to collect data on 25 subjects with 18 of those post-tested. When COVID struck, we necessarily halted data collection for a period of time. Fort Bragg data collection was only 2 short of the planned number for recruitment, so when our project was approved to resume, we were able to meet the target there. JBLM COVID management remained more conservative than Ft Bragg, so halted our data collection efforts in the fall of 2020 in order to shift our focus to the CAMP project that is continuing to use the POWAR run/roll maneuver as part of that test battery. COVID prevented us from attending and presenting at several conferences where abstracts were accepted, and generally caused difficulty at the University as personnel there (including the PI) were enlisted to shift coursework online and into the summer months to accommodate students who were not able to engage in their typical clinical rotations. This caused a significant reduction in time available to work on publications from the project (which is typically a summer focus for the project PI).

In order to continue our dissemination efforts, we used an additional no-cost extension that applied to the Geneva subcontract. This allowed us to increase efforts of Dr. Cecchini to work on coordinating and formatting publications, work with our statistician to obtain necessary analyses and invest time in additional dissemination efforts. We published two papers that have been published in *Military Medicine* that share the main results from the group comparisons. Three additional papers are in process, one that focuses on responsiveness of the measure (submitted to the journal *Physical Therapy*), one that focuses on analysis of the dual-task interference from the measure (target *Journal of Neurologic Physical Therapy*), and one that uses machine learning to examine variables in addition to the self-report measures used in the study (target *Journal of Neurotrauma*).

With our healthy control data we developed prototype feedback screens to

evaluate best options for display for patient and clinicians, and sought feedback about therapist preferences for these displays at the APTA Combined Sections meeting from active duty therapists who will be end-users of the test. We are continuing to work on feedback screens in our CAMP project that will extend this work to provide information to clinicians and possibly patients.

We were not able to accomplish the translation goals that were initially planned as the result of several factors: 1- The T2 entity within DoD was disbanded, making the collaboration with those who had been charged with carrying out translation work more limited; 2-sensor technology is advancing rapidly, causing us to shift our motion sensor data collection strategy to the use of inexpensive commercially available inertial sensors instead of the phone sensors used in this project; 3- the incorporation of the POWAR task into the Complex Assessment of Military Performance (CAMP) test battery required modification in the interfaces for the examiner using the test, therefore we are continuing the translation goal in the CAMP project with a more robust set of performance tests, building a user interface that will collate information from multiple sensors and share feedback with the examiner. Data from POWAR will inform feedback that is based on healthy control performance by age.

What opportunities for training and professional development has the project provided?

Our group has continued to provide presentations to share results of our work in the past year, with recent presentations being in virtual conferences given the effects of the COVID pandemic. While some presentations have targeted interactions with professionals who treat concussion and therapists who serve the US military, frankly the amount of interaction with attendees has been quite limited. This seems to be the nature of these virtual conferences, unfortunately, that there is limited "traffic" for presentations offered in this format.

✦ How were the results disseminated to communities of interest?

Presentations

Our group has participated in 24 presentations throughout the project offering information about our work to colleagues in various venues: 2 invited presentations, 17 posters, 5 platforms, although 2 platforms and 1 poster were not shared when MHSRS was cancelled because of COVID. We have 1 additional platform and 1 poster scheduled in our APTA Combined Sections Meeting in 2022.

We worked with our site collaborators at Fort Bragg to allow them to present findings from our study for 4 of the presentations described above. The meetings that were included were national and international meetings for physical therapists (APTA Combined Sections including Federal Section venues, Academy of Neurologic PT meeting), rehabilitation therapists (America Congress of Rehabilitation Medicine, International Brain Injury Association), and military providers (AMSUS, US Public Health Service conference, MHSRS). The details of these presentations are included in the products section of the report.

Articles:

Two articles have been published in Military Medicine that share the major findings of our study, indicating the ability of the POWAR test to differentiate between those with mTBI and healthy control active-duty peers with respect to single and dual-task performance of both the motor and cognitive tasks used in the measure. Both are attached as appendices with citations listed in the Products section. A third paper has been submitted to PTJ that focuses more specifically on how individuals with mTBI changed in performance of the measure as a result of intervention. Two additional papers should be submitted early in 2022, one on the dual-task data analyses and one on machine learning methods applied to the movement sensor data.

4. **IMPACT:**

✦ **What was the impact on the development of the principal discipline(s) of the project?** Within physical therapy, there is increasing movement toward the use of more challenging and context specific testing for patients post-concussion, including in the military context. The use of inertial sensors to analyze movement in this context is also gaining support in the literature. While we can't claim that our project alone caused this to occur, it certainly is in line with where the research in this area seems to be moving. The importance of turning in the context of the POWAR motor task is one that is emphasized in other recently funded projects, supporting the findings that we have of turning being especially discriminative. A platform presentation that focuses on the responsiveness of the measure will be shared as part of the APTA Federal Section agenda at the national Combined Sections Meeting in February of 2022, as will a poster describing our machine learning analyses.

We have reached out to Karen Lambert, PT, DPT who leads the Hearing Center of Excellence component that provides vestibular training and resources for physical therapists in VA and DoD settings who treat service members, sharing our two papers published in Military Medicine. She coordinates the Military Vestibular Assessment and Rehabilitation course that is provided for military/VA therapists and facilitates an ongoing seminar series held online. She has not responded to our query about the possibility of sharing information about POWAR-TOTAL with her group, but we will continue to pursue this avenue as one to share information about our study.

✦ **What was the impact on other disciplines?** Dr. McCulloch was invited to present about our line of research with the Uniformed Health University for Health Sciences Center for Neuroscience and Regeneration by Dr. David Brody in part because of his keen interest in the approach we have in testing that is not solely focused on self-report, but uses objective markers of performance with movement sensors as offering an advantage over traditional testing methods. He has encouraged submission of work from our project for publication in the Journal of Neurotrauma, for which he is the Editor in Chief.

✦ **What was the impact on technology transfer?** We have decided to move in the direction of using a laptop for collecting and displaying test data, as we are planning

for the Complex Assessment of Military Performance project, where we have need for additional Bluetooth physiologic measurement that is better handled with a laptop vs. a tablet. This interface is a custom built system that was created at UNC. We are seeking industry collaborators to assist with possible transfer of this technology to a format that is readily available as part of the CAMP project we are currently conducting.

- ✦ **What was the impact on society beyond science and technology?** While we have moved our project closer to translation in the real world, we are still a few steps away from being able to advocate that directly.

5. CHANGES/PROBLEMS:

- ✦ **Changes in approach and reasons for change**

Based on work with other projects at Fort Bragg, we have a greater understanding of the difficulty in obtaining information about return to duty. Our original intention was to use therapist recommendation about ability to return to duty as the variable (recommended for return to duty or not) as the value we intended to predict in our 3rd aim (using regression). We thought that we would be able to access a brain injury team decision for those patients who were being seen for intensive outpatient services, and PT recommendations for those who are only being seen for single services vs. an intensive program. Our most consistent information about return to duty comes from the self-report a service member provides when they participate in post-testing after they are finished with PT services. It is our plan to use this information as a variable we predict in our Aim 3 analysis, as we don't have reason to suspect that this self-report is inaccurate. We are also using chart review to determine if official notification of approval for return to duty is available in the chart by which we will have an external validation of the service member's self-report.

- ✦ **Actual or anticipated problems or delays and actions or plans to resolve them**

- ✦ COVID 19 had a significant impact on our ability to administer and complete the project in a timely way as data collection was halted in March of 2020. It resumed more quickly at Fort Bragg, but not at JBLM. With the temporary halting of PT services/transitions to telehealth, there were subjects who were lost to follow-up because of discontinuing typical PT services. We used chart review to identify patterns of PT service delivery with the individuals who have been involved in the pre- post-test component of the study, but have not determined a cohesive way to summarize this information, given the diversity of treatment patterns that were employed especially disrupted by COVID.

✦ **Changes that had a significant impact on expenditures**

The tempo of recruitment and testing at Fort Bragg did not necessitate full time coverage, therefore our project manager has reduced her hours (by her choice) to accommodate personal work priorities. Our JBLM research assistant had a baby, and although she trained another Geneva employee to continue with data collection during her maternity leave, the number of subjects recruited during her leave was very limited. When she (Annabell Oh) returned to her position, COVID occurred soon after. We have continued to have both of our Geneva employees work on drafting publications during the time when they were not allowed to collect data, but the total number of hours of work has been reduced across both sites. This has allowed us to reserve funds to continue funding on the project to continue to try to reach our project goals. As a result we have considerable funding in the Geneva subcontract budget that will be returned to the DoD.

✦ **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents** Nothing to Report

6. **PRODUCTS:**

✦ **Publications, conference papers, and presentations**

Citations for poster and platform abstracts:

1. Scherer MR, Lester M, Weightman MW, King L, McCulloch KL. Functional Return to Duty Decision Making Post mTBI and Musculoskeletal Injury, APTA Combined Sections Meeting, Federal Section Plenary, Washington, DC, **January 2019** (invited)
2. McCulloch KL, Cecchini A, Prim J. Characteristics of Service Members with Concussion Referred to Physical Therapy Who Seek to Return to Active Military Duty, International Brain Injury Association, Toronto, CA, **March 2019** (platform)
3. McCulloch KL, Favorov O, Cecchini A, Prim J. Individuals with Concussion Perform More Slowly on a Test of Tactical Agility Designed to Assist with Military Return to Duty Decision Making, International Brain Injury Association, Toronto, CA, **March 2019** (poster)
4. Prim JH, Cecchini AS, Krok M, Favorov O, McCulloch KL. Portable Warrior Test of Tactical Agility, US Public Health Service Scientific and Training Symposium, Minneapolis MN, **May 2019**. (poster, site collaborator)
5. Prim J, Favorov O, Cecchini A, McCulloch KL. Individuals with Concussion Perform More Slowly on a Test of Tactical Agility Designed to Assist with Military Return to Duty Decision Making, Military Health Services Research Symposium, Kissimmee, FL, **August 2019** (poster)
6. McCulloch KL, Prim J, Petrenko LM, Cecchini AS. Characteristics of Service Members with Concussion Referred to Physical Therapy Who Seek to Return to Active Military Duty, Military Health Services Research Symposium, Kissimmee, FL, **August 2019** (poster)
7. Adams K, Prim J, Cecchini A, McCulloch KL. Characterization of healthy control group in the development of the power-total- a test of return to duty readiness following concussion, Military Health Services Research Symposium, Kissimmee, FL, **August 2019** (poster)
8. Petrenko L, Prim J, Adams K, Cecchini A, McCulloch KL. Comparison of subjects with mTBI and healthy controls in the development of the POWAR-TOTAL: a test of return to duty readiness following mTBI, Military Health Services Research Symposium, Kissimmee, FL,

August 2019 (poster)

9. Cecchini AS, Favorov O, Prim JH, McCulloch KL. Service Members with Concussion Improve Performance on a Test of Tactical Agility After Rehabilitation, American Congress of Rehabilitation Medicine, Chicago, IL, **November 2019** (platform)
10. McCulloch KL, Cecchini AS, Prim JH. Portable Warrior Test of Tactical Agility (POWAR-TOTAL) Differences in Healthy Control and mTBI Service Members, American Congress of Rehabilitation Medicine, Chicago, IL, **November 2019** (poster)
11. Klimp S, Cecchini A, Favorov O, Prim JH, McCulloch KL. Comparison of healthy and concussed service members using POWAR-TOTAL: a test of return to duty readiness following concussion, Washington DC, **December 2019** (poster, site collaborator)
12. Cecchini AS, Prim JH, Favorov O, O'Block LM, McCulloch KL. Test-Retest Reliability of a Return to Duty Performance-Based Assessment: Practice Effects in Healthy Servicemembers, APTA Combined Sections Meeting, Denver CO **February 2020** (poster)
13. McCulloch KL, Cecchini AS, Prim JH, O'Block LM, Favorov O. Servicemembers with mTBI Improve in Tactical Agility Task Performance after Physical Therapy, APTA Combined Sections Meeting, Denver CO **February 2020** (poster)
14. McCulloch KL, Cecchini AS, O'Block L, Prim JH, Oh A, Zhang W. Portable Warrior Test of Tactical Agility: comparison of concussed active duty service members to healthy controls, American Congress of Rehabilitation Medicine Platform Presentation – Military SIG, **November 2020** (poster)
15. Cecchini AS, Krok M, McCulloch KL. The Portable Warrior Test of Tactical Agility: validity and discrimination between active duty service members diagnosed with concussion and healthy controls, AMSUS Poster presentation, **December 2020** (poster, site collaborator)
16. Krok M. Service members with concussion improve performance of a test of tactical agility after rehabilitation, AMSUS Verbal presentation, **December 2020** (virtual platform, site collaborator)
17. McCulloch KL. Dual-task and multitask performance assessment for return to duty decision making after mild TBI, Center for Neuroscience and Regeneration invited seminar presentation, **December 8, 2020** (invited)
18. Cecchini AS, Prim J, Favorov O, O'Block LM, McCulloch KL. Test-Retest Reliability of a Return to Duty Performance-Based Assessment: Practice Effects in Healthy Service members, APTA Combined Sections Meeting, **2020** (poster)
19. McCulloch KL, Cecchini AS, Prim J, O'Block LM, Favorov O. Service members with mTBI Improve in Tactical Agility Task Performance after Physical Therapy, APTA Combined Sections Meeting, **2020** (poster)
20. McCulloch KL, Cecchini AS, O'Block L, Prim J, Oh A, Zhang W. Further development of the portable warrior test of tactical agility: a test of return to duty readiness: Comparison of performance between active duty service members diagnosed with concussion and healthy controls, MHSRS **2020** (invited as poster, meeting cancelled)
21. Cecchini AS, Prim JH, O'Block LM, Oh A, Wanqing Zhang, McCulloch KL. The portable warrior test of tactical agility (POWAR-TOTAL): service members with concussion improve performance after rehabilitation, MHSRS **2020** (invited as platform, meeting cancelled)
22. McCulloch KL, Cecchini AS, O'Block LM, Prim J, Oh A. Portable Warrior Test of Tactical Agility Differentiates Concussion from "Duty Ready" Active Duty Service Members, APTA: Platform Presentation, Geneva Foundation Tacoma, WA, **February 2021** (Virtual)
23. MHSRS platform presentation invited, MHSRS Platform presentation invited, meeting cancelled. Return to Duty Determination after mTBI - Predicting Physical Therapy Change for Active Duty Service Members Post-Concussion Requires More Than Self-Report Measures
24. Observational and Inertial Sensor Measures Discriminate Active Duty Service Members with mTBI from Healthy Controls in the POWAR-TOTAL task, Academy of Neurologic Physical Therapy annual conference **October 2021** (virtual)

✦ **Journal publications.**

Favorov O, Kursun O, Challener T, Cecchini A, McCulloch KL. Wearable Sensors Detect Movement Differences in the Portable Warrior Test of Tactical Agility After mTBI in Service Members. Mil Med. 2021 Sep 3;usab361. doi: 10.1093/milmed/usab361. Epub ahead of print. PMID: 34476483.

Cecchini AS, Prim J, Oh A, Zhang W, Harrison CH, McCulloch KL. The Portable Warrior Test of Tactical Agility: A Novel Functional Assessment That Discriminates Service Members Diagnosed

With Concussion From Controls. Mil Med. 2021 Aug 19:usab346. doi: 10.1093/milmed/usab346. Epub ahead of print. PMID: 34414438.

- ✦ **Books or other non-periodical, one-time publications.** Nothing to report
- ✦ **Other publications, conference papers, and presentations.** See above
- ✦ **Website(s) or other Internet site(s)** We are creating a website that will house information about the POWAR-TOTAL measure that will allow us to share information about its administration so that clinicians can use the test in their practice. This website will continue to be improved as we work on the CAMP project that is advancing this research line further.
- ✦ **Technologies or techniques** Nothing to report
- ✦ **Inventions, patent applications, and/or licenses** Nothing to report
- ✦ **Other Products** Nothing to report

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

✦ What individuals have worked on the project?

Name:	<i>Karen McCulloch</i>
Project Role:	<i>Principal Investigator</i>
Researcher Identifier (e.g. 0000-0003-4228-0517)	<i>0000-0003-4228-0517</i>
Nearest person month worked:	<i>2.4</i>
Contribution to Project:	<i>Dr. McCulloch is the project PI, coordinating the efforts of the research team on the project, troubleshoot project challenges and identify recruitment strategies based on site specific needs. Writing reports and drafting abstracts, coordinating writing efforts and soliciting feedback onr display for clinical use of the measure.</i>
Name:	<i>Amy Cecchini</i>
Project Role:	<i>Project Coordinator</i>
Nearest person month worked:	<i>9</i>
Contribution to Project:	<i>Dr. Cecchini has managed the project at Ft Bragg including recruitment and data collection, established project procedures,</i>
	<i>taken the lead on regulatory efforts, coordinated training of the MAMC staff to ready them for data collection, assisted with report writing, and provide ongoing guidance for Dr. Oh at MAMC.</i>
Name:	<i>Annabell Oh</i>
Project Role:	<i>Project Manager</i>
Nearest person month	<i>5</i>
Contribution to Project:	<i>Dr. Oh has been trained to recruit and collect data at the MAMC site, coordinating efforts with Dr. O'Block. She is assuming responsibility for regulatory efforts at MAMC, and will initiate data collection as soon as we get IRB approval.</i>

Name:	<i>Courtney Harrison</i>
Project Role:	<i>Research Assistant</i>
Nearest person month worked:	3
Contribution to Project:	<i>Ms. Harrison has set up the RedCap database, coordinated ongoing research team conference calls and record keeping, and worked with Dr. Favorov on data analyses for poster presentations, assisted with presentations and development of posters.</i>
Name:	<i>Oleg Favorov</i>
Project Role:	<i>Co-investigator</i>
Nearest person month worked:	4.8
Contribution to Project:	<i>Dr. Favorov takes the lead on motion sensor analyses, including supervision of a research assistant who set up the procedures for use of the the cell phone sensors for the project.</i>
Name:	<i>Wanqing Zhang</i>
Role:	<i>Co-investigator</i>
Nearest person month worked:	1
Contribution to Project:	<i>Dr. Zhang has worked with RA support on the RedCap database development and has taken primary responsibility for FITBIR data sharing agreement and administration.</i>
Name:	<i>CDR Scott Klimp</i>
Project Role:	<i>Site PI – Fort Bragg</i>
Nearest person month worked:	1
Contribution to Project:	<i>CDR Klimp works with project staff as the site PI at Ft Bragg to assist with recruitment and involvement of his staff (physical therapy) to identify potential subjects for the study. He meets with Dr. McCulloch quarterly to assure the project is going smoothly.</i>

Name:	<i>Lisa O'Block</i>
Project Role:	<i>Site PI - MAMC</i>
Nearest person month worked:	<i>1</i>
Contribution to Project:	<i>Dr. O'Block serves as the site PI for MAMC. She initiated the IRB protocol for their site, hired and assisted with training an RA to administer the project. She provides ongoing guidance to the project team related to feasibility and clinical utility.</i>
Name:	<i>Timothy Challener</i>
Project Role:	<i>Research Assistant</i>
Nearest person month worked:	<i>1</i>
Contribution to Project:	<i>Mr. Challener is a post-doc working with Dr. Favorov on sensor data collection, offering technical support if difficulties arise with data collection. He has developed interactive screens/guidance for our testers in the field and is also testing smaller sensors to validate them for future applications of the POWAR test.</i>
Name:	<i>Olcay Kursun</i>
Project Role:	<i>Consultant</i>
Nearest person month worked:	<i>1</i>
Contribution to Project:	<i>Dr. Kursun works in collaboration with Dr. Favorov on the analysis of accelerometry/gyroscopic data to develop custom or deep learning algorithms to differentiate those with mTBI from healthy controls.</i>

- ✦ **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?** No
- ✦ **What other organizations were involved as partners?**
 - ✦ **Organization Name:** Geneva Foundation
 - ✦ **Location of Organization:** Tacoma, WA
 - ✦ **Partner's contribution to the project** Subcontractor for personnel at Ft Bragg and MAMC
 - ✦ **Financial support;** support provided to Geneva to hire personnel and administer project at local military treatment facilities
 - ✦ **In-kind support Facilities** N/A
 - ✦ **Collaboration/Personnel exchange** N/A

- ✦ **Organization Name: Fort Bragg – Intrepid Spirit Center**
- ✦ **Location of Organization:** Fayetteville, NC
- ✦ **Partner's contribution to the project** local site for subject recruitment and data collection
- ✦ **Financial support** N/A
- ✦ **In-kind support** partner has made office space, computer, phone available to project staff, and also provides access to a pool of healthy control subjects through the DVBIC Newcomer's briefing that occurs at Ft Bragg
- ✦ **Facilities** Data collection takes place in the physical therapy treatment area during non treatment hours (lunch time, late afternoon, meeting times)
- ✦ **Collaboration** CDR Klimp and physical therapists Shaun Carlson and Michael Krok are collaborators to assist with recruitment, provision of feedback to project staff on testing feasibility and preferences to improve clinical utility.
- ✦ **Personnel exchanges** N/A
- ✦ **Other.**
- ✦ **Organization Name: MAMC**
- ✦ **Location of Organization:** Tacoma WA
- ✦ **Partner's contribution to the project** Provision of site PI and additional physical therapist collaborator, access to former staff of the T2 to assist with translation questions
- ✦ **Financial support** N/A
- ✦ **In-kind support** Partner allows project RA space, laptop computer, that she can use in office space at the Intrepid Spirit Center
- ✦ **Facilities** Partner allows testing to occur in the physical therapy treatment space during non-treatment hours;
- ✦ **Collaboration** Provision of physical therapist (Lisa O'Block, site PI, Holly Roberts) and psychologist collaborations (for translation issues)
- ✦ **Personnel exchanges** N/A
- ✦ **Other.**

8. SPECIAL REPORTING REQUIREMENTS

✦ **COLLABORATIVE AWARDS:** N/A

✦ **QUAD CHARTS:** *If applicable, the Quad Chart (available on <https://www.usamraa.army.mil>) should be updated and submitted with attachments) Provided on following page.*

PORTable WARrior Test Of Tactical AgiLity (POWAR-TOTAL): A dual-task test to aid return-to-duty (RTD) decision making after military concussion

Focus area: *Sensory systems, military relevance for return to duty assessment*



PI: Karen McCulloch, PT, PhD, NCS

Org: UNC-Chapel Hill/Geneva Foundation

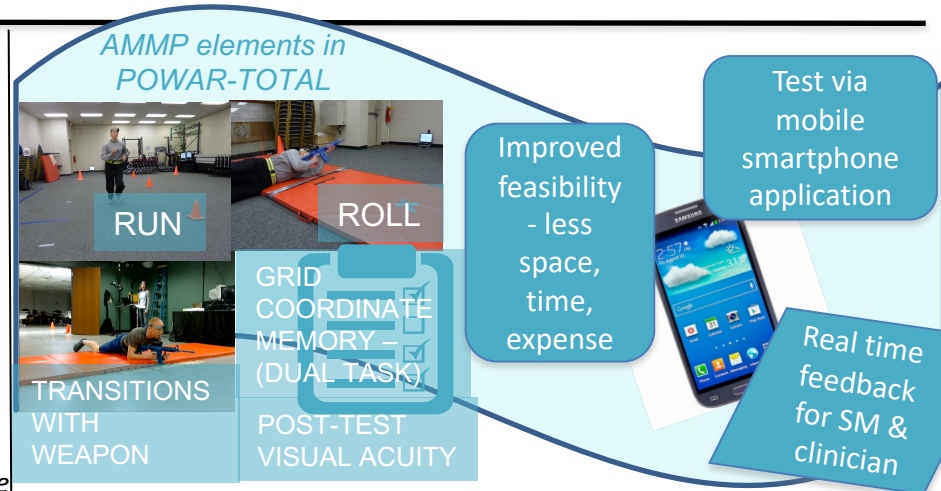
Award Amount: \$950K

Study/Product Aim(s)

- Compare POWAR TOTAL responses of healthy control participants to those with concussion
- Examine changes in POWAR-TOTAL performance as a result of outpatient intervention at Intrepid Spirit Centers at Fort Bragg and Joint Base Lewis-McChord (JBLM)
- Examine the relationship between POWAR-TOTAL scores and return to duty indicators used in clinical practice.

Approach

Our goal is to assess the performance-based POWAR-TOTAL, that requires tactical mobility skills in a dual-task scenario. We will improve clinical feasibility over similar validated AMMP test components by *requiring less space & time while using less expensive smartphone technology to measure movement*. This will provide a portable clinical test to inform RTD decision making and provide clinician and SM feedback in real time.



The POWAR-TOTAL uses the *most sensitive elements* from a recently validated dual- and multi-task battery, the Assessment of Military Multitask Performance (AMMP), that challenges cognitive and motor performance simultaneously. This testing approach proved effective in detecting differences between ADSM and SM with symptoms post-concussion.

Timeline and Cost

Activities	months	1-6	7-12	13-18	19-24
Project infrastructure/procedures		█			
Data collection for Aims 1 & 2			█		
Transition and clinical use plan			█		
Iterative data analysis & dissemination				█	
Estimated Budget (\$950K)		\$450K		\$550K	

Goals/Milestones

CY17 Milestones –Regulatory goals, staff training.

Healthy control data at Ft Bragg – 30/50 subjects, Concussion:6/50 subjects

CY18-19 Goals – Data collection continued.

CY20 Goals - Completed data collection, 75 mTBI subjects, 50 post-tested.

2 manuscripts submitted, 2 additional manuscripts in process.

CY 21 – 2 papers published, one additional submitted, 2 in process.

Additional work on immediate feedback display will also occur in conjunction with CAMP project.

Comments/Challenges/Issues/Concerns

Budget Expenditure to Date

Projected Expenditures: \$950,000

Actual Expenditures: UNC	\$381,756,
Geneva Fdtn	<u>\$363,383</u>
total	\$745,139

Updated: (12/2021)

APPENDICES:**Appended are published and submitted manuscripts from the project:****Two published papers**


Favorov O, Kursun O, Challener T, Cecchini A, McCulloch KL. Wearable Sensors Detect Movement Differences in the Portable Warrior Test of Tactical Agility After mTBI in Service Members. *Mil Med.* 2021 Sep 3:usab361. doi: 10.1093/milmed/usab361. Epub ahead of print. PMID: 34476483.

Cecchini AS, Prim J, Oh A, Zhang W, Harrison CH, McCulloch KL. The Portable Warrior Test of Tactical Agility: A Novel Functional Assessment That Discriminates Service Members Diagnosed With Concussion From Controls. *Mil Med.* 2021 Aug 19:usab346. doi: 10.1093/milmed/usab346. Epub ahead of print. PMID: 34414438.

And one under review:

McCulloch KL, Oh AS, Cecchini AS, Zhang W, Harrison C, Favorov O. Validity and Responsiveness of the Portable Warrior Test of Tactical Agility After Rehabilitation in Service Members with Mild Traumatic Brain Injury, *Physical Therapy*

The Portable Warrior Test of Tactical Agility: A Novel Functional Assessment That Discriminates Service Members Diagnosed With Concussion From Controls

Amy Seal Cecchini, DPT^{*}; Julianna Prim, PhD[†]; Wanqing Zhang, PhD[‡]; Courtney H. Harrison, MS[†]; Karen L. McCulloch, PT, PhD, FAPTA  [†]

ABSTRACT

Introduction:

Return-to-duty (RTD) readiness assessment for service members (SM) following concussion requires complex clinical considerations. The Portable Warrior Test of Tactical Agility (POWAR-TOTAL) is a functional assessment which improves on previous laboratory-based RTD assessments.

Methods:

Sixty-four SM diagnosed with concussion and 60 healthy control (HC) SM participated in this study. Group differences were analyzed to validate the POWAR-TOTAL. The High-level Mobility Assessment Test (HiMAT) was used to examine concurrent construct validity. An exploratory logistic regression analysis examined predictive validity.

Results:

The groups were demographically well-matched except for educational level. POWAR-TOTAL measures were statistically significantly different between the groups with moderate to large effect sizes. Concussed participants were less likely to be able to complete all trials of the POWAR-TOTAL. Motor scores correlated highly with HiMAT scores. POWAR-TOTAL motor task performance and membership in the control group was significantly associated with self-reported physical readiness to deploy.

Conclusion:

The POWAR-TOTAL is a clinically feasible, military relevant assessment that is sensitive to differences between concussed and HC SM. This analysis supports the discriminant and construct validity of the POWAR-TOTAL, and may be useful for medical providers evaluating RTD readiness for SM who have sustained a concussion.

INTRODUCTION

Since 2000, over 413,000 active-duty service members (ADSM) have sustained a traumatic brain injury (TBI), with 83% of these being categorized as mild (mTBI), or concussion. Concussion sustained by ADSM has the potential to significantly impact individual, unit and mission readiness. Symptoms and impairments associated with this type of injury

typically resolve in 7-30 days^{1,2}; however, anywhere from 10% to 30% of those who sustain concussion have symptoms and impairments that may last for months to years after injury. Causes of injury include blunt trauma, a mechanism common in contact sport athletes, as well as blast trauma, associated with improvised explosive devices or planned breaching operations, which are more uniquely associated with the military. The nature of military service increases the risk of multiple exposures to potentially concussive events over one's time in service. Military training intensity, mission variability and complex environments require dynamic abilities. These demands underscore the importance of ensuring recovery prior to full return to duty (RTD); physiological systems must be functional under real life conditions for mission success.

Return-to-duty (RTD) readiness assessment following concussion requires consideration of many impairments.³⁻⁶ After a concussive event, service members (SMs) may present with deficits in balance, agility, memory, vision, and dual- or multi-tasking, among other complaints. Self-report measures for concussion assessment may be of limited value^{7,8} in this population due to under- or over-reporting of symptoms. Self-report inaccuracy may occur because of operational demands, pressure from peers or command, or aspects of military culture that provide unique stressors.

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Information related to this manuscript was presented previously in poster format at American Congress of Rehabilitation Medicine Annual conference in 2019 and 2020 (virtual), poster format at AMSUS annual conference in 2020 (virtual) and was scheduled for a platform presentation at Military Health Services Research Symposium in 2020 (cancelled).

The views expressed herein are those of the author(s) and do not reflect the official policy or position of the U.S. Army Medical Department, Department of the Army, Department of Defense, or the U.S. Government.

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While there are validated objective measures for evaluating a concussion injury, few include military specific motor skills.⁹⁻¹⁴ An exception is the Military Functional Assessment of Performance, however, this test battery requires considerable space, equipment, and time, and has not been standardized or evaluated for scoring reliability.⁵ Balance measures studied in an ADSM population include the Community Balance & Mobility Scale (CBMS)⁹ and the NeuroCom™ Sensory Organization Test (SOT),¹⁵ with normative reference values available for the SOT.¹⁶ Other mobility assessments, such as the Dynamic Gait Index and the Functional Gait Assessment examine very basic mobility skills considerably below ADSM physical demands resulting in potential ceiling effects.¹⁷⁻²² Neuropsychological tests have been validated for evaluating cognition in ADSM, but are typically administered as single task assessments.¹¹ Most concussion assessments focus on tasks that explore single functional domains (i.e., vision, memory, balance) and are administered in static positions.

Challenging concussion tests that use dual task, multi-task, or exertional conditions may expose undetected subtle impairments that are not evident if abilities are tested singly.²³⁻³¹ Impairment under complex conditions is particularly relevant to a military population, relating to core duty activities and participation roles.²⁸ Such functional assessments are recommended by practice guidance for many rehabilitation specialties³² and are mandated by the Department of Defense's guidance for evaluation of a SM who has sustained greater than three concussions in a 12-month period, or who has sustained a concussion requiring specialty care due to the persistence of symptoms and impairments beyond the acute recovery phase.³² Guidance from the Traumatic Brain Injury Center of Excellence (TBICoE) (i.e., "Progressive Return to Activity Following Acute Concussion/Mild TBI," "Recurrent Concussion Evaluation Card")³² recommends standardized and validated military-specific functional assessments, but no tests have been published that are clinically feasible. Validation of such assessments would fill an existing gap in military concussion care.

The Portable Warrior Test of Tactical Agility (POWAR-TOTAL) is a performance-based exertional and dual-task assessment which requires less time, space, and technology than previous laboratory-based RTD assessments. The Assessment of Military Multitask Performance (AMMP), a test battery requiring laboratory equipment, extensive space and time, was validated by Weightman et al. and informed the development of the POWAR-TOTAL task.³³ A mobility task included in AMMP, the "Run-Roll-Aim" task (RRA)³⁴ and a simple working memory task, the "grid coordinate" cognitive task³³ were combined to challenge SMs in a smaller testing space with tasks that had discriminant validity in the AMMP study.³⁴ Visual testing was incorporated into the study as dizziness or gaze instability with rapid head or body movement are common post-concussion complaints. POWAR-TOTAL includes rapid position changes that may be

provocative to the visual-vestibular system and retained externally valid components from RRA (i.e., carrying a simulated weapon, movements from training activities).¹⁷ To examine the validity of the POWAR-TOTAL and its ability to differentiate those with concussion from their fit for duty HC peers, we conducted a cross-sectional case-control study.

METHODS

POWAR-TOTAL refined and improved upon the RRA task described previously,^{33,34} removing task elements with unacceptable inter-rater reliability or that did not discriminate between those with and without concussion. Inertial sensors used in the RRA task, were retained, as hand timing using a stopwatch was not a sensitive discriminator.³⁴ The test sequence was simplified, so it was more quickly learned, took less space, and retained the movement components that were most challenging and discriminative based on the RRA data analysis.

The purpose of this study was to compare performance on the observational measures from the POWAR-TOTAL test between concussed ADSM (referred for physical therapy with the intent to RTD) with a peer group of fit for duty ADSM. This study was conducted at Ft. Bragg, North Carolina and at Joint Base Lewis McChord, Washington. The study received approval from the Regional Health Command-Atlantic Institutional Review Board (IRB) as well as the Madigan Army Medical Center IRB and all participants provided informed consent.

Participants

Participants included ADSM aged 18-42 who were screened to ensure that they had the medical clearance and the ability to perform the study activities. Patient participants were ADSM diagnosed with concussion (≤ 2 years) who were initiating a course of treatment, including physical therapy, at an Intrepid Spirit Clinic (ISC). Patients had completed their physical therapy initial evaluation and were tested within the following week, prior to starting in-clinic treatment. A home exercise program may have been initiated. No effort was made to control for the physical therapy interventions, nor was timing of treatment controlled. We did not review records to determine care provided by other providers before this episode of care. We retested these individuals following this episode of care to examine responsiveness of the measures, those results will be reported in a future manuscript.

Fit for duty healthy controls (HC) were concussion free in the same time period, were on unrestricted active duty, and were eligible for deployment. To assure older ADSM in our control sample, a remote concussion history (> 2 years) was allowed but only if the SM was without ongoing symptoms that required intervention for that prior concussion. Participants were recruited via large group briefings for ADSM of all ages, ranks, units, and military occupational specialties (MOS). Participants were excluded from either group if they had a medical condition that restricted moderate exertion, had

a history of major psychiatric disorder, had a history of moderate, severe, or penetrating brain injury, or had visual or hearing deficits that prevented participation in testing. Screening occurred after informed consent and prior to initiating study procedures.

Measures

In a 1-h test session intake, self-report and performance measures were completed. The intake recorded demographics (age, gender, ethnicity, education level, first language, history of ADD/ADHD, history of learning disability, and history of treatment for depression, anxiety, and combat stress), military history (service, pay grade, MOS, time in service, and deployment history), and concussion history (lifetime estimated number, most recent, prior symptoms, and for patient participants, current symptoms for which they were seeking care). A question about perceived physical readiness to be deployed to a combat zone in the next 72 h was also collected, a question of predictive value in a prior study.³⁴ All participants completed the Neurobehavioral Symptom Inventory (NSI) measuring symptoms associated with concussion, the Defense and Veterans Pain Rating Scale (DVPRS), and the Posttraumatic Stress Disorder Checklist DSM-5 (PCL-5). All participants also completed the POWAR test and the 8 item High-Level Mobility Assessment Test (HiMAT), a standardized assessment of mobility tasks that includes timed measures of forward and backward walking, toe walking, running, skipping, and hopping, and a distance measure of leaping.

The POWAR-TOTAL is a multiple trial high-level complex task integrating physical and cognitive components, and was preceded and followed by visual testing. Dynamic stability, working memory, dual task ability, visual stability, and tolerance to visual-vestibular provocative movements were all challenged. The motor task required running with rapid position changes while carrying a simulated weighted service weapon (Bluegun™ M4). *Visual testing:* Binocular visual acuity was tested using a Snellen Eye Chart. There were 11 lines on the chart ranging from 20/500 (line 1) to 20/10 (line 11) with line 8 representing 20/20 vision. Self-rated visual clarity using an 11-point Likert Scale (0 = perfectly clear and stable, 10 = extremely blurry and/or unstable) was also recorded. Visual acuity and clarity were assessed in standing to record a baseline score and after all task trials were completed. *Cognitive testing:* Working memory was measured by asking the participant to retain an eight-character grid coordinate (e.g., Echo-Bravo 5-2-3-9-4-1), a method used by military personnel to identify operational locations. *Single task cognition:* The SM was instructed to remember the grid coordinate, provided verbally once at a rate of one character per second, in the exact sequence it was provided. After a 15-s delay (average time to complete the motor task), the SM recalled the grid coordinate. Verbatim responses were recorded and scored to allow credit for partial recall.

Letters were counted as correct if recalled accurately in the correct order. Digits were counted as correct if stated in the correct first or last position or for any correct string of three digits together anywhere in the span. On the first trial, if recall was less than four characters, a second ST cognitive trial was conducted using a different letter/number sequence. The better of the two scores was recorded as the ST cognitive score (0-8). *Motor testing:* The motor component was administered as a ST beginning with the SM in prone (Fig. 1). Trials were timed by hand using a stopwatch. After a “go” signal the SM stood, ran forward and diagonally to the left, transitioned to prone, performed a combat roll to the right, transitioned back to standing, back pedaled to the starting position, side shuffled several feet to the left, ran forward and diagonally to the right, transitioned to prone, performed a combat roll left, transitioned to standing, and back pedaled to complete the trial. Timing stopped when the first foot crossed the finish line at the end of the course. The SM was instructed to perform the task as quickly and safely as possible while carrying the weapon as they normally would. Inertial sensors worn at the occiput and lumbar spine were used to record movement in a more sensitive way. Procedures and results of this analysis are described in a separate manuscript.³⁵ The SM performed a practice trial first, followed by a ST timed trial. A second ST trial was conducted only if some error in course navigation or task understanding occurred. *Dual task testing:* Three dual-task trials required the SM to perform the motor task while remembering a grid coordinate. No instructions were provided as to prioritization of the cognitive or motor task. For each trial a new grid coordinate was provided while in the prone start position. After the last number was provided, the examiner paused briefly before signaling “go” and the start of timing. Motor and cognitive scores were recorded. The task resulted in single task scores for cognition and motor and dual task cognitive and motor scores. Visual acuity and clarity scores were recorded prior to the POWAR test (baseline) and after its completion (final).

Statistical Analysis

Data were entered and verified using Research Electronic Data Capture 209 (REDCap), an online, password protected database. All statistical analyses were conducted using SPSS statistical software (version 22). Descriptive analyses were performed on demographic data. Data normality was checked by Kolmogorov-Smirnov test and coefficients of skewness and kurtosis. Independent t-tests were used to test for differences between groups for continuous data, categorical data were analyzed using Chi-square. Pearson correlations were used to assess the relationships of POWAR-TOTAL motor score to HiMAT scores. An exploratory logistic regression analysis was performed to determine the ability to predict self-reported readiness for physical deployment considering group status and single task motor trial time. Receiver operating characteristic curve analysis was performed to characterize

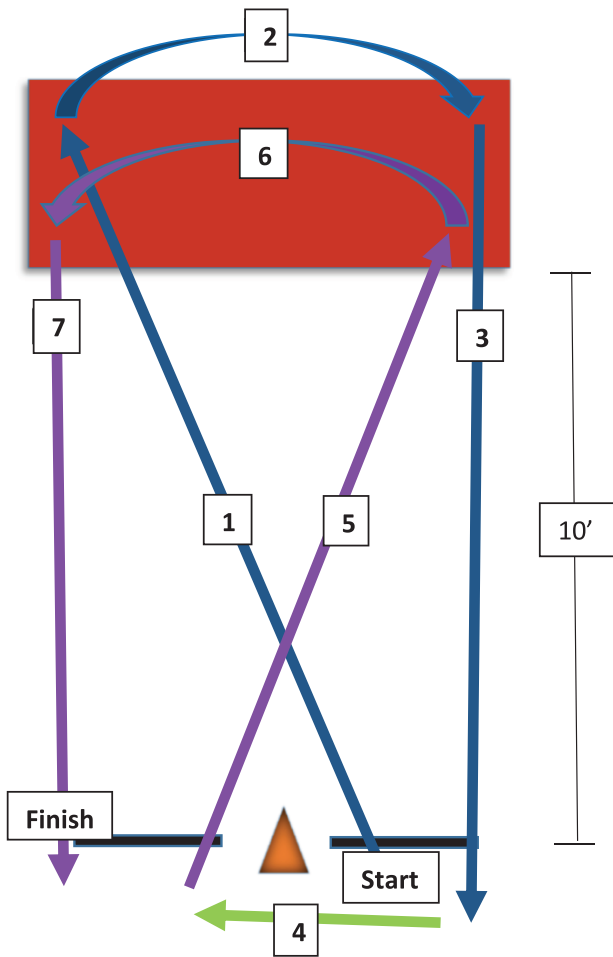


FIGURE 1. POWAR-TOTAL motor task schematic. The entire task is performed while carrying a simulated weapon, beginning in a prone position. Segments 1 and 5 require running forward to a mat and transition to prone, where a combat roll is performed (segment 2, roll to the right; segment 6, roll to the left), segments 3 and 7 require a transition to standing from the mat and backpedaling to the start/finish line.

POWAR motor performance with respect to the question of perceived readiness to be deployed as a binary dependent variable. A *P* value of less than 0.05 was considered statistically significant.

RESULTS

One hundred twenty four ADSM (60 HC, 64 concussed) were enrolled in the study; however, one control participant’s data was excluded from the analysis due to high symptom burden, poor test performance, and extensive remote concussion history that resulted in him seeking a referral for evaluation at the ISC. The groups were well matched demographically with the exception of education level (Table I). The concussed group had significantly higher scores on the NSI, PCL-C, and DVPRS than their control peers (*P* < 0.001) demonstrating higher symptom complaints. The concussed group had significantly lower HiMAT scores than the control group (*P* < 0.001), reflecting slower performance on high level mobility tasks. The groups differed with respect to

TABLE I. Demographic and Self-report Variables

Measure	Fit for duty controls <i>n</i> = 59	ADSM seeking concussion care <i>n</i> = 64	<i>P</i> -value
	Mean (SD)	Mean (SD)	
Age	29.5 (6.73)	29.7 (6.98)	0.848
Time in service	7.7 (6.84)	8.5 (6.34)	0.532
Sex	<i>n</i> (%)	<i>n</i> (%)	0.575
Male	54 (93)	60 (94)	
Female	4 (7)	4 (6)	
Ethnicity			0.404
Caucasian	38 (66)	47 (74)	
African American	9 (15)	4 (6)	
Hispanic/Latino	5 (9)	7 (11)	
Other	6 (10)	6 (9)	
Education			0.041
High school	10 (17)	18 (28)	
Trade school	0 (0)	3 (6)	
Some college/ associates degree	30 (51)	34 (53)	
Bachelor’s or advanced degree	19 (32)	9 (15)	
NSI (range 0-88)	7.88 (10.24)	37.97 (15.96)	<0.001
PCL-C (range 0-80)	6.63 (10.39)	28.25 (20.48)	<0.001
DVPRS (range 0-10)	1.36 (1.67)	4.36 (2.09)	<0.001
HiMAT (range 0-32)	30.63 (2.32)	22.23 (7.71)	<0.001

Abbreviations: NSI: Neurobehavioral Symptom Inventory; PCL: Posttraumatic Stress Disorder Checklist DSM-5; DVPRS: Defense and Veterans Pain Rating Scale; HiMAT: High Level Mobility Assessment Test.

multiple variables (Table II). Those in the concussed group were more likely to have duty restrictions such as light duty, to be working outside their assigned occupational specialty, or to have physical training restrictions. They were also more likely to report that they were not physically ready to deploy in the next 72 h. The index injury for inclusion in this study was the first lifetime concussion for 22% of the concussed group, however the group had a mean 5.5 (SD 6.99) lifetime concussions. Median time from the index injury to testing was 5 months for the concussed group. In the HC group 57.6% had previously had a concussion, mean 6.43 (SD 9.45) lifetime concussions, and median time from most recent concussion to initial testing was 57 months.

While concussion may occur during a deployment, it has been reported that the majority of concussions in ADSM occur in garrison or while off duty.^{1,22,36} In this sample, the concussed group was more likely to have been deployed, although the average number of prior deployments between ADSM with a history of deployment in each group did not differ significantly. The majority of our sample was recruited from Ft Bragg, where airborne operations provide additional exposures to potential injury.

TABLE II. Group Comparison: Categorical and POWAR-TOTAL Variables

Categorical variables		Fit for duty controls <i>n</i> = 59	ADSM seeking concussion care <i>n</i> = 64	X ² <i>P</i> -value
		<i>n</i> (%)	<i>n</i> (%)	
History of concussion	N	25 (42.4)	0 (0)	<0.001
	Y	34 (57.6)	64 (100)	
History of deployment	N	30 (50.8)	19 (29.7)	=0.0017
	Y	29 (49.2)	45 (70.3)	
Duty restrictions	N	7 (11.9)	34 (53.1)	<0.001
	Y	52 (88.1)	30 (46.9)	
Ready to deploy	N	3 (5.1)	45 (70.3)	<0.001
	Y	56 (94.9)	19 (29.7)	
Completed all POWAR-TOTAL trials	N	0	5 (8)	0.0589
	Y	59 (100)	59 (92)	
POWAR TOTAL variables		Mean (SD)	Mean (SD)	<i>t</i> -Test <i>P</i> -value (effect size)
ST-cognitive (items of 8 correct)		6.95 (1.41)	5.39 (1.97)	<0.001 (−0.91)
DT-cognitive (items of 8 correct)		6.35 (1.38)	5.08 (1.91)	<0.001 (−0.76)
ST-motor (seconds)		13.9 (2.04)	16.0 (3.74)	<0.001 (0.70)
DT-motor (seconds)		13.7 (2.12)	15.6 (4.30)	0.004 (0.56)
Pretest vision line (of 11, higher is better, 8 represents 20/20 vision)		8.26 (1.42)	7.63 (1.37)	0.014 (−0.45)
Pretest vision clarity self-report (0-10 rating, lower is better)		1.40 (1.68)	3.61 (1.98)	<0.001 (1.2)
Final vision line		8.28 (1.48)	7.12 (1.42)	<0.001 (−0.80)
Final vision clarity		1.84 (1.90)	4.86 (2.32)	<0.001 (1.4)

Abbreviations: ST: single task; DT: dual-task.

Known-Group Validity

Five concussed participants could not complete all POWAR-TOTAL trials due to symptom provocation that required stopping the test (2 dizziness, 2 pain, 1 headache). All control participants completed all trials, with the ability to complete the test approaching statistical significance (*P* = 0.059). The concussed participants were slower than fit for duty controls for single and dual task motor performance (*P* < 0.001, *P* = 0.050) with moderate effect sizes and were less accurate in recalling grid coordinates in both single and dual task conditions (*P* < 0.001) with moderate to large effect sizes (Table II, Figs. S1 and S2). Concussed participants reported lower visual acuity and clarity at both baseline and final timepoints compared to the control group (*P* < 0.001) with moderate to large effect sizes (Table II, Fig. S2).

Construct Validity

POWAR motor components were significantly correlated with total HiMAT scores (single task *r* = 0.551, *P* < 0.01; dual task *r* = 0.409, *P* < 0.01), supporting construct validity. Single task motor (ST-M) times were significantly correlated with each HiMAT subtask score, ranging from 0.453 to 0.661. The most significant correlation was between the HiMAT “run” subtask and S-TM (*r* = 0.661, *P* < 0.01).

Predictive Validity

The logistic regression model using ST-M performance indicated that participants in the control group were 34 times

more likely to report “physical readiness to deploy” when compared to participants in the concussion group [95% CI (8.99, 128.35), *P* < 0.001]. The odds ratio for S-TM was 0.715 [95% CI (0.573, 0.893), *P* = 0.003]. With a cut-off point of 0.6, the area under the curve for this model is 0.903 [95% CI (0.850, 0.956)] making this an excellent model for prediction of self-reported physical readiness to deploy (Fig. S3).

Healthy Control Analysis

Separate analyses compared control group data for those with and without a history of concussion (Table III). Those with a history of concussion were older (*P* = 0.01), were more likely to have been deployed (*P* < 0.001), and reported higher scores on the self-report measures (NSI, DVPRS, PCL-C). There were no significant differences in HiMAT performance or on the observational POWAR-TOTAL measures, except for reports of poorer baseline and final visual clarity for those with a history of concussion.

DISCUSSION

POWAR-TOTAL motor and cognitive performance demonstrated significant differences between ADSM seeking concussion care and their HC peers, with moderate to large effect sizes. Simple hand timing, which was reliable in the AMMP version of this task but did not discriminate between groups in AMMP, **did** distinguish between groups for the POWAR task, increasing the clinical feasibility of this task. These findings are consistent with previous studies showing reduced dual-task cognitive and motor ability post-concussion

TABLE III. Fit for Duty Control Group Comparison

Measure	History of concussion <i>n</i> = 35	No history of concussion <i>n</i> = 24	<i>p</i> -Value
	Mean (SD)	Mean (SD)	
Age	31.3 (6.7)	26.8 (6.0)	0.010
Prior deployment	24 (68.65%)	5 (20.8%)	<0.001
NSI (0-88)	12.8 (11.4)	3.1 (3.7)	<0.001
DVPRS (0-10)	1.9 (1.9)	0.6 (0.9)	0.001
PCL-C (0-80)	9.8 (11.8)	2.0 (5.7)	0.001
HiMAT (0-32)	30.7 (2.1)	30.6 (2.8)	0.896
POWAR-TOTAL			
metrics			
ST-cognitive	6.9 (1.3)	7.0 (1.6)	0.972
DT-cognitive	6.5 (1.3)	6.1 (1.5)	0.289
ST-motor	14.1 (2.1)	13.7 (2.0)	0.566
DT-motor	13.8 (2.0)	13.7 (2.3)	0.900
1st vision line	8.3 (1.3)	8.3 (1.6)	0.993
1st vision clarity	1.8 (1.7)	0.8 (1.5)	0.019
Final vision line	8.3 (1.4)	8.3 (1.7)	0.911
Final vision clarity	2.3 (1.8)	1.1 (1.8)	0.013

with lower level skills such as standing and walking.^{23–27,37} POWAR motor performance was significantly correlated with the HiMAT, supporting construct validity. Exploratory predictive validity for RTD readiness appears promising.

The POWAR-TOTAL was developed to provide rehabilitation clinicians with a more useful tool to assess RTD readiness for ADSM who sustain a concussion and receive physical therapy for their persistent symptoms and impairments, challenging known vulnerabilities that may affect higher level functional skills. The POWAR-TOTAL is proposed to supplement evaluation findings when medical providers are making RTD recommendations after a concussion, but is not a stand-alone assurance for soldiering skill and mastery. Symptom self-report and perception of readiness for deployment have many limitations indicating a need for valid measures to support or refute subjective reports. ADSM may exaggerate or minimize their symptoms and may over or under assess readiness for deployment. There is no psychometric measure of POWAR-TOTAL to validate effort. It is possible that an individual who does not have true impairment may under perform on the POWAR-TOTAL, but it is unlikely that an individual with true impairment will over perform. Performance based measures may have an advantage to identify SM who are truly not ready for RTD (e.g., unable to complete multiple trials of the test).

POWAR-TOTAL had a floor effect for some ADSM who were unable to complete the test, however, the test was administered during the week that a physical therapy course was initiated. Four of the five participants who could not complete the test were 4 or fewer months post injury with symptom complaints that prevented task completion. When a patient has a high symptom burden, therapy may focus on

symptom management prior to initiating challenging physical activities.³⁸ POWAR-TOTAL provides an option for evaluation that can be accomplished in typical clinical space with minimal equipment and can be used to track performance changes over the course of treatment. A therapist may decide to use POWAR-TOTAL as a measure to gauge return to typical military training activities or for performance optimization,³⁸ and implement the evaluation at the appropriate time in an episode of care.

Within the fit for duty HC group, several important findings emerged. Those with a remote (>2 years) history of concussion, but reported no current concussion related difficulties and no duty or deployment limitations, had significantly higher report of symptoms associated with concussion, higher perception of post-traumatic stress, and higher overall pain levels (all $P < 0.001$), compared to those who had no history of concussion. HiMAT and POWAR-TOTAL performance did not differ between those with and without concussion history, with the exception of vision, which may have been related to age; the never-concussed group was significantly younger than the remotely concussed group. These findings suggest “functional recovery” of SMs who have sustained a concussion in the past (median 57 months post-injury) when compared to the patient group in this study. Despite reporting a modest level of concussion related symptoms, ADSMs with a remote concussion history exhibited recovery of high-level skills relevant to the military, as tested by this task. These findings support the importance of further study of ADSM who have sustained a concussion in the past but who have RTD, but may continue to demonstrate higher symptom burden than those without concussion history. Performance-based measures that are more sensitive than observational scores and timing may further clarify subtle differences undetected by observational measures.³⁵

The patient participant group was limited to those who had sustained a concussion within the prior two years, which is a wide range, however, the median time post injury was 5 months. Providers at the Intrepid Spirit Centers regularly see ADSM whose most “recent” concussion was well outside the 2-year time frame, so we chose that cutoff in order to ensure sufficient recruitment to power our study. Although there are aggressive efforts by the military medical community to promote early identification of concussion and acute treatment, symptom burden and functional impairment for some ADSM with remote history of concussion continues to result in a need for military specialty care. The ability of POWAR to detect performance decrements in a post-acute group supports its potential value as a measure for ISC practice settings.

The POWAR-TOTAL task was designed to evaluate functions that are necessary for ADSM to perform no matter what their specific MOS. The main difference of POWAR-TOTAL from other previously validated concussion assessments is its ability to examine cognitive and motor abilities separately as well as in combination, more closely approximating tasks

used in typical military training scenarios and in more complex and potentially dangerous forward operations. Returning a SM to duty has unique implications and therefore must rise to a higher standard, using relevant challenges beyond those that might be applied to civilians for return to activity, school and work; or even for athletes for return to play and competition. SMs must perform at the highest level of skill due to the unique environments and conditions under which they may be required to operate, not only ensuring their own and their team's safety, as well as the safety and success of the overall mission.

Limitations

Study evaluators were not blinded to group status, this may have also introduced bias. Significantly higher education may have contributed to better control group cognitive task performance, although both groups prioritized motor performance over cognitive accuracy, as illustrated by faster run times and lower cognitive accuracy in the dual-task condition. Significantly higher levels of pain, other symptoms, or medication use in the concussed group may have degraded performance. POWAR-TOTAL does not differentiate factors that contribute to poorer performance. The impairments targeted in POWAR-TOTAL (visual-vestibular, dual task) may not have been an individual's primary complaints or focus of the physical therapy plan of care, therefore additional means of evaluation are likely to be necessary to comprehensively detect physical impairments post-concussion.

Finally, regarding the predictive validity analysis, the variable of perceived physical readiness to deploy was used as a proxy for RTD. As with all self-report information, candor of the response is subject to potential bias or inaccuracy. Given the exploratory nature of this analysis, seeking a RTD variable with higher external validity was beyond the scope of the study. Examination of the relationship of performance-based testing to actual RTD is an important area for future study.

CONCLUSION

The POWAR-TOTAL detected differences between concussed and HC ADSM based on simple observational scoring when used early in rehabilitation. The motor, cognitive, dual-task and visual components all demonstrated robust statistically significant differences between groups. Interestingly, even the single-task components of the POWAR-TOTAL discriminated between groups, perhaps due to the difficulty of the tasks, providing support for the continued development of performance-based assessments with challenging and military-specific skills.^{28,33,34,39} The POWAR-TOTAL task appears to be a valid, clinically feasible method for evaluating functional skills that are highly relevant to a military population.

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SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

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CONFLICT OF INTEREST STATEMENT


None declared.

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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.

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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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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.

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 task⁷ 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 running¹⁰ 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 Obradovic¹⁵ 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:

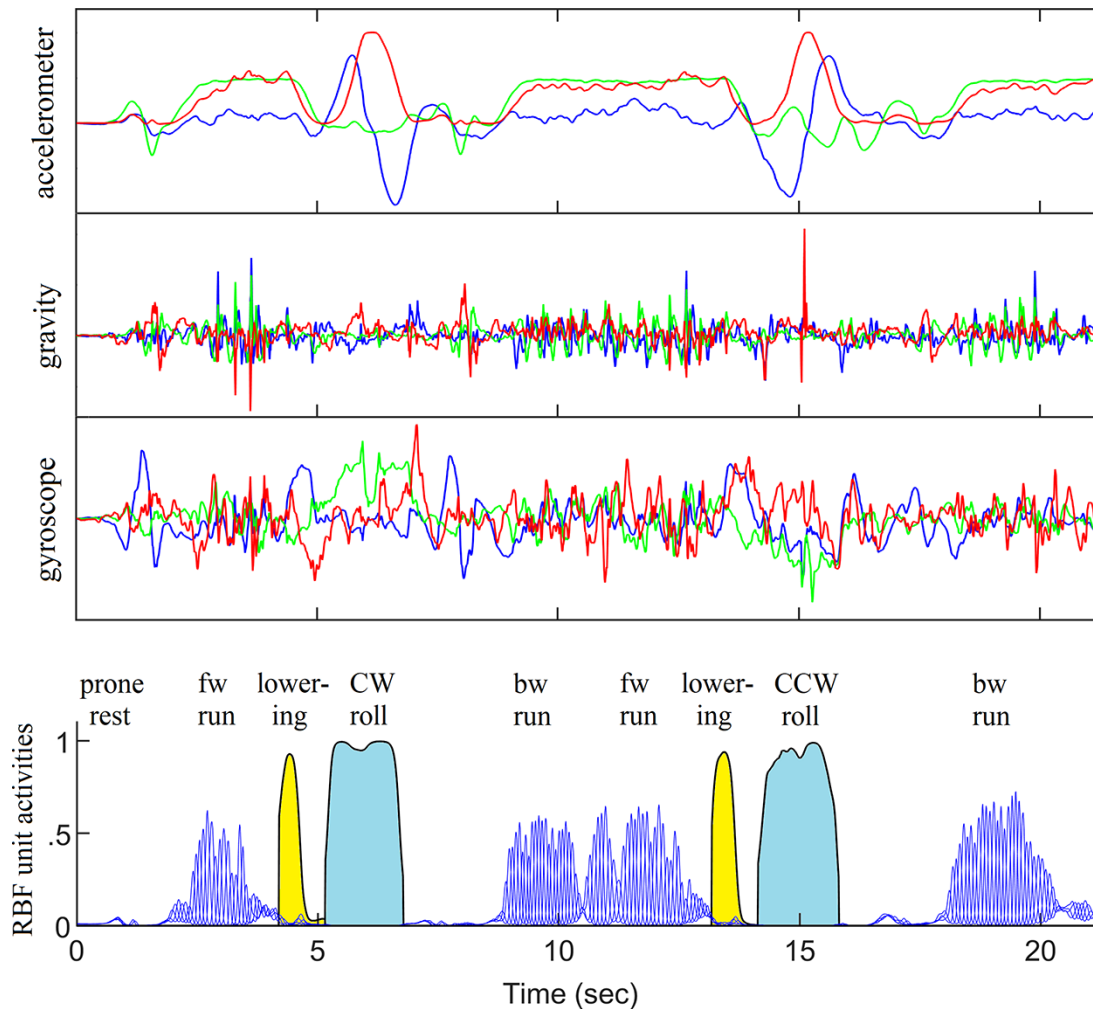


Figure 1. Inertial sensor recordings during an exemplary Portable Warrior Test of Tactical Agility (POWAR-TOTAL) trial. Red, green, and blue curves in the top three panels show the time courses of activities recorded along the x , y , and z axes of the accelerometer, gravity, and gyroscope. The bottom 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

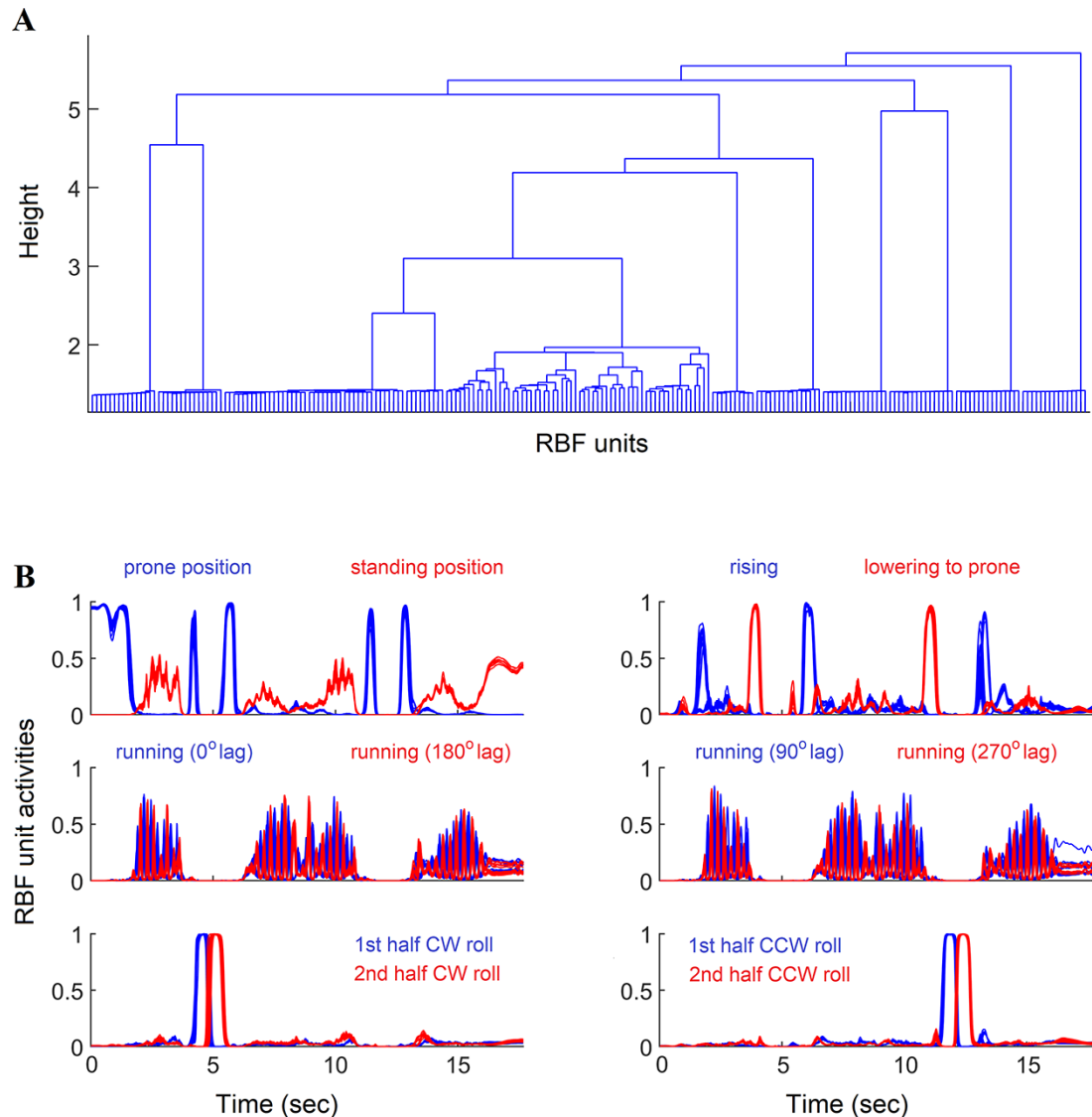


Figure 2. Clustering of radial basis function (RBF) units by their feature selectivities. (A) Dendrogram generated by hierarchical clustering of 225 RBF units from 15 independently developed RBF networks based on their responses to 2,000 sensor activity patterns. (B) Superimposed time courses of RBF 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

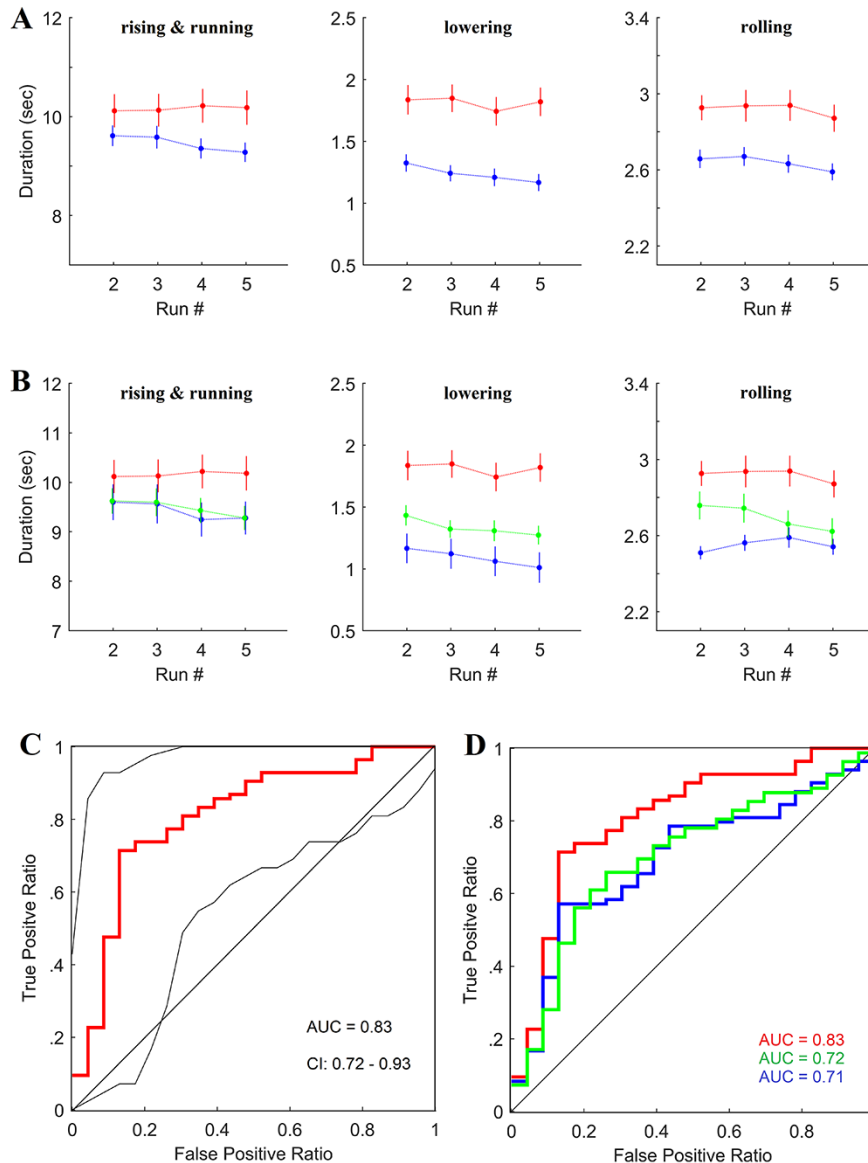


Figure 3. Average durations of the three main phases in trials 2-5 and receiver operating characteristic (ROC) analysis of phase durations of the mTBI subjects vs. healthy control (HC) subjects with no history of concussions. (A) The averages computed for the HC subjects (blue) and the mTBI subjects (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 <i>t</i> -test of the in-subject difference of the phase durations between trials 2 and 5 (<i>P</i> value)	HC group	0.0033	0.0004	0.0080
	mTBI group	0.68	0.82	0.20
(B) <i>t</i> -test of the difference of the means of phase durations between HC and mTBI samples (<i>P</i> 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 <i>d</i> for HC and mTBI samples	trial 2	0.27	0.79
	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 (<i>r</i> ² / <i>p</i>)	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 ADMS 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 observational⁸ 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.

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CONFLICT OF INTEREST STATEMENT

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

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Validity and Responsiveness of the Portable Warrior Test of Tactical Agility After Rehabilitation in Service Members with Mild Traumatic Brain Injury

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ABSTRACT

Objective: The Portable Warrior Test of Tactical Agility (POWAR-TOTAL) is a performance-based test designed to assess Active Duty Service Members (ADSM) diagnosed with a mild traumatic brain injury (mTBI) and could potentially inform return to duty decision making. To examine validity and responsiveness of the POWAR-TOTAL measure, we collected self-report and performance measures by ADSM before and after an episode of physical therapy care.

Methods: 74 individuals, enrolled in care for mTBI symptoms at one of two concussion specialty Intrepid Spirit Centers, were examined the week they initiated physical therapy with the intention to return to active duty. Self-report measures of concussion symptoms, pain, post-traumatic stress, headache, dizziness and sleep quality were used, as were concurrent measures of mobility and balance. The POWAR-TOTAL task (motor/cognitive skills in single and dual-task conditions) was administered. 49 ADSM returned for post-therapy testing using the same test battery. Effect sizes for change on measures were calculated. Construct validity was

assessed by correlating change scores on POWAR with concurrent self-report and mobility measures. Responsiveness was evaluated using an anchor-based approach.

Results: Significant improvements on self-report and performance based measures, including POWAR, were observed after therapy with moderate to large effect sizes. Improvement in POWAR performance was correlated with improvement in both performance and self-report measures. After therapy, individuals who registered improvement on the Patient Global Impression of Change scale demonstrated significantly faster POWAR motor performance than those who rated little or no improvement in their condition.

Conclusion: The POWAR-TOTAL captured improvement on a military specific task after completing physical therapy for mTBI and could serve as an indicator of physical recovery and readiness for return to duty.

Impact Statement: Realistic RTD readiness measures for a military population are critical to inform clinician assessment of recovery and the ability to successfully return to duty after concussion.

Keywords (7): concussion, mTBI, military, multi-task assessment, return to duty, functional assessment, rehabilitation

INTRODUCTION

Over 434,000 ADSM have sustained a traumatic brain injury (TBI) since 2000. Most of these injuries are classified as concussion, or mild TBI.¹ ADSMs are often able to return to unrestricted duty in 2-4 weeks, following rest and a progressive return to activity process,² but some demonstrate longer standing symptoms and impairments that required rehabilitation.³ Persistent impairments could impede performance of specialized military skills required for active duty, leading to an increased risk of injury or risk to others in more dangerous forward operations. Therefore, it is important to ensure that a ADSM diagnosed with mTBI has recovered and is ready to return to full duty including deployment to dangerous environments .

Symptom self-report as an indicator of recovery has limitations, as ratings are subject to under- or over-reporting effects, and may be influenced by social pressures associated with military service^{4,5} or for other reasons associated with personal or professional gain. Many self-report measures used for concussion, including the Neurobehavioral Symptom Inventory (NSI), a standard measure in military practice,⁶ lack specificity. Common symptoms may be associated with other conditions or stressors.⁷ Observational or performance measures offer benefits of detecting impairments to corroborate symptom report, and may also serve as markers of physical performance necessary for military duty.

Most balance and mobility measures commonly used by physical therapists do not incorporate high level challenging tasks typical of military training. Simple tasks such as standing or walking may not reveal subtle impairments that ADSMs experience or demonstrate ceiling effects and erroneously imply recovery, result in premature return to training, increase risk of injury to the ADSM, or negatively affect duty and mission capability. Tasks that reflect the dynamic and challenging conditions faced by ADSMs may be more sensitive to subtle symptoms associated with mTBI including dual-task or multitask conditions.^{8,9} Clinically feasible ecologically valid measures that assess exertional or dual-task abilities would fill a gap in concussion care in the military.

The Portable Warrior Test of Tactical Agility (POWAR-TOTAL, or POWAR) is a brief exertional dual-task assessment that could be administered in an a typical clinic or a more austere setting using readily available equipment (Figure 1). Construct validity of POWAR has

been previously described, and it discriminates between ADSM with concussion and their fit for duty ADSM peers via simple observational measures¹⁰ and inertial sensor measures.¹¹ Faster performance of the POWAR motor measure was significantly associated with self-reported physical readiness for deployment.

This paper addresses the responsiveness of POWAR in a group of ADSM diagnosed with concussion after completing physical therapy (PT). Self-report measures and validated performance measures of balance and mobility were measured before and after an episode of physical therapy to examine the relationship of change on POWAR with change on those measures to address construct validity. A rating of overall improvement, the Patient Global Impression of Change,¹² provided an anchor for evaluating responsiveness of the POWAR. Guidance for interpretability was also calculated for motor performance on the POWAR task.

METHODS

This pre-post longitudinal study was conducted at Intrepid Spirit Center (ISC) Clinics at Womack Army Medical Center (WAMC) at Fort Bragg in Fayetteville, NC and Madigan Army Medical Center (MAMC) at Joint Base Lewis-McChord, WA. The study received approval from the Regional Health Command-Atlantic and MAMC Institutional Review Boards and all participants provided informed consent. The funder played no role in the administration of the study.

Participants

Participants were ADSM (18 to 45 years) stationed at either Fort Bragg or Joint Base Lewis-McChord who were recruited from ISCs and were initiating treatment related to complaints associated with mTBI that was documented in the medical record and sustained greater than two weeks, but less than two years prior to enrollment. Exclusion criteria included confirmed pregnancy, presence of a major psychiatric diagnosis or medical condition that would prevent performance of cardiovascular exercises or rendered them unable to perform moderate exertion for up to 30 minutes, lifetime history of severe or penetrating head injury,

activity restriction that limited ability to run or perform military exercise for up to 10 minutes, and functional deficits in vision or hearing.

Measures and Procedures

Patients were scheduled for an initial test within a week of their initial PT evaluation. The final test session was scheduled as close as possible to the patient's final PT session or discharge from care by the physical therapist. The nature of and duration of PT intervention was not controlled.

Participants completed a questionnaire and self-report surveys at both sessions that included demographic and military service information (Table 1). Self-report measures targeted impairment areas that could influence ability to resume active duty after mTBI: the Neurobehavioral Symptom Inventory (NSI)^{13,14}, the Defense and Veterans Pain Rating Scale (DVPRS)^{15,16}, the Post Traumatic Stress Disorder Checklist-Civilian (PCL-C)^{17,18}, the Dizziness Handicap Inventory (DHI)¹⁹, the Headache Impact Test (HIT-6)²⁰⁻²², and the Pittsburgh Sleep Quality Index (PSQI).²³ Measures were selected based on known reliability and validity, and were consistent with TBI Center of Excellence recommendations for military research.

There are no validated measures of tactical agility that could be used as a gold standard for validation. Since the POWAR task requires balance and the ability to run, we included measures of mobility and balance that were conducted at pre- and post-therapy test sessions to examine rates of change on the POWAR task in relation to change on those measures. The NeuroCom Sensory Organization Test (SOT)²⁴ composite score, a test used by physical therapists to assess balance under varying sensory conditions, provided a measure of postural stability and balance. SOT was extracted from the medical record, or was completed by project staff at enrollment in the study if not administered by the treating physical therapist. Participants also completed the revised High Mobility Assessment Tool (HiMAT)²⁵ which has been validated in a civilian population diagnosed with mTBI, and requires running and other higher level mobility tasks. Since testing was conducted in ISCs that are single story structures, the HiMAT without stairs was used, and the test was repeated concurrently with the POWAR test before and following therapy. POWAR may provoke symptoms from individuals with vestibular impairment given the transitional movements required in the motor task that may

manifest in visuo-vestibular complaints. Therefore, we also extracted dynamic visual acuity test results (line(s) lost during horizontal head turning) from the medical record at the start of therapy, to measure the ability to stabilize visual images during head movement. In addition we tested vision for acuity and self-reported clarity at the beginning and following the POWAR test.

Participants who returned for the second test session completed a questionnaire which updated military service information collected at the pre-treatment session and completed the same self-report, POWAR, and HiMAT measures. The Patient Global Impression of Change (PGIC) was completed by the subject to characterize perceived change as a result of therapy intervention.

POWAR test procedures have been reported previously^{10,11} with details summarized in Figure 1. A prior version of this test that included a similar motor task demonstrated good interrater reliability²⁶, and the cognitive task used in the task had strong interrater reliability in a prior study.⁹ Visual acuity testing was conducted prior to and following the mobility components of the POWAR, using a Snellen chart and a visual analog scale rating of visual clarity that was used in a prior study.^{8,9} Single-task motor and cognitive testing was followed by 3 trials of dual-task performance. An important factor to consider with the use of novel mobility and balance measures is the potential for practice or learning effects that confound interpretation of change in performance. As part of the larger POWAR- study that included 60 healthy fit for duty control ADSMs,^{10,11} we tested a small sample (n=11) of control subjects twice approximately one month apart to examine possible learning or practice effects.

Statistical Analysis

Data were entered and verified using Research Electronic Data Capture 209, an online, password protected database. All statistical analyses were conducted using SAS statistical software (version 9.4). Demographic and clinical characteristics were assessed at baseline, where mean and standard deviation (SD) were used for continuous variables and frequencies and percentages for categorical variables. Data normality was checked by the Kolmogorov–Smirnov test and coefficients of skewness and kurtosis. Pre-post self-report standardized measures and performance measures were examined with paired sample t-tests for continuous

data to detect significant changes over the course of therapy, and to determine possible differences in the participants lost to follow-up and the group that returned for post-testing. Chi-square tests were used to compare frequencies between pre- and post-categorical variables (eg, readiness for deployment). We have previously reported the significant correlation of the POWAR measures with the balance and mobility measures in ADSMs with mTBI as well as healthy control peers (cite), but here analyze the change in these measures and their correlation with change on POWAR measures using Pearson correlation coefficients.

For self-report and performance-based measures, we characterized change in the entire sample across measures by computing within-subjects repeated-measures Cohen's *d* effect sizes:²⁷

$$d = \frac{m_{post} - m_{pre}}{\sqrt{s_{pre}^2 + s_{post}^2 - 2rs_{pre}s_{post}}} \sqrt{2(1 - r)}$$

where m_{pre}/s_{pre} and m_{post}/s_{post} are the means/standard deviations of the evaluated measure before and after the therapy, respectively; *r* is Pearson correlation coefficient between the two sets of observations.

An anchor-based responsiveness assessment was performance based on creating two groups (Improved/Not Improved) based on self reported post-test PGIC ratings. The PGIC is a measure that was developed by the TBI CoE to reflect overall improvement during a course of treatment and is recommended as an outcome measure for military mTBI research.^{12, 28}

Patient Global Impression of Change

Since beginning treatment at this facility, how would you describe the change (if any) in ACTIVITY LIMITATIONS, SYMPTOMS, EMOTIONS and OVERALL QUALITY OF LIFE, related to your painful condition?

Choose ONE.

- No change (or condition has gotten worse) (1)
- Almost the same, hardly any change at all (2)
- A little better, but no noticeable change (3)
- Somewhat better, but the change has not made any real difference (4)
- Moderately better, and a slight but noticeable change (5)
- Better and a definite improvement that has made a real and worthwhile difference (6)
- A great deal better and a considerable improvement that has made all the difference (7)

We determined a grouping of greater than or equal to 6 to characterize those who had meaningful improvement and PGIC scores of 5 and less to characterize those without meaningful improvement. Minimal clinically important differences (MCID) were calculated for POWAR motor performance based on individuals who rated PGIC at level 6-7. Minimal detectable changes (MDC) were calculated for POWAR motor performance based on individuals who rated PGIC at ≤ 5 , as we reasoned that the wording of the PGIC description for level 5 seemed consistent with definition of MDC, whereas levels 6-7 were more in line with a perception of MCID.

Test-retest reliability of the entire POWAR task was examined with a two-way repeated-measures linear mixed effect model with absolute agreement (first vs. second testing session, subject by subject variation). ICCs were calculated for POWAR metrics (single and dual-task condition stability of motor and cognitive tasks). A p value < 0.05 was considered statistically significant.

Results

Pre-post therapy testing

Demographic information for the 49 participants who returned for post-therapy testing is summarized in Table 1. The SM in this study had sustained their most recent concussion an average of 7.57 months prior to initial Physical Therapy evaluation, with a range of 1.45 to 23 months. They completed an average of 9.75 PT visits, with a wide range from 1 to 44, that included 1:1 physical therapy sessions, home exercise program only format, and/or group based therapy sessions. These participants were often also seeing other disciplines related to cognitive, visual or behavioral health concerns. There was no attempt to standardize or control interventions given our focus on validation of the POWAR-TOTAL measure.

Following treatment, on average self-report measures (NSI, PSL-5, DVPRS, DHI, PSQI) reflected statistically significant improvements in their respective domains (Table 2). HiMAT total, SOT composite score, and DVAT lines lost following completion of therapy also improved indicating higher level motor ability, static postural stability and visual acuity with head movement. It is important to note that even though improvements occurred, they were only

partial. On average, self-reported symptoms and functional limitations, albeit at a reduced level, remained after intervention.

Significant improvements were noted in POWAR-TOTAL results for single-task (ST) and dual-task (DT) performance for both cognitive and motor tasks as well as visual acuity after exertion, but there were no differences in pre-test visual acuity and clarity (Table 2). At both test sessions, average DT motor time was faster than ST motor time, reflecting practice effects associated with learning this novel task. DT cognitive score, measured as an average of 3 trials, was lower than the ST cognitive score, indicating a DT interference effect. On average ADSMs prioritized the motor component of the task over the cognitive.

POWAR motor performance (ST and DT conditions) was significantly inversely correlated to HiMAT, the measure we considered closest to a gold standard for assessing validity, [ST $r=-.55$, $p<.001$ (95% CI $-.72$, $-.30$); DT $r=-.37$, $p=.01$ (95% CI $-.60$, $-.09$)] in the complete sample ($n=74$). To examine responsiveness, change scores for the POWAR motor task were correlated with changes in HiMAT, SOT, NSI, and DHI, given POWAR is intended to challenge vestibular and balance function (Table 3). HiMAT changes demonstrated the most significant correlations to changes in POWAR motor scores, followed by the SOT. The DHI, which is designed to identify complaints of dizziness, had higher correlation values than the more generic self-report measure, the NSI, supporting discriminant validity.

Effect sizes of the performance-based tests were all in the medium range (Table 2). Anchor-based responsiveness was examined by comparing those who scored the the PGIC at 1-4 (little to no change or worse) and those who scored the PGIC at greater than or equal to 5 (self-rated improvement). This analysis included a total of 47 subjects who had complete data on all necessary measures. At post-testing, POWAR ST motor was significantly faster in those reporting improvement on the PGIC [$n=31$ ($-2.87s$, sd 3.98s)] compared to those in the no change or worsening group [$n=16$ ($0.12s$, sd 3.14 points)] ($p=0.008$). POWAR DT motor was also significantly faster between those reporting improvement ($-3.00s$, sd 5.08s), and the group reporting no change or worsening averaging ($-0.07s$, sd $\pm 3.01s$), $p=0.02$.

Minimal clinically important differences (MCID) were computed as the mean change in individuals who reported what we interpreted as significant change on the PGIC (levels 6 or 7,

n=17), resulting in an MCID of -3.65s for single-task motor and -3.85s for dual-task motor. Cognitive task performance was not significantly different in the two groups as sorted by PGIC. Minimal detectable changes (MDC) were computed based on individuals who reported a PGIC of ≤ 5 , who reported only slight or no improvement after therapy (n=30), resulting in MDC of -1.96s for POWAR single-task motor and -2.05s for POWAR dual-task motor.

Test-retest stability for ADSM controls

Observational measures (hand timing, cognitive task scoring) for POWAR-TOTAL components for the 11 healthy control subjects improved on average on the second test for the motor task (by 0.82s and 1.06s for single and dual-task conditions, respectively), but not the cognitive task. These improvements fall far short of the MDC ($<52\%$) and MCID values ($<28\%$). ICC values for the motor task were 0.88 for the single-task condition and 0.84 for the dual-task condition. For the cognitive task, ICC values were 0.81 and 0.83 for the single and dual-task conditions, respectively.

Lost to Follow-up Group characteristics

The lack of treatment control in this study created challenges for engaging participants in post-testing. The scope and duration of therapy for individuals varied widely. Data collection for the study spanned from May 2018 to August 2020, including months in 2020 where the COVID pandemic caused suspension of research operations and halted intervention prior to transitions to telehealth. We collected data on 74 ADSM with concussion, but 25 of those participants were lost to follow-up, leaving 49 ADSM in the final analysis. Analysis of those lost to follow up did not identify any group differences on demographics, self-report or performance-based measures with the exception of visual acuity, where those lost to follow up had significantly better acuity at rest and following the POWAR test motor trials at their initial test session (Table 2).

Discussion

Results of the study support the construct validity of the POWAR measure and its responsiveness to meaningful change that occurs over an episode of physical therapy care. POWAR has face validity in its similarity to skills commonly required of ADSM, can be conducted in typical clinical space, and takes less than 15 minutes to conduct. Within-person

responsiveness was supported by medium effect sizes for POWAR-TOTAL variables. Improvements in motor and cognitive performance following therapy were correlated with changes in other performance-based and self-report measures in the expected directions. External responsiveness of the measure was supported through use of the PGIC as an anchor. Using PGIC anchor ratings, minimal clinically important difference (MCID) and minimal detectable change (MDC) values were calculated to provide *preliminary* interpretability guidance for clinicians, suggesting that improvements of 3.65 (ST) and 3.85 (DT) seconds are associated with clinically important change; and improvements of 1.96 (ST) and 2.05 (DT) seconds are necessary to conclude actual change has occurred. The extent of the practice effects of the test with a healthy control group was examined in a small subsample, but it suggests that such practice effect is much smaller than MDC and MCID. Additional study of test-retest reliability in a larger sample of healthy controls and development of age and sex related reference values is necessary to guide interpretation of test results in clinical practice.

Stronger correlations of single-task POWAR measures to the HiMAT follows logically, as the single-task condition has a sole focus on motor performance. The introduction of the dual-task condition requires attention be allocated to two tasks, but detailed analysis of POWAR dual-task performance is beyond the scope of this paper. The POWAR motor task could be used without the dual-task condition to shorten testing time, as single and dual-task motor task metrics were similar in their relation to concurrent measures. Pre-post therapy effect size for the HiMAT for the patient group was small ($d = 0.32$).

This testing protocol included visual acuity and clarity testing prior to and following the POWAR-TOTAL test trials. Within initial test sessions, visual acuity and clarity showed a significant decline after completion of the single- and dual-task motor trials when compared to pre-test status, reflecting the impact of the agility task on vision and suggesting that the effects of concussion on vestibulo-ocular function may not be apparent at rest. Dynamic challenge of the vestibular system may be particularly important to critical soldiering skills, such as marksmanship while maneuvering. No significant differences in resting visual acuity or clarity were observed following PT intervention. This may indicate a true lack of change in static visual acuity or an inability of our basic measures to detect subtle changes.

Study examiners were not blind to group status in the larger study, which may have induced bias, however data were measured using a stopwatch, inertial sensors, and verbatim recording of verbal responses, so the influence on results is likely to be low. During the initial testing, 7 participants did not complete the entire POWAR test protocol because of participant requests to stop because of onset of increased symptoms (n=4) or by project staff because of concerns for symptom increase or safety (n=3). Of the ADSM who could not complete the entire POWAR test battery at baseline, 4 were lost to follow up, but 3 returned for post-testing and were able to complete all trials. The floor effect (9.5%) observed in initial testing, could discourage those who are very symptomatic in their recovery, and may have influenced return for post-testing. However, examination of self-report and performance measures did not indicate significant differences in the lost to follow-up group and those who returned for post-testing, with the exception of self-reported visual ratings, which were better in those lost to follow up (Table 2). The timing of the initial assessment was in the first week of an episode of physical therapy care, when symptom burden of some individuals was high. If this test is used in clinical practice, the therapist could use the test when symptoms have stabilized and preparing for return to full duty is a focus of treatment.

The POWAR motor task was devised to challenge the vestibular system, however, participants in this study were receiving PT for other reasons that may or may not have had a vestibular etiology. Performance-based measures that target other areas (e.g., exertion or cervicogenic impairment) may be needed to evaluate ADSMs and inform providers about overall recovery and physical readiness for return to duty. Enrollment of participants in PT may have excluded individuals with subtle impairments who were seen by the ISC PTs for evaluation only and physical therapy interventions were not recommended.

The PGIC is a measure that is advocated for use in the military mTBI population, but is complex in its targets encompassing global quality of life and it refers to “your painful condition”. Although there are versions of the scale that instead reference “your post-concussive condition” that might have better captured targets of PT, we used the version that mentions pain, shared by the TBI CoE site.²⁹ Pain is a common complaint in ADSM. On average the self-reported DVPRS level reduced from 4.4 (4=distracts me, can do usual activities;

5=interrupts some activities) to 3.1 (3=sometimes distracts me) in the sample who returned for testing. It is possible that PT was focused on non-pain related impairments instead making this measure less applicable for some enrolled in the study. Physical function is clearly an important factor in quality of life for an ADSM, but many other factors could also influence responses to the PGIC question.

Only ADSM ratings on the PGIC were recorded. We did not collect provider impressions of improvement that would have provided an additional anchor-based method of evaluation. A question more focused on functional recovery may provide a better self-report anchor when evaluating measures that are physical performance-based. The timing of post-physical therapy testing did not necessarily coincide with conclusion of rehabilitation, as participants may have also been receiving services for headache, behavioral health conditions, visual impairments, or cognitive impairments that also influence perception of quality of life and ability to fully return to active duty.

Conclusion

The POWAR-TOTAL captured improvements in high-level mobility after an individualized outpatient physical therapy treatment program targeting impairments that were related to concussive injury. Reliability of the measure is acceptable. Construct validity is supported by correlation with concurrent measures, discriminant validity is supported with the analysis of change scores, and responsiveness to change of the measure is promising. The POWAR-TOTAL as a clinical tool for providers who inform return-to-duty decisions incorporates tasks that are military specific and addresses a range of vulnerabilities known to be affected by mTBI. Ensuring the fighting force is recovered after a mTBI will aid in supporting individual and unit readiness for effective mission capability. Additional study will provide more refined guidance for interpretation of scores and timing of its use in clinical practice.

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Table I. Demographic variables

Variables	Total Sample Mean (SD) n=74	Returned for post-testing Mean (SD) n=49	Lost to Follow-up Mean (SD) n=25
Age	29.6 (6.8)	29.2 (6.4)	30.4 (7.7)
Time in service	8.6 (6.2)	8.1 (5.9)	9.6 (6.8)
Number of Deployments	3.6 (2.7) Range (1-12)	3.9 (2.9) Range (1-12)	3.2 (2.5) Range (1-11)
Time since recent concussion (mos)	7.8 (6.6)	7.6 (6.5)	8.1 (6.8)
Prior number of Concussions	5.5 (6.4) Range (1-40)	6.0 (7.5) Range (1-40)	4.4 (3.1) Range (1-10)
Connor Davidson Resilience Scale*	74.5 (15.7)	73.8 (15.9)	75.7 (15.7)
Patient Global Index of Change ^	-	4.7 (1.46)	-
Categorical variables	n (%)	n (%)	n (%)
Sex			
Male	68 (91.9)	46 (93.9)	22 (88.0)
Female	6 (8.1)	3 (6.1)	3 (12.0)
Ethnicity			
Caucasian	55 (74.3)	39 (79.6)	16 (64.0)
African American	4 (5.4)	2 (4.1)	2 (8.0)
Hispanic / Latino	8 (10.8)	5 (10.2)	3 (12.0)
Other	7 (9.5)	3 (6.1)	4 (16.0)
Education			
High School	21 (28.4)	14 (28.6)	7 (28.0)
Some College/Associates Degree	44 (59.5)	28 (57.1)	16 (64.0)
Bachelor's Degree or higher	9 (12.2)	7 (14.3)	2 (8.0)
Concussion history prior to this injury	58 (78.4)	40 (81.6)	18 (72.0)
No duty restrictions	33 (44.6)	21 (42.9)	12 (48.0)
Physically ready to deploy in 72 hours	22 (29.7)	13 (26.5%)	9 (36.0)

* assessed at initial test session only

^ assessed at final test session only

Table 2. Self-report, Performance and POWAR-TOTAL Variables

Measure	LTFU Group Mean (SD) n=25	Initial Mean (SD)	Final Mean (SD)	p	Effect Size
NSI (0-88)	41.3 (19.1)	37.6 (15.1)	28.2 (16.9)	<.001	-0.58
PCL (0-80)	31.3 (20.4)	28.8 (20.1)	21.1 (18.9)	<.001	-0.39
DVPRS (0-10)	4.2 (2.2)	4.4 (2.0)	3.1 (2.2)	<.001	-0.62
DHI (0-100)	42.1 (21.5)	33.5 (20.0)	24.4 (19.7)	<.001	-0.46
HIT-6 (36-78)	60.5 (8.1)	62.3 (8.1)	57.4 (8.9)	<.001	-0.58
PSQI (>5 referral threshold)	12.9 (4.7)	13.5 (4.5)	11.1 (5.0)	<.001	-0.50
DVAT (lines lost)	2.3 (1.2)	2.6 (1.5)	1.8 (1.0)	<.001	-0.71
SOT Composite (of 100)	68.5 (14.3)	68.6 (15.3)	75.7 (13.9)	<.001	0.72
HiMAT (of 32)	21.4 (7.3)	22.3 (8.1)	24.3 (7.6)	<.001	0.32
POWAR-TOTAL metrics					
ST-Cognitive (of 8)	5.7 (2.1)	5.4 (1.9)	6.6 (1.5)	<.001	0.67
DT-Cognitive (avg of 3 trials, of 8)	5.1 (2.1)	5.2 (1.8)	5.9 (1.7)	0.003	0.42
ST-Motor (sec)	17.7 (6.6)	16.1 (4.0)	14.3 (3.0)	0.002	-0.51
DT-Motor (avg of 3 trials, sec)	16.8 (6.5)	15.9 (4.6)	14.0 (2.8)	0.006	-0.50
Pre-test vision line	8.1 (1.3)*	7.4 (1.3)*	7.6 (1.2)	0.124	0.16
Pre-test self-rated vision clarity	3.8 (2.1)	3.6 (2.1)	3.8 (2.2)	0.553	0.09
Post-test vision line	8.1 (1.0)*	6.8 (1.3)*	7.4 (1.5)	0.053	0.36
Post-test self rated vision clarity	5.2 (2.1)	4.7 (2.4)	4.3 (2.1)	0.277	-0.18
Completed all trials	20 (80%)	47 (95.9%)	48 (98.0%)		

* Significant difference in initial test values in the lost to follow-up group and the group that was tested before and following therapy. Visual acuity was rated on a Snellen chart with line 8 representing 20/20 vision. Visual clarity was rated on a 0-10 visual analog scale with 0 as “perfectly clear” and 10 “extremely blurry and/or unstable.”

Table 3

Correlations in change scores	POWAR ST motor (95% CI)	p value	POWAR DT Motor (95% CI)	p value
HiMAT	0.52 (.26, .71)	<.001	0.55 (.29, .73)	<.001
SOT	0.46 (.16, .67)	.004	0.42 (.11, .65)	.009
NSI	0.35 (.07, .58)	.01	0.29 (-.004, .53)	.05
DHI	0.44 (.17, .64)	.002	0.30 (.01, .54)	.04

Figure 1.

Portable Warrior Test of Tactical Agility (POWAR-TOTAL) testing protocol

Visual acuity testing: Binocular visual acuity was assessed in standing using a Snellen Eye Chart. Vision line was recorded to assess acuity, with Line 8 reflecting 20/20 vision. Self-reported visual clarity for that line was recorded using an 11-point Likert Scale (0 = perfectly clear and stable; 10 = extremely blurry and/or unstable).

Cognitive task: A single task working memory task required the participant to remember an 8 item grid coordinate (e.g. Echo-Bravo-4-2-9-6-3-7), a familiar type of military location description. If 4 or fewer of the 8 items of the grid coordinate were recalled, a second trial was conducted. The better of the two scores was recorded as the baseline single task cognitive score.

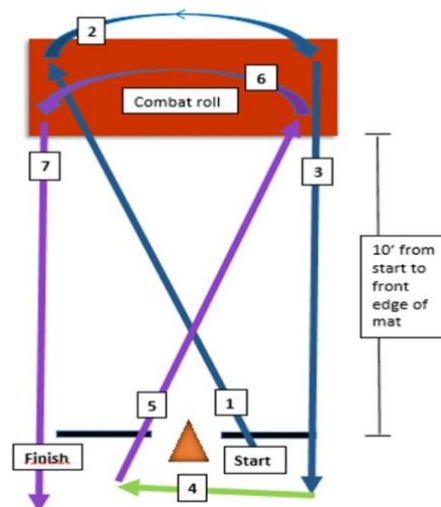
Motor task: The POWAR-TOTAL motor task is a rapidly performed mobility-agility maneuver that begins with the participant lying in the prone position while holding a simulated M16 weapon (Bluegun™).



The participant quickly transitions to standing, runs diagonally 10 feet forward to a gym mat, completes a left-to-right combat roll, transitions to standing, runs straight backward to the start position, shuffles laterally around a cone, runs forward diagonally 10 feet to the opposite side of the mat, transitions to prone and completes a right-to-left combat roll, transitions to standing and runs backward again toward the end position (schematic in right panel).



The motor task was hand-timed and recorded. Movements were recorded via the AndroSensor application (v1.9.6.3, www.fivasim.com) on Samsung Galaxy cell phones using its triaxial accelerometers and gyroscopes. Phones were attached to the head and torso via adjustable neoprene straps. After a practice trial to assess safety and recall of the components of the task, up to two single-task motor trials were performed.



Dual-task trials: Three dual-task trials combined the motor and cognitive tasks, each consisting of a new grid coordinate provided to the participant while in the start position. After a one second pause, the participant was signaled to begin the motor task with a ready, set, go command. Upon completion of each trial, the recalled the grid coordinate items were recorded.

Rest and stopping criteria: Rest was allowed in between trials if needed. If a subject experienced symptoms that did not quickly resolve or there were safety concerns based on their performance, testing was halted prior to completing all trials.

Post-testing visual acuity: After the first single task trial and the final dual-task trial, visual acuity and clarity were reassessed using the same approach as at the beginning of the test.

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