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Development of a Fitness-for-Duty Assessment Battery for Recovering Dismounted Warriors

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14. ABSTRACT
Balance problems and dizziness are common symptoms of mild traumatic brain injury (mTBI). Anecdotal reports from occupational and physical therapists indicate that Soldiers recovering from mTBI are experiencing balance-related difficulties with weapons utilization. The purpose of the present study is to determine the vestibular and balance-related effects of mTBI on standard marksmanship abilities, as well as the sensitivity and reliability of a new dynamic marksmanship battery in detecting the effects of mTBI. Phase 1 collected data from sixty U.S. Army Soldiers (without a history of mTBI) using USAARL's Engagement Skills Trainer 2000 weapons simulator. Test-retest reliability of the novel battery was examined as well as the battery's sensitivity to induced vestibular disruption. Phase 2 collected data from nine U.S. Army Soldiers (with a history of mTBI). While there were no significant differences between the mTBI and control group, the mTBI group performed worse in terms of accuracy and shot radius on the narrow kneeling task. Implications for return-to-duty decision making are discussed.

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Table of contents

Page

Table of contents (continued)

Page

Table of contents (continued)

Page

List of figures

Table of contents (continued)

List of tables

Page

Introduction

A recent report published by the RAND Corporation (Tanielian & Jaycox, 2008) surveyed 1,965 veterans from Operation Enduring Freedom (OEF; Afghanistan) and Operation Iraqi Freedom (OIF; Iraq); 19% of those surveyed reported a probable traumatic brain injury (TBI) during deployment. According to the National Center for Injury Prevention and Control, mild TBI (mTBI) is a "silent epidemic," as most of its symptoms are more difficult to detect than the obvious physical symptoms and structural damage associated with severe brain injury (2003). Furthermore, there are difficulties with the neuropsychological test battery that was being used to screen Soldiers for mTBI (Zoroya, 2010). Given the difficulties in diagnosing, mTBIs are believed to be underreported (Scherer & Schubert, 2009).

Currently, there is no universal definition of mTBI (Management of Concussion/mTBI Working Group, 2009). The most widely accepted criteria are those of the American Congress of Rehabilitation Medicine (1993). They include "a physiological disruption of brain function as a result of a traumatic event as manifested by at least one of the following: alteration of mental state, loss of consciousness (LOC), loss of memory or focal neurological deficit, that may or may not be transient; but where the severity of the injury does not exceed the following: post-traumatic amnesia (PTA) for greater than 24 hours, after the first 30 minutes Glasgow Coma Score (GCS) 13 -15, and loss of consciousness is less than 30 minutes."

Those who suffer an mTBI may experience physical (headache, balance problems, sleep disturbances), cognitive (attention and memory problems), and/or behavioral symptoms (depression, anxiety, aggression), and these symptoms may resolve quickly (within minutes to hours). However, some develop persistent symptoms, including headache, fatigue, dizziness, concentration problems, and anxiety, known as post-concussive syndrome (PCS; Management of Concussion/mTBI Working Group, 2009). Generally, symptoms lasting more than three months are considered PCS (Bigler, 2008).

Mild TBI can arise as a result of explosive blasts or blunt forces on the battlefield. Blast-related injuries account for more than 80 percent of all battlefield injuries in Iraq and Afghanistan (Hoffer et al., 2010). They can result from improvised explosive devices (IEDs), rocket-propelled grenades (RPGs), and landmines. Injuries from blast-related mTBI can be caused by three main mechanisms: primary effects are due to the pressure waves and can include injury to internal organs due to air pressure; secondary effects are due to objects that strike the victim, and tertiary effects result when an individual strikes a stationary object (Ling, Bandak, Armonda, Grant & Ecklund, 2009; Cernak & Noble-Haeusslein, 2010). Blunt-related mTBI result from impacts to the head from vehicle accidents, falls, or other accidents.

It has been reported that approximately 90 percent of acute mTBI patients and 80 percent of chronic mTBI patients exhibit vestibular disorders (Balaban & Hoffer, 2009). Common symptoms include vertigo, dizziness, disequilibrium, and gaze instability. In fact, dizziness has been reported as one of the top five post-concussive symptoms that distinguishes mTBI patients from healthy controls (Paniak, Reynolds, Phillips, Toller-Lobe, Melnyk, & Nagy, 2002). Postural sway is another common complaint among Soldiers who have sustained an mTBI (McNamee, Walker, Cifu, & Wehman, 2009). It is estimated that recovery from vestibular disorders in TBI patients is one to three times longer compared to recovery from vestibular disorders from other causes (Shumway-Cook, 2007).

Brain injuries can cause vestibular dysfunction by damaging the inner ear itself, the vestibular nerve, or the central structures (Shumway-Cook, 2007). Table 1 presents the sites and mechanisms of head trauma-induced dizziness. The vestibular apparatus provides information about head position and motion. It is located in the inner portion of each ear and contains three semicircular canals and two otolith organs. The semicircular canals are responsive to angular acceleration along three perpendicular axes, while the otolith organs (the utricle and saccule) respond to linear acceleration and changes in head position relative to the forces of gravity. The receptor cells within each vestibular apparatus relay motion information through the vestibular branch of cranial nerve VIII to nuclei within the brainstem, which project to the cerebellum, oculomotor nerves, and spinal cord (Widmaier, Raff, & Strang, 2006).

Table 1.
Sites and mechanisms of head trauma-induced "dizziness" (Shumway-Cook, 2007).

SITE	SYNDROME	MECHANISM
Inner ear	Benign paroxysmal positional vertigo	Dislodging of otoliths, cupulolithiasis or canalithiasis
	Post-traumatic endolymphatic hydrops	Decreased endolymphatic flow
	Perilymphatic fistula	Rupture of round or oval window or of membranous labyrinth
	Labyrinthine concussion	Endolymphatic hemorrhage
Vestibular nerve	Temporal bone fracture	Disruption of VIIIth cranial nerve
Brainstem or vestibulocerebellum	Downbeat, upbeat, and torsional nystagmus	Contusion or hemorrhage of brainstem or cerebellum
	Central positional vertigo	
	Ocular tilt response	
	Postconcussive syndrome	
Cerebral cortex	Tornado epilepsy	Post-traumatic seizures
Neck	"Whiplash"	Flexion-extension injury
Psychological	Panic disorder, chronic anxiety	Psychogenic
	Depression	
	Somatization	
	Compensation neurosis	

Current vestibular assessments

There are a number of vestibular assessments currently being used by clinicians to assess vestibular function. Shumway-Cook (2007) recommends that vestibular assessments should evaluate a patient's ability to perform functional skills requiring postural control in addition to static balance tests. For example, the Berg Balance Scale (BBS) measures a patient's ability to perform 14 different tasks, including but not limited to moving from a sitting to standing position, picking an object off the floor, and standing with a narrow base of support (i.e., one foot in front of the other; Berg, Wood-Dauphinée, & Williams, 1995; Berg, Wood-Dauphinée, Williams, & Gayton, 1989; Berg, Wood-Dauphinée, Williams, & Maki, 1992). The BBS was originally developed to measure the risk of falls for elderly patients; however, it has shown promise for use with TBI populations. Feld, Rabadi, Blau, and Jordan (2001) assessed 40 brain injury patients with the BBS and suggested the BBS may enhance the prediction of rehabilitative outcome. The Dynamic Gait Index (DGI) assesses a patient's ability to modify their gait in response to changes in task demands (Shumway-Cook & Wollacott, 1995). It contains eight tasks, including walking around obstacles and gait with pivot turns and steps. The patient's performance of each task is rated from 0 (severe impairment) to 3 (normal), with total scores ranging from 0 to 24. Like the BBS, the DGI was developed for use with an elderly population; however, Simon and Harro (2004) provided support for the validity and reliability of the DGI in a brain-injured population. The Functional Gait Assessment (FGA) is a modified version of the DGI that is designed to be used with patients with vestibular disorders (Wrisley, Walker, Echternach, & Strasnick, 2003). It is comprised of 10 items, including gait with horizontal and vertical head turns and gait with eyes closed.

Shumway-Cook (2007) also recommends adding cognitive tasks during balance assessments, as dual task assessments may be more sensitive to balance dysfunctions. An additional task is believed to take away mental resources that a patient may need in order to maintain a stable posture. This is particularly important for TBI populations, as they often experience problems with attention and concentration (Management of Concussion/mTBI Working Group, 2009).

Marksmanship and mTBI

Anecdotal reports from occupational and physical therapists indicate that Soldiers recovering from mTBI are experiencing physical and cognitive difficulties with weapons utilization. Occupational therapists at the Center for the Intrepid at Brooke Army Medical Center have observed that Soldiers who have sustained mTBI have significant difficulties with weapon usage. These difficulties include balance impairment, fine motor movement (e.g., adjusting rear sight and loading a new magazine), and cognitive endurance (i.e., mentally fatigue easily, unable to concentrate/focus on single and multiple targets, differentiate targets; Personal communication with Jim Ferneyhouth, OT and MAJ Jay Clasing, OT, 24 February 2009). In addition, these Soldiers also display physical impairments, inasmuch as they have difficulty firing in the three primary positions (i.e., kneeling, prone, and standing), as well as steadying a weapon and taking aim at a given target (Personal communication with Navy LT John Fraser, PT, no date).

Shooting accuracy is a critical task required of all military personnel. The ability to correctly hit a target depends on several cognitive and physical factors, and marksmanship errors can have destructive consequences. Chung et al. (2006) report that a rifle muzzle that is off 1/16 of an inch from the center line can result in a bullet strike being off by over 2 feet at 500 yards. The authors further describe the complexity of marksmanship:

> *Effective shooting is the simultaneous coordination among breathing; gross-motor control of positioning the hands, elbows, legs, feet, and cheek; fine-motor control of the*

trigger finger with respect to the trigger; and the processing of perceptual cues related to the target, the front sight, and rear sight. The coordination is intended to minimize muzzle movement by controlling body movement.

Previous research has shown that psychomotor factors impact marksmanship abilities. Expert shooters have been found to hold a rifle steadier than novice shooters (Mononen, Konttinen, Viitasalo, & Era, 2007) as well as produce smaller body sway amplitudes compared to novice shooters (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996). A common limitation among these studies is the use of relatively static shooting positions using measurements derived from force plates. Static shooting positions are not representative of the shooting positions used in combat situations. More research is needed examining marksmanship in dynamic environments.

Weapons utilization is a global task required of all Soldiers, regardless of their military occupational specialty (MOS). Not much is known about the effects of mTBI on marksmanship abilities, although it is believed that mTBI will lead to poor marksmanship (Cordts, Brosch, & Holcomb, 2008). The present study sought to better understand the effects of mTBI on marksmanship abilities.

In this study, the authors developed a novel dynamic marksmanship battery, based on dynamic vestibular assessments like the BBS, DGI, and FGA, which may be more sensitive to the effects of mTBI than the standard static marksmanship qualification. As discussed above, current weapons qualification tasks are relatively static, in that Soldiers fire from one of three shooting positions at a time and are not changing positions or deciding which target to engage. For example, the Military Functional Assessment Program (MFAP), used by the Fort Campbell Warrior Resiliency and Recovery Center to assess Soldier readiness to return to duty, includes the standard 40 target qualification task and shoot/don't shoot marksmanship scenarios as part of their RTD battery (Warrior Resiliency and Recovery Center, n.d.). Dynamic shooting tasks, such as shooting after picking up a weapon or shooting while walking, are more representative of weapons utilization in combat situations. Such tasks also are more likely to detect balance deficits after mTBI. The development of a dynamic marksmanship battery that is sensitive to the effects of mTBI would provide useful information for return to duty (RTD) determinations.

Objectives

The purpose of the present study is to examine the effects of mTBI on marksmanship abilities and weapons utilization tasks. The current protocol was comprised of two phases: phase 1 examined the test-retest reliability of the newly-developed dynamic marksmanship battery as well as the sensitivity of the new battery to induced vestibular disruption, and phase 2 was a preliminary examination of the sensitivity of the battery in detecting a difference between mTBI and control populations. It was hypothesized that Soldiers with mTBI would perform worse on marksmanship tasks than healthy controls, in terms of objective performance measures including accuracy, reaction time, shot radius (distance of the shot from center of mass [CM] of the target), and root mean square (RMS) distance from target CM as a measure of aiming drift.

Phase 1: Reliability of dynamic battery

Methods

Research design

The primary objective of phase 1 was to examine the test-retest reliability of the newly-developed dynamic marksmanship battery in a control (non-mTBI) sample. Participants performed the tasks in the battery on day 1 and day 2, and the data were assessed using Pearson correlation analysis.

A second objective of phase 1 was to provide confidence to researchers that the selected battery would provide meaningful data in phase 2. In phase 1, participants were exposed to brief vestibular disruption via a motorized Barany chair exposure and then asked to complete selected newly- developed shooting tasks. The data were analyzed using one-way repeated measures ANOVAs. The three levels of the independent variable were day 1, day 2, and day 2 (disrupted). The data were also analyzed with binary logistic regression. The goal was to use participants' performance metrics from the EST to classify whether they were normal (i.e., day 1 performance) or disrupted (i.e., after the Barany chair).

Participants

Sixty participants completed phase 1. Their mean age was 27.35 years (*SD* = 5.39). They were all right-handed shooters. With regard to marksmanship ability of the sample, all participants completed a weapons qualification task (on the same EST 2000 used for data collection) prior to learning the dynamic battery. The distribution of qualification ratings is presented in figure 1. These qualifications are based on the number of target hits on the standard 40-target marksmanship task, with "Experts" correctly hitting 36 to 40 targets, "Sharpshooters" hitting 30 to 35 targets, and "Marksmen" hitting 23 to 29 targets, and "did not qualify" hitting 22 or less targets (Department of the Army, 2008).

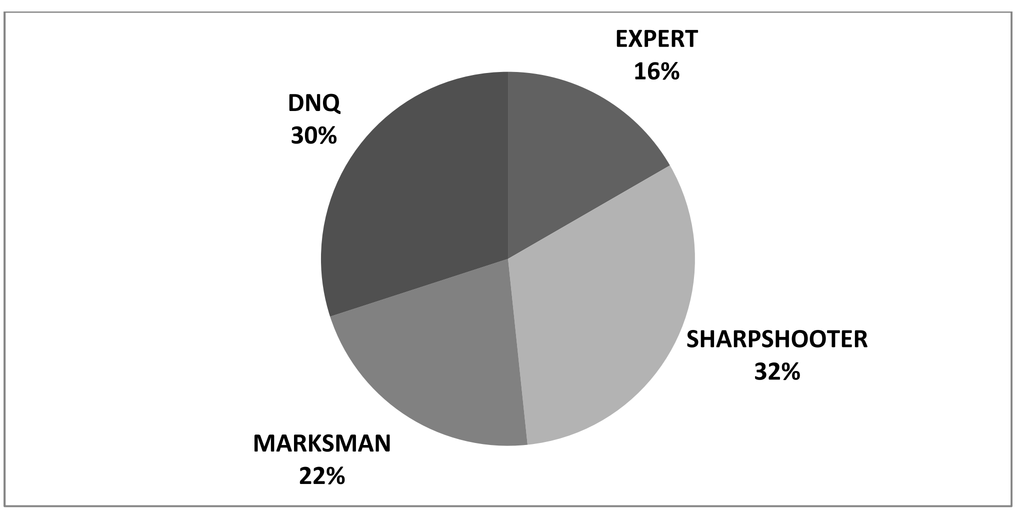

Figure 1. Phase 1: Distribution of marksmanship qualification scores.

The study population was limited to U.S. Army Active Duty or National Guard/Reserve Soldiers, or civilians with recent military experience (within 2 years). This criterion was necessary to ensure participants received basic training and were familiar with the weapons utilization tasks. There were no gender restrictions, but females were screened for pregnancy prior to participation. Four participants were female.

Exclusion criteria included visual acuity not correctable to 20/20 and history of brain injury including blunt, blast, or penetrating mechanism. In addition, use of medications affecting vestibular function (considered on a case-by-case basis) was also disqualifying as determined by the study physician.

Finally, participants reporting severe posttraumatic stress disorder (PTSD) symptoms were excluded (as measured by the PTSD CheckList – Military Version [PCL-M]). The PCL-M is a widely used self-administered questionnaire with 17 questions assessing trauma-related stress (Weathers, Litz, Herman, Huska, & Keane, 1993) and is presented in appendix A. Response options range from "Not at All" to "Extremely" (1-5) with higher numbers indicating greater stress. Possible scores range from 17 to 85. Potential volunteers were excluded if they responded to any question with a four or five. A similar exclusion criterion was used in Stetz (2007). Participants mean PCL-M score in phase 1 was 18.18 (SD = 2.48).

Materials

Engagement Skills Trainer 2000

The Engagement Skills Trainer (EST) 2000 is a U.S. Army small arms training device. This device is used in the U. S. Army Infantry Schools Basic Rifle Marksmanship (BRM) strategy and allows for weapons training in a controlled (simulated) environment. As can be seen in figure 2, a participant fires from a lane (the USAARL has a five lane configuration) at "targets" which appear on a projection screen at a distance of 26 feet and 3 inches from the firing line. This is the standard setup. The weapons have been modified to use with the EST 2000 but maintain their form, fit, feel, and function. Participants completed two marksmanship batteries utilizing the EST 2000: a standard marksmanship qualification, and a new dynamic marksmanship battery.

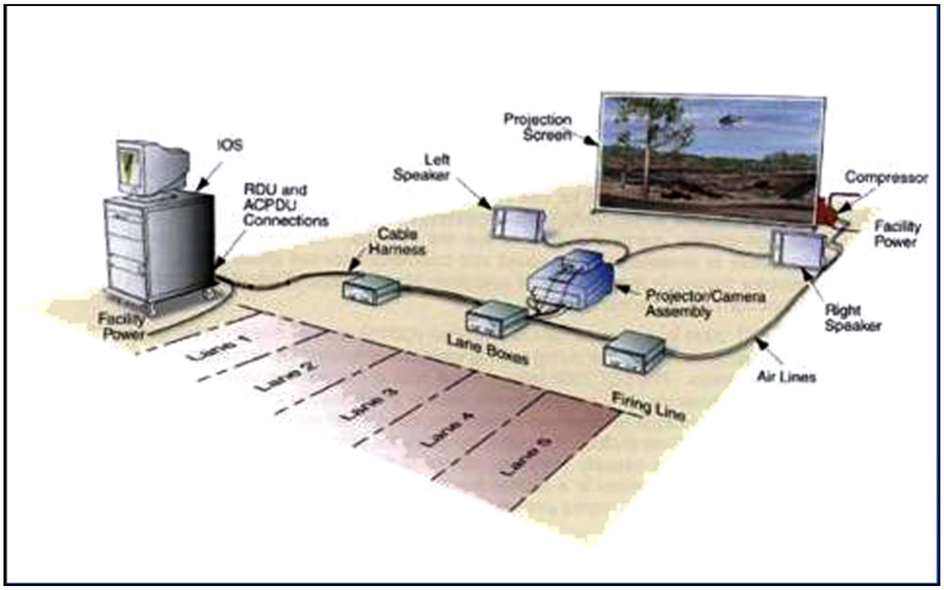

Figure 2. EST 2000 set-up (Anthony, 2006).

In the standard marksmanship qualification, participants shoot with a rifle at 40 targets presented sequentially. The targets vary in distance, from 50 to 300 meters. The subject fires from three positions: prone supported, prone unsupported, and kneeling. The key dependent variables for these tasks are accuracy, reaction time, shot radius, and root mean square (RMS) of the aim trace.

The tasks selected for the dynamic marksmanship battery are described in table 2 and pictured in figures 3-7. They were chosen based on the types of balance challenges imposed by established clinical vestibular assessments, including the DGI and FGA (Herdman, 2007). Most established vestibular and gait assessments involve rapid head movements, challenges to gaze stability, timed locomotion, and/or a reduction of useful non-vestibular cues (e.g., visual, somatosensory). Participants performed all shooting tasks using a rifle.

It should be noted that to conduct the dynamic battery, the EST was modified from the standard Army configuration shown in figure 2. Specifically, 13-foot cables were purchased from the manufacturer to allow more room for locomotion. In addition, the room was configured for right-handed shooters by moving air lines, lane boxes and speakers to the edges of the room.

The discussion of the novel dynamic battery would not be complete without mentioning the process of developing the tasks. The EST 2000 is designed as a small arms *training* device. The USAARL EST 2000 is unique in that it can be used for *research* purposes. It possesses specialized software to allow for the collection of the objective performance data (reaction time, shot radius, aiming drift). Targets for the novel battery were developed through an iterative trial-and-error process; for example, some target size and location concepts would not allow data to be recorded.

Table 2.
Dynamic marksmanship battery.

Task	Description	EST Scenario	Participant Instructions
1. Turn to Shoot	Facing 180° to target, rapid turn to acquire, sight and fire	3 lane configuration Targets appear at 15 m Participant takes 5 shots at target Black screen, black target with flashing light	Low ready; Center behind projector; Listen to metronome for when to turn (every 4 seconds); Allow participant 5 minutes to dark adapt
2. Kneel and Shoot	Perform kneeling portion of marksmanship battery with a narrow stance (knee to heel)	3 lane configuration 1 target at a time, 10 targets total, targets appear at 75m; Targets appear at extremes of lane width Target up for 2 seconds, 2 seconds between targets	Stay aimed at last target until next pops up; kneel at location (90 inches from screen)
3. Pickup Rifle and Shoot	Pick up weapon from floor, aim and shoot at target at top of screen as quickly as possible; place weapon back on ground and await instructions to pick up and shoot again	3 lane configuration 1 targets at top of screen, 2 shots Note: altitude: 7 and -3 targets appear at 40m	Pick up rifle with 2 hands; Center behind projector; Make sure participants has some pitch in waist; Start facing perpendicular to screen; Must keep eyes on rifle all the way down
4. Walk, Head Swivel, and Shoot	Walk with 180° horizontal head/rifle turns on every 2 steps, fire at target whenever facing screen	3 lane configuration 1 target, 2 shots total Target appears at 15m	2 steps, fire, 2 steps, wall, 2 steps, fire; Start facing perpendicular to screen; Start with left foot
5. Traverse Beam and Shoot	Walk on narrow beam parallel to screen, fire as many accurate shots as possible at target	3 lane configuration 4 targets from left to right Targets appear at 25m	Goal is to walk across the beam as quick as possible while accurately hitting all targets

Figure 3. Task 1: Turn to Shoot.

Figure 4. Task 2: Kneel and Shoot.

Figure 5. Task 3: Pickup and Shoot.

Figure 6. Task 4: Walk and Shoot.

Figure 7. Task 5: Traverse Beam and Shoot.

NASA Task Load Index

The NASA Task Load Index (TLX) provides a workload assessment based on ratings for six dimensions, namely mental demands, physical demands, temporal demands, own performance, effort and frustration. For the present study, it was used to assess participants' perceived workload immediately after performing each shooting task (appendix B). Detailed instructions can be found in the test administration guide (NASA, n. d.). A raw TLX scoring procedure was utilized (Cao, Chintamani, Pandya, & Ellis, 2009; Hart, 2006).

Debriefing Questionnaire

An important source of data was the patients' subjective reports of the testing conditions. Participants were asked to complete a questionnaire at the completion of the testing to capture any other issues related to the marksmanship task, including pain, fatigue, and headache (appendix C).

Procedures

The study protocol was approved by the Headquarters, U.S. Army Medical Research and Materiel Command Institutional Review Board (HQ USAMRMC IRB). Written informed consent was obtained from all volunteers. Complete participation required approximately 3 hours of the volunteers time over 2 days. The schedule of events is presented in table 3.

Table 3.
Phase 1: Schedule of events.

Day	Session	Activities
1	1- In-processing	Informed consent Report of Medical History Demographics PTSD Checklist Vision screening
	2- Orientation	EST- zero weapon Marksmanship qualification Introduction to dynamic battery
	3- Testing	Dynamic battery
2	4- Testing	Dynamic battery
	5- Vestibular	Dynamic battery after vestibular disruption

On day 1, all interested participants attended an information session and completed the in-processing procedures. Next, participants were introduced to the weapons simulator, the EST 2000. Participants first zeroed their weapon, calibrating the laser sensor to the equivalent of the mechanical weapon zero. They then completed the standard marksmanship qualification. Next, participants were introduced to the new dynamic marksmanship battery. A member of the research team instructed participants in the proper execution of each task. Participants then practiced each shooting task three times prior to obtaining baseline data. The order of the tasks in the dynamic battery was randomized to reduce order effects.

On day 2, participants completed all tasks in the dynamic battery for an additional time to allow for analysis of reliability from day 1 to day 2. The final testing session induced a transient vestibular disruption (resulting in vertigo and nystagmus) prior to completing three randomly selected shooting tasks (figure 8). The standard protocol was for the participant to be seated with his/her eyes closed and is then turned at a constant velocity, one turn per 2 seconds for a total of ten turns in 20 ± 0.25 seconds (Rubin, Winston, Metz-Rubin, & Berwick, 1951). The order of the tasks was randomized.

Figure 8. Vestibular disruption via motorized Barany chair.

Results

All statistical analyses were conducted using SPSS® 19.0. As previously discussed, reaction time data were available only for tasks 2 and 5, and RMS data could not be collected for task 5, due to the design of the scenarios.

Reliability

Test-retest reliability was examined by calculating Pearson's reliability correlation coefficients between participants' performance on day 1 and day 2 (sessions 3 and 4 per table 3). The correlation coefficients for each task variable are presented in table 4.

Table 4.
Phase 1: Reliability analysis.

Task	Variable	*r*	*p*
1. Turn to Shoot	Accuracy	- 0.075	.571
	Reaction Time	--	--
	Radius	0.340	.008
	RMS	0.125	.374
2. Kneel and Shoot	Accuracy	0.582	<.001
	Reaction Time	0.538	<.001
	Radius	0.752	<.001
	RMS	0.621	<.001
3. Pickup and Shoot	Accuracy	0.293	.023
	Reaction Time	--	--
	Radius	0.473	<.001
	RMS	0.282	.031
4. Walk and Shoot	Accuracy	0.188	.150
	Reaction Time	--	--
	Radius	0.311	.016
	RMS	0.141	.287
5. Traverse Beam and Shoot	Accuracy	0.370	.004
	Reaction Time	0.582	<.001
	Radius	0.338	.009
	RMS	--	--

Sensitivity

The data were analyzed using one-way repeated measures ANOVAs (Table 5). The three levels were day 1, day 2 (no chair) and day 2 (disrupted). Means are presented in figure 9 and pairwise comparisons are included in appendix D. The use of the Barany chair degraded performance on the shooting tasks as expected.

The data for each task were also analyzed with binary logistic regression. The goal was to use participants' performance metrics from the EST to classify whether they were normal (i.e., day 1 performance) or disrupted (i.e., after the Barany chair). All dependent variables were entered into the model. Those that were significant predictors are included in table 6. The Pseudo R^2 value is a measure of variance explained by the model, with the higher value the greater proportion of variance accounted for by the model (Gray & Kinnear, 2012).

Table 5.
Phase 1: Repeated Measures ANOVA analysis.

Task	Variable	*F*	*p*
1. Turn to Shoot	Accuracy	14.638	< 0.001
	Reaction Time	-	-
	Radius	9.364	< 0.001
	RMS	4.231	0.021
2. Kneel and Shoot	Accuracy	7.845	0.001
	Reaction Time	22.251	< 0.001
	Radius	7.382	0.001
	RMS	27.865	< 0.001
3. Pickup and Shoot	Accuracy	5.005	0.009
	Reaction Time	-	-
	Radius	1.462	0.238
	RMS	5.181	0.008
4. Walk and Shoot	Accuracy	1.522	0.225
	Reaction Time	-	-
	Radius	3.507	0.035
	RMS	2.080	0.133
5. Traverse Beam and Shoot	Accuracy	28.733	< 0.001
	Reaction Time	9.651	< 0.001
	Radius	4.959	0.010
	RMS	-	-

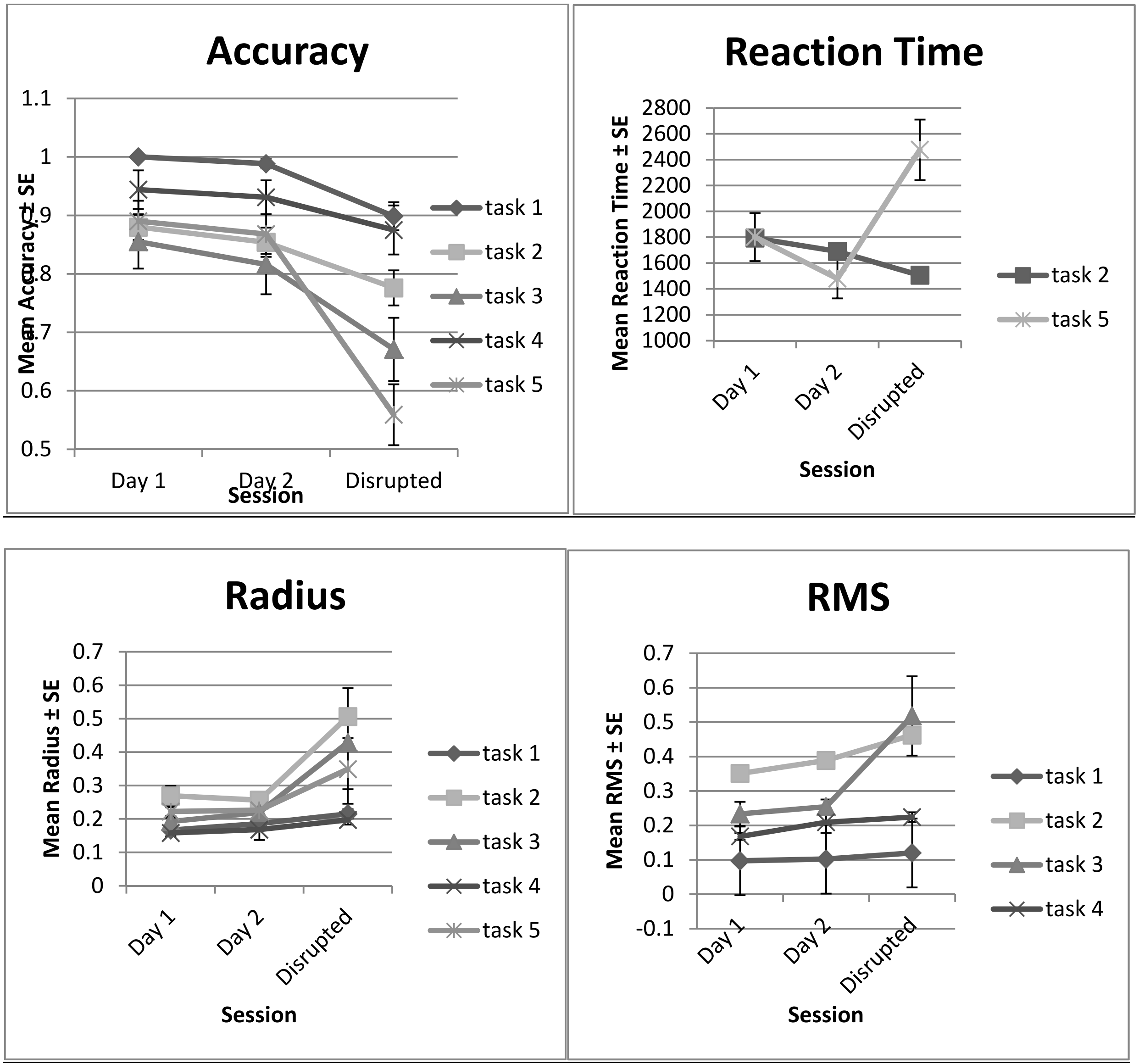

Figure 9. Phase 1: Mean ± SE dynamic marksmanship performance by session.

Table 6.
Phase 1: Logistic regression analysis.

Task	Variables included in model	Pseudo R^2
1. Turn to Shoot	Accuracy	0.263
2. Kneel and Shoot	Reaction Time, RMS	0.537
3. Pickup and Shoot	RMS	0.342
4. Walk and Shoot	RMS	0.306
5. Traverse Beam and Shoot	Accuracy	0.412

Workload

Participants completed the NASA TLX after each shooting task. Figure 10 presents mean (± standard error) workload ratings for each of the five dynamic marksmanship tasks. It should be noted this graph includes only ratings on day 1.

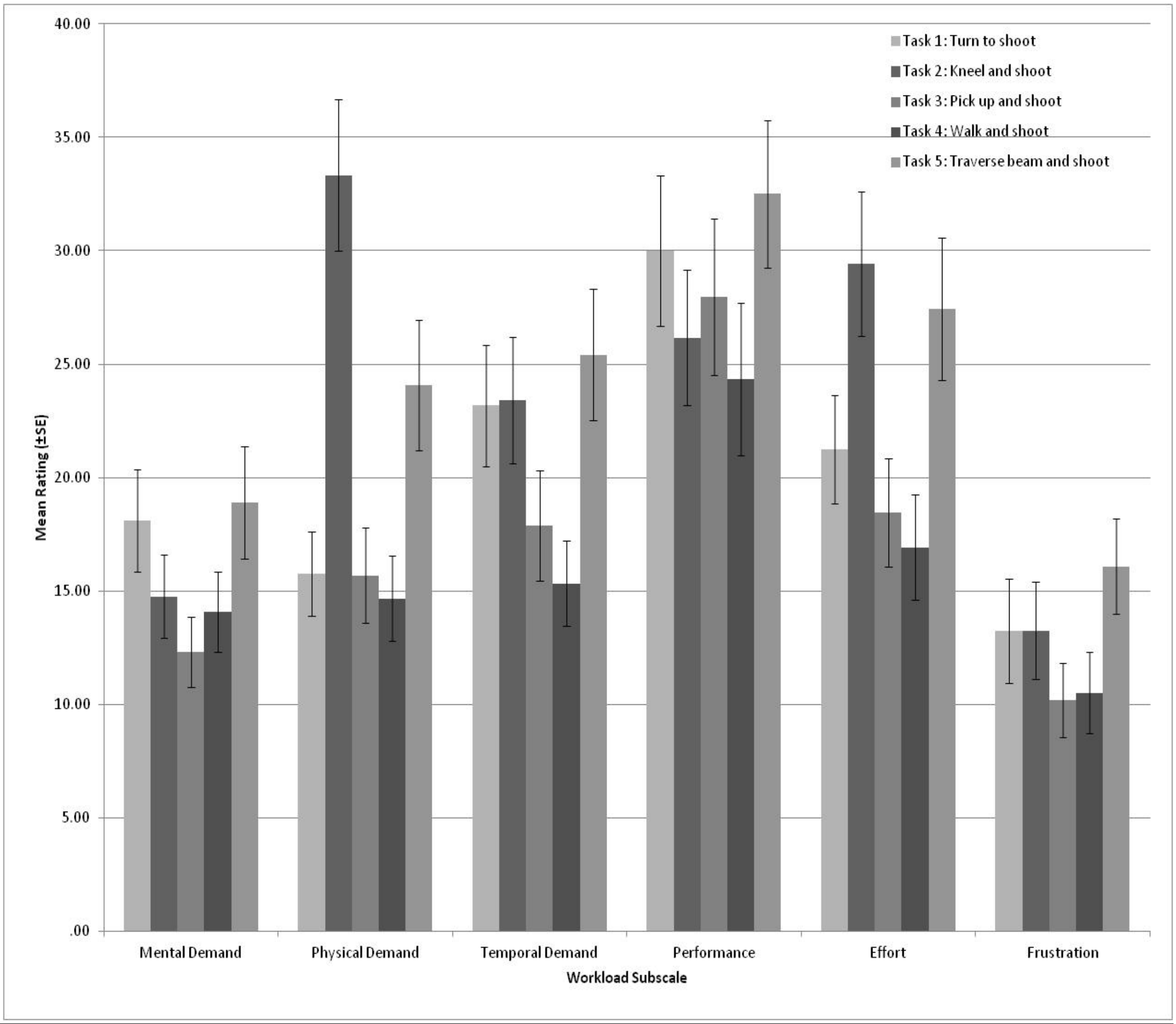

Figure 10. Phase 1: Mean (± SE) workload ratings by task.

Debrief comments

Participants were asked to rank the five novel shooting tasks in order of difficulty. The narrow kneeling task was most frequently ranked as the most difficult, followed by the traverse beam task. The pick up and shoot task was most frequently ranked as the least difficult, followed by the turn to shoot task.

Discussion

Based on the test-retest reliability data, participants performed most consistently on task 2 (the narrow kneel and shoot task) followed by task 5 (traverse beam and shoot task). In comparison, performance on task 1 (the turn to shoot task) was the least consistent and reliable. This same pattern was found in the results of the logistic regression analysis, with tasks 2 and 5 explaining the most variance, and task 1 explaining the least variance. Interestingly, the debrief comments revealed that tasks 2 and 5 were also the most challenging to participants.

The use of the Barany chair degraded performance on the shooting tasks as expected. The one exception was the reaction time for task 2 (the narrow kneel and shoot task). Reaction time increased after vestibular disruption, most likely due to the distance of the chair to where the participants needed to be for task 2. Participants were told to get to the position as fast as possible, which most likely carried over for their entire performance of the task.

The workload ratings provide useful qualitative data regarding the difficulties associated with certain tasks. For example, the mental demands of tasks 2, 3, and 4 were relatively low. Future research with the dynamic battery may consider incorporating a cognitive element to these tasks, such as a friend-or-foe discrimination element or a dual-task element to these tasks.

The discussion of the phase 1 results would not be complete without mentioning the process of developing the novel dynamic tasks. The design of certain scenarios prevented certain dependent measures to be collected. For example, for tasks 1, 3, and 4, reaction time could not be calculated due to the type of target used. In addition, task 5 required the participant to walk while engaging targets, a task for which the EST 2000 was not designed (i.e., stationary shooting). In addition, consideration should be given to including a throughput measure (e.g., number of accurate hits per unit of time) in future data analyses. Due to issues such as the documented trade-off between accuracy and speed, throughput (number of significant events per unit of time) has been identified as a more useful and informative measure of human cognitive and psychomotor performance than accuracy or speed alone, and one which should be preferred in performance studies (Kane and Kay, 1992). Throughput is also an important measure from an operational perspective, since the number of accurate shots per unit of time will usually be more important during combat than accuracy of shooting without time as a constraint.

A limitation of phase 1 was the wide range of variability in shooting performance. As shown in Figure 1, approximately 30 percent of the sample failed to qualify on the record fire task, meaning they hit less than 23 of the 40 targets. Given the location of the study (Fort Rucker, an aviation training post) the study sample was comprised of a unique group of Soldiers. This limitation impacts the generalizability of the results. For example, one would expect differences in marksmanship abilities in our sample compared to infantry Soldiers. Furthermore, this limitation also impacts learning/practice effects. Participants practiced each dynamic shooting task three times prior to obtaining their baseline data. Although two participants commented about the excessive length of the practice session, some participants would have benefited from more practice, given the wide variability in the data. Analysis of practice data was not conducted for the present study.

Phase 2: Preliminary assessment in mTBI sample

Methods

Research design

Phase 2 was a preliminary assessment of the dynamic battery in differentiating between a control and mTBI population. The independent variable of interest was mTBI history, and its two levels were positive history and negative history (control group). The study utilized a quasi-experimental design given that the participants could not be randomly assigned to the two treatment conditions.

In order to control for differences in marksmanship abilities between the mTBI and control group, the present study matched participants from phase 1 to participants in the mTBI group based on gender, approximate age, and marksmanship ability. These qualifications are based on the number of target hits on the standard 40-target marksmanship task that was completed prior to learning the dynamic battery. That is, data were collected on the mTBI sample first, and then matched controls were selected from the phase 1 population.

Participants

Nine mTBI participants completed phase 2. Their mean age was 29.56 years (*SD* = 8.89). They were all right handed shooters. The study population was limited to U.S. Army Active Duty or National Guard/Reserve Soldiers. There were no gender restrictions, but females were screened for pregnancy prior to participation. One participant was female.

With regard to marksmanship ability of the sample, all participants completed a weapons qualification task prior to learning the dynamic battery. The distribution of ratings is presented in figure 11.

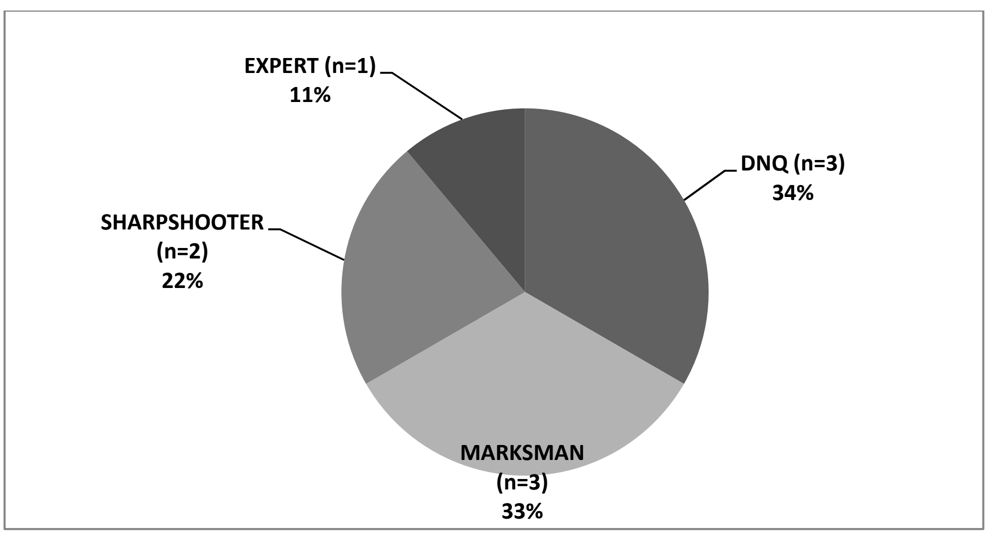

Figure 11. Phase 2: Distribution of marksmanship qualification scores.

Exclusion criteria also included visual acuity not correctable to 20/20. In addition, use of medications affecting vestibular function (considered on a case-by-case basis) were also disqualifying as determined by the study physician. With regard to the mTBI group, *mild* was defined according to the criteria of the American Congress of Rehabilitation Medicine (1993). Soldiers with an mTBI diagnosis were recruited from the William Beaumont Warrior Transition Battalion at Fort Bliss. Positive history of mild brain injury (blunt or blast etiology) was verified by AHLTA/records review of formal clinical assessment and self-report. The mean time since injury was 12.33 months (median = 10 months). In addition, Soldiers with severe posttraumatic stress disorder (PTSD) as measured by the PCL-M, were excluded. Participants' mean PCL-M score in phase 2 was 29.2 (SD = 8.36).

To characterize Soldiers' perceived disabilities related to vestibular dysfunction, they were asked to complete the Dizziness Handicap Inventory (DHI; Jacobson & Newman, 1990). The questionnaire consists of 25 items (appendix E) related to physical (e.g., Do quick movements of your head increase your problem?), functional (e.g., Because of your problem, do you have difficulty reading?), and emotional (e.g., Because of your problem, are you embarrassed in front of others?) domains. Answers are scored as "no" = 0, "sometimes" = 2, and "yes" = 4. The highest score possible is 100, with higher scores indicating a greater impairment. Participants' mean DHI score in study 2 was 33.11 (SD = 22.12).

Materials

Engagement Skills Trainer (EST) 2000

Participants performed two tasks utilizing the EST 2000: a standard marksmanship task, and the new dynamic marksmanship battery. Phase 2 participants at Fort Bliss used the same EST 2000 that was used by Phase 1 participants at Fort Rucker, and the EST was calibrated according to the EST 2000 instruction manual (EST 2000, n.d.). The tasks selected for the dynamic marksmanship battery for phase 2 were the same as those in phase 1, except task 1 (turn to shoot) was not administered in phase 2.

NASA Task Load Index

Similar to phase 1, the NASA TLX was used to assess participants' perceived workload immediately after performing each shooting task.

Debriefing Questionnaire

Similar to phase 1, the debriefing questionnaire was used at the completion of the testing to capture any other issues related to the marksmanship task, including pain, fatigue, and headache.

Procedures

Complete participation required approximately 3 hours of the volunteers time for 2 days. The schedule of events is presented in table 7. The only differences from phase 1 procedures was the elimination of session 4 (testing) and session 5 (vestibular disruption).

Table 7.
Phase 2: Schedule of events.

Day	Session	Activities
1	1- In-processing	Informed consent
		Report of Medical History
		Demographics
		PTSD Checklist
		DHI
		Vision screening
2	2- Orientation	EST- zero weapon
		Marksmanship qualification
		Introduction to dynamic battery
	3- Testing	Dynamic battery

Results

Standard record fire

The data from the nine mTBI Soldiers were compared to matched non-mTBI Soldiers by gender, marksmanship ability, and approximate age. Mean ± SE record fire marksmanship performance by sample is presented in appendix F. Performance on the standard record fire were compared using mixed model ANOVAs. Independent variables were group (mTBI or control) and target distance.

Prone supported

The main effect of group was not significant for the reaction time ($F(1,16) = 1.916$, $p = .185$, power = .256), radius ($F(1,16) = .409$, $p = .531$, power = .092), accuracy ($F(1, 16) =0.036$, $p = .852$, power = .054) or RMS data ($F(1,16) = .230$, $p = .638$, power = .074). No interactions of group and distance were significant. The effect of target distance was significant for all four dependent measures ($p < .05$).

Prone unsupported

The main effect of group was not significant for the reaction time data ($F(1,12) = 0.019$, $p = .893$, power = .052), radius ($F(1,12) = 0.122$, $p = .733$, power = .062), accuracy ($F(1,12) = 0.044$,

$p = .838$, power= .054) and RMS data ($F(1,16) = 0.557$, $p = .466$, power = .108). No interactions of group and distance were significant. The effect of target distance was significant for the reaction time and RMS measures.

Kneeling

The main effect of group was not significant for the reaction time ($F(1,16) = 0.155$, $p = .699$, power = .066), radius ($F(1,16) = .894$, $p = .358$, power = .144), accuracy ($F(1,16) = 0.014$, $p = .909$, power = .051) and RMS data ($F(1,16) = 1.916$, $p = .185$, power= .256). No interactions of group and distance were significant. The effect of target distance was significant for all 4 dependent measures ($p < .05$).

Dynamic marksmanship battery

The data from the nine mTBI Soldiers were again compared to matched non-mTBI Soldiers. Mean (±SE) dynamic marksmanship performance by sample is presented in figure 12. Performance on the dynamic tasks was compared using independent samples t-tests (table 8). There were no significant differences between the samples. It should be noted that the sample size for task 2 (narrow kneel and shoot task) was seven as two participants were unable to complete the task. One was experiencing back pain and one was unable to balance himself due to the narrow base of support (knee-to-heel).

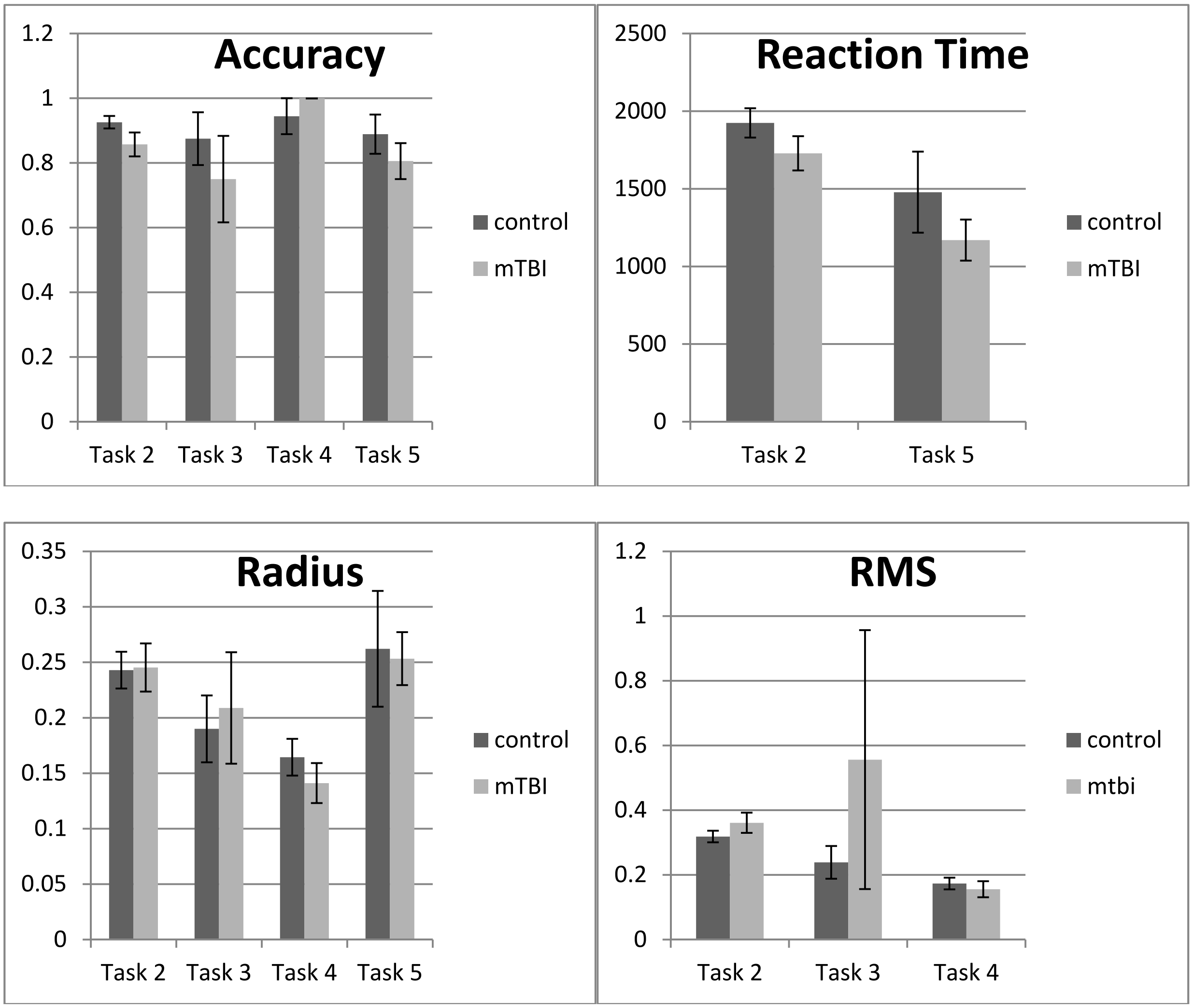

Figure 12. Phase 2: Mean (±SE) dynamic marksmanship performance by sample.

Table 8.
Phase 2: Results of independent samples *t*-test by shooting task.

Task	Variable	*t*	*p*	Cohen's *d*
2. Kneel and Shoot	Accuracy	1.646	.126	0.880
	Reaction Time	1.351	.202	0.722
	Radius	-.024	.981	-0.013
	RMS	-1.184	.259	-0.633
3. Pickup and Shoot	Accuracy	.798	.438	0.376
	Reaction Time	-	-	-
	Radius	-.320	.754	-0.151
	RMS	-.787	.444	-0.371
4. Walk and Shoot	Accuracy	-1.0	.332	-0.471
	Reaction Time	-	-	-
	Radius	.951	.356	0.448
	RMS	.575	.573	0.271
5. Traverse Beam and Shoot	Accuracy	1.014	.326	0.478
	Reaction Time	1.056	.307	0.498
	Radius	.155	.879	0.073
	RMS	-	-	-

Workload

Participants completed the NASA TLX after each shooting task. The data were analyzed using a 2 by 4 mixed model ANOVA. The between subjects factor was group (mTBI or control) and the within subjects factor was task (2, 3, 4, or 5). A separate ANOVA was run for each of the six dimensions. Appendix G presents mean (± standard error) workload ratings for each of the four dynamic tasks by group.

Mental

The interaction between task and group was not significant (F(3,45, = 2.424, p = .078). There was a significant main effect of group (F(1,15) = 11.482, p = .004), with the mTBI participants reporting higher mean mental demand ratings than the control group. The main effect of task was not significant (F(3,45) = .906, p = .445).

Physical

The interaction between task and group was not significant (F(3, 45) = 1.111, p =.345). There was a significant main effect of task (F(3,45) = 9.866, p <.001). Pairwise comparisons revealed the ratings for task 2 were significantly higher than those of tasks 3, 4, and 5. There was also a significant main effect of group (F(1,15) =10.793, p =.005), with the mTBI participants reporting higher mean physical demand ratings than the control group.

Temporal

The interaction between task and group was not significant ($F(3, 45) = 1.480$, $p = .233$). The main effect of task was not significant ($F(3,45) = 1.552$, $p = .214$). The main effect of group was significant ($F(1, 15) = 7.035$, $p = .018$), with the mTBI participants reporting higher mean temporal demand ratings than the control group.

Performance

The interaction between task and group was significant ($F(3,45) = 4.019$, $p = .013$). Independent samples *t*-tests were used to investigate the interaction for each task and a Bonferroni correction was used ($\alpha = .05/4 = 0.0125$). The mTBI group had significantly lower performance ratings for task 5 than the control group ($p < .001$). The remaining group differences were not significant for tasks 2, 3, or 4.The main effect of task was not significant ($F(3,45) = 1.445$, $p = .242$), while the main effect of group was significant ($F(1,15) = 6.316$, $p = .024$).

Effort

The interaction between task and group was not significant ($F(3, 45) = 0.093$, $p = .964$). There was a significant main effect of task ($F(3,45) = 4.138$, $p = .011$). Pairwise comparisons revealed the ratings for task 2 were significantly higher than those of task 4 ($p = 0.001$), and the ratings for task 5 were significantly higher than those of task 3 ($p = .049$). There was also a significant main effect of group ($F(1,15) = 20.222$, $p < .001$), with the mTBI participants reporting higher mean effort ratings than the control group.

Frustration

The interaction between group and task was not significant ($F(3,45) = 0.585$, $p = .628$). The main effect of task approached significance ($F(3,45) = 2.785$, $p = .052$. The main effect of group was statistically significant ($F(1,15) = 4.896$, $p = .043$) with the mTBI participants reporting higher mean frustration ratings than the control group.

Debrief comments

Participants were asked to rank the four novel shooting tasks in order of difficulty. The narrow kneeling task (task 2) was most frequently ranked as the most difficult, followed by the traverse beam task (task 5). The walk and shoot task (task 4) was most frequently ranked as the least difficult.

Discussion

Phase 2 was preliminary assessment of the novel dynamic battery in differentiating between a control and mTBI sample. While there were no significant differences between the samples in the present study, much can be learned from descriptive results. The narrow kneel and shoot task was very challenging in the mTBI population, with two participants unable to complete the task. While not significant, the mTBI sample had poorer accuracy, larger shot radius and larger RMS than the control group for task 2. Both groups rated tasks 2 and 5 as the most difficult. More data are needed to make any claims regarding the sensitivity of the novel battery in differentiating between a control and mTBI population.

While our small sample of mTBI Soldiers reported dizziness symptoms (via the DHI), we are unsure if they were being clinically treated for vestibular symptoms. Perhaps results from phase 2 would be different with Soldiers with confirmed vestibular impairments. In addition, results may differ in a sample of mTBI Soldiers that do not report dizziness symptoms. Future research with the dynamic battery should consider comparing performance among 1) Soldiers with mTBI in a transition setting, 2) Soldiers with an mTBI with confirmed vestibular impairments, 3) mTBI Soldiers not reporting dizziness, and 4) control non-mTBI Soldiers.

General discussion and conclusions

The present study examined the effects of mTBI on marksmanship abilities and weapons utilization tasks. Phase 1 examined the test-retest reliability of the newly-developed dynamic marksmanship battery. Based on the test-retest reliability data, participants performed most consistently on task 2 (the narrow kneel and shoot task) followed by task 5 (traverse beam and shoot task). Phase 2 was a preliminary examination of the sensitivity of the battery in detecting a difference between mTBI and control populations. While there were no significant differences between the mTBI and control group, the mTBI group performed worse in terms of accuracy and shot radius on the narrow kneeling task. Overall, performance on the narrow kneeling task and the beam task was the most consistent, most difficult, and most likely to be affected by vestibular disruption. In addition, participants in the mTBI group reported higher workload ratings than the control group with regard to five of the six workload dimensions (i.e., mental, physical, temporal, effort, and frustration) for the dynamic tasks.

There are numerous factors to consider when deciding whether a Soldier is ready to RTD following a concussion. There is a need for evidence-based criteria for RTD standards (Kelley, et al., 2013). There are RTD issues far-forward on the battlefield, as well as in the medical rehabilitation setting. Further research of the dynamic marksmanship battery using Soldiers who have experienced mTBI is planned in order to better determine whether they perform more poorly in dynamic shooting versus healthy Soldiers. If so, the most sensitive tests will be incorporated into a RTD Clinical Toolkit currently being developed at USAARL. Future research with the dynamic marksmanship battery should also investigate more portable and less-expensive equipment than the EST 2000. It should be noted that the narrow kneeling task lends itself naturally to a future portable application wherein objective sway would be readily quantifiable (e.g., via a posturography platform).

Independent of its usefulness in RTD decision making, the narrow kneeling and beam tasks may prove useful for future marksmanship research. Much benefit could be derived from the development of dynamic shooting tasks that bridge the gap from static range qualification to real shooting, which often places higher demands on the shooter concerning coordination of balance and body movement.

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Appendix A.

PCL-M.

INSTRUCTIONS TO PARTICIPANT: Below is a list of problems and complaints that veterans sometimes have in response to stressful military experiences. Please read each one carefully, put an X in the box to indicate how much you have been bothered by that problem in the past month.

		Not at all (1)	A little bit (2)	Moderatel y (3)	Quite a bit (4)	Extremely (5)
1.	**Repeated, disturbing memories, thoughts, or images of a stressful military experience?**					
2.	**Repeated, disturbing dreams of a stressful military experience?**					
3.	**Suddenly acting or feeling as if a stressful military experience were happening again (as if you were reliving it)?**					
4.	**Feeling very upset when something reminded you of a stressful military experience?**					
5.	**Having physical reactions (e.g., heart pounding, trouble breathing, sweating) when something reminded you of a stressful military experience?**					
6.	**Avoiding thinking about or talking about a stressful military experience or avoiding having feelings related to it?**					
7.	**Avoiding activities or situations because they reminded you of a stressful military experience?**					
8.	**Trouble remembering important parts of a stressful military experience?**					
9.	**Loss of interest in activities that you used to enjoy?**					
10.	**Feeling distant or cut off from other people?**					
11.	**Feeling emotionally numb or being unable to have loving feelings for those close to you?**					
12.	**Feeling as if your future will somehow be cut short?**					
13.	**Trouble falling or staying asleep?**					
14.	**Feeling irritable or having angry outbursts?**					
15.	**Having difficulty concentrating?**					
16.	**Being "super-alert" or watchful or on guard?**					
17.	**Feeling jumpy or easily startled?**					

Appendix B.

NASA TLX.

Please evaluate the task you just completed by putting an "x" on each of the 6 scales at the point which matches your experience.

Mental Demand How mentally demanding was the task?

Very Low — Very High

Physical Demand How physically demanding was the task?

Very Low — Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low — Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix C.

Debriefing Questionnaire.

1. Did you experience any pain during your participation? If so please describe (during which tasks, location of pain, severity of pain, duration of pain, etc.).

____
____
____
____

2. Did you experience any headaches during you participation? If so please describe (during which tasks, location, severity, duration, etc.).

____
____
____
____

3. Did you experience any fatigue during your participation? If so please describe (during which tasks, intensity, duration, etc.).

____
____
____
____

4. Did you experience any dizziness during you participation? If so please describe (during which tasks, severity, duration, etc.).

____
____
____
____

5. Please rank the shooting tasks, with 1 = most difficult and 5 = least difficult:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

6. Any additional comments?

____
____
____
____

Appendix D.

Phase 1: Pairwise comparisons.

Task	Variable	Comparison	*p* value
1. Turn to shoot	Accuracy	day 1 vs day 2	.160
		day 1 vs disrupted	<.001*
		day 2 vs disrupted	.001*
	Reaction Time	day 1 vs day 2	-
		day 1 vs disrupted	-
		day 2 vs disrupted	-
	Radius	day 1 vs day 2	.027
		day 1 vs disrupted	<.001*
		day 2 vs disrupted	.029
	RMS	day 1 vs day 2	.513
		day 1 vs disrupted	.016*
		day 2 vs disrupted	.049
2. Kneel and Shoot	Accuracy	day 1 vs day 2	.265
		day 1 vs disrupted	.001*
		day 2 vs disrupted	.011*
	Reaction Time	day 1 vs day 2	.014*
		day 1 vs disrupted	<.001*
		day 2 vs disrupted	<.001*
	Radius	day 1 vs day 2	.634
		day 1 vs disrupted	.013*
		day 2 vs disrupted	.005*
	RMS	day 1 vs day 2	.002*
		day 1 vs disrupted	<.001*
		day 2 vs disrupted	<.001*
3. Pick Up and Shoot	Accuracy	day 1 vs day 2	.474
		day 1 vs disrupted	.003*
		day 2 vs disrupted	.047
	Reaction Time	day 1 vs day 2	
		day 1 vs disrupted	
		day 2 vs disrupted	
	Radius	day 1 vs day 2	.092
		day 1 vs disrupted	.207
		day 2 vs disrupted	.267
	RMS	day 1 vs day 2	.605
		day 1 vs disrupted	.023
		day 2 vs disrupted	.027
4. Walk and Shoot	Accuracy	day 1 vs day 2	.711
		day 1 vs disrupted	.096
		day 2 vs disrupted	.254
	Reaction Time	day 1 vs day 2	

		day 1 vs disrupted	
		day 2 vs disrupted	
	Radius	day 1 vs day 2	.513
		day 1 vs disrupted	.016*
		day 2 vs disrupted	.075
	RMS	day 1 vs day 2	.209
		day 1 vs disrupted	.001*
		day 2 vs disrupted	.672
5. Traverse Beam and Shoot	Accuracy	day 1 vs day 2	.571
		day 1 vs disrupted	<.001*
		day 2 vs disrupted	<.001*
	Reaction Time	day 1 vs day 2	.097
		day 1 vs disrupted	.013*
		day 2 vs disrupted	<.001*
	Radius	day 1 vs day 2	.753
		day 1 vs disrupted	.028
		day 2 vs disrupted	.034
	RMS	day 1 vs day 2	-
		day 1 vs disrupted	-
		day 2 vs disrupted	-

*significant (bonferroni correction: α =.05/3= 0.0167)

<u>Appendix E.</u>

<u>Dizziness Handicap Inventory.</u>

Instructions: The purpose of this scale is to identify difficulties that you may be experiencing because of your dizziness or unsteadiness. Please answer "yes", "no" or "sometimes" to each question.
Answer each question as it applies to your dizziness or unsteadiness only.

ITEM	QUESTION		Y	N	S
1	Does looking up increase your problem?	P			
2	Because of your problem, do you feel frustrated?	E			
3	Because of your problem, do you restrict your travel for business or recreation?	F			
4	Does walking down the aisle of a supermarket increase your problem?	P			
5	Because of your problem, do you have difficulty getting into or out of bed?	F			
6	Does your problem significantly restrict your participation in social activities such as going out to dinner, the movies, dancing or to parties?	F			
7	Because of your problem, do you have difficulty reading?	F			
8	Does performing more ambitious activities such as sports or dancing or household chores such as sweeping or putting dishes away increase your problem?	P			
9	Because of your problem, are your afraid to leave your home without having someone accompany you?	E			
10	Because of your problem, are you embarrassed in front of others?	E			
11	Do quick movements of your head increase your problem?	P			
12	Because of your problem, do you avoid heights?	F			
13	Does turning over in bed increase your problem?	P			
14	Because of your problem, is it difficult for you to do strenuous housework or yard work?	F			
15	Because of your problem, are you afraid people may think you are intoxicated?	E			
16	Because of your problem, is it difficult for you to walk by yourself?	F			
17	Does walking down a sidewalk increase your problem?	P			
18	Because of your problem, is it difficult for you to concentrate?	E			
19	Because of your problem, is it difficult for you to walk around the house in the dark?	F			
20	Because of your problem, are you afraid to stay at home alone?	E			
21	Because of your problem, do you feel handicapped?	E			
22	Has your problem placed stress on your relationship with members of your family or friends?	E			
23	Because of your problem, are you depressed?	E			
24	Does your problem interfere with your job or household responsibilities?	F			
25	Does bending over increase your problem?	P			
			X 4	X 0	X 2
		=			
		TOTAL			

P ________________ E ________________ F ________________

Appendix F.

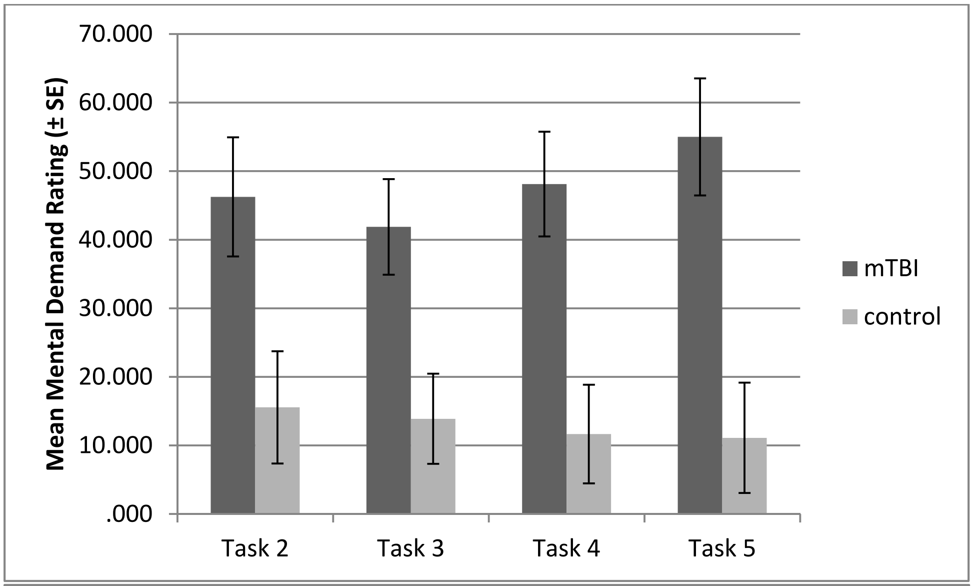
Mean ± SE record fire marksmanship performance by sample.

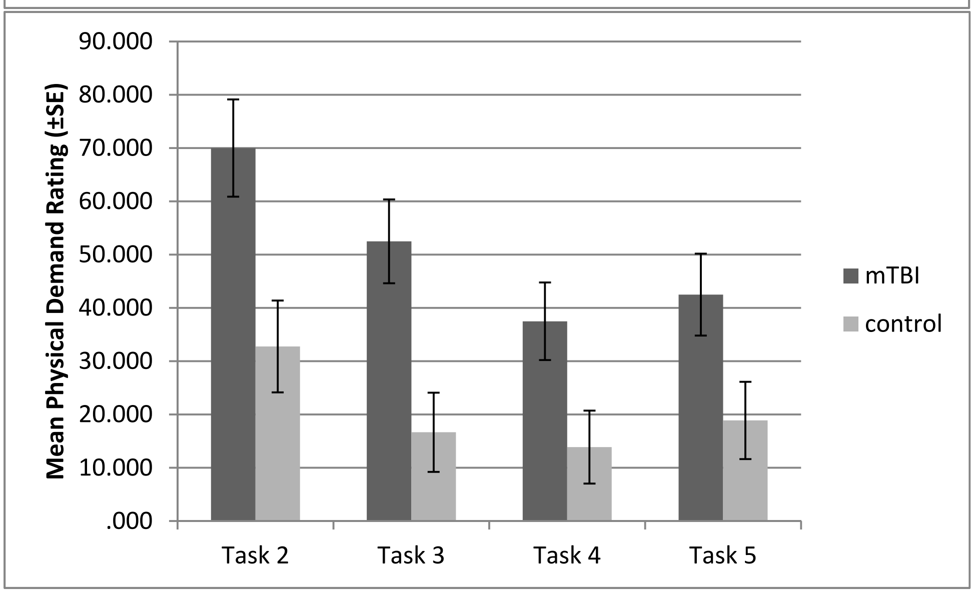
Position	Variable	Target distance	control group mean	control group SE	mTBI group mean	mTBI group SE
Prone supported	Accuracy	50	0.926	0.049	0.926	0.074
		100	0.589	0.103	0.522	0.108
		150	0.861	0.073	0.944	0.056
		200	0.472	0.121	0.657	0.110
		250	0.630	0.103	0.519	0.122
		300	0.500	0.118	0.500	0.083
	Reaction time	50	2192.756	93.780	2099.083	87.448
		100	3021.128	210.066	3116.729	237.342
		150	3017.775	197.441	2964.356	91.565
		200	3779.756	187.733	3411.701	111.740
		250	4108.550	233.284	3655.993	210.384
		300	5641.017	322.417	5047.322	276.513
	Radius	50	0.131	0.016	0.131	0.020
		100	0.263	0.037	0.239	0.026
		150	0.174	0.017	0.181	0.023
		200	0.326	0.037	0.240	0.030
		250	0.296	0.025	0.349	0.064
		300	0.378	0.058	0.306	0.042
	RMS	50	0.144	0.016	0.180	0.020
		100	0.257	0.040	0.238	0.031
		150	0.217	0.025	0.195	0.023
		200	0.389	0.048	0.284	0.038
		250	0.327	0.026	0.359	0.066
		300	0.450	0.075	0.409	0.069
Prone unsupported	Accuracy	150	0.781	0.088	0.658	0.129
		200	0.531	0.121	0.569	0.154
		250	0.563	0.165	0.667	0.136
		300	0.375	0.173	0.500	0.183
	Reaction time	150	2985.481	179.840	3045.346	223.627
		200	4056.966	331.235	3935.682	246.998
		250	4126.181	359.058	4361.492	324.940

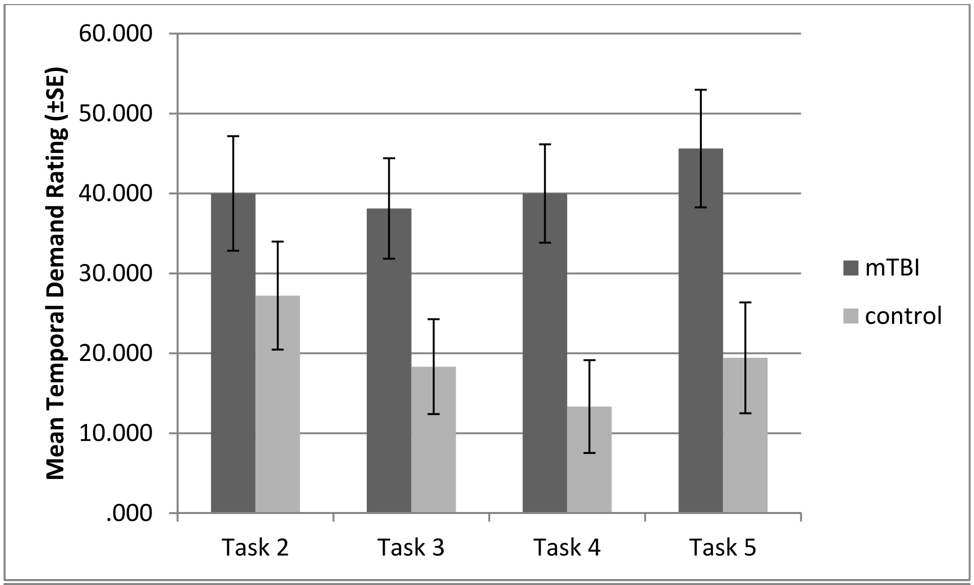
		300	6652.525	649.360	6728.767	561.516
	Radius	150	0.237	0.025	0.378	0.116
		200	0.750	0.433	0.940	0.456
		250	0.343	0.058	0.320	0.047
		300	0.632	0.240	0.573	0.154
	RMS	150	0.318	0.039	0.385	0.115
		200	0.355	0.045	0.542	0.143
		250	0.220	0.060	0.176	0.032
Kneeling	Accuracy	50	1.000	0.000	0.926	0.074
		100	0.417	0.125	0.472	0.128
		150	0.611	0.118	0.667	0.111
	Reaction time	50	2180.559	149.570	2058.737	62.995
		100	2542.000	181.567	2481.433	147.435
		150	2834.107	174.969	2810.193	134.632
	Radius	50	0.134	0.012	0.138	0.019
		100	0.268	0.027	0.246	0.036
		150	0.390	0.113	0.287	0.033
	RMS	50	0.206	0.028	0.180	0.014
		100	0.315	0.046	0.258	0.041
		150	0.486	0.107	0.354	0.030

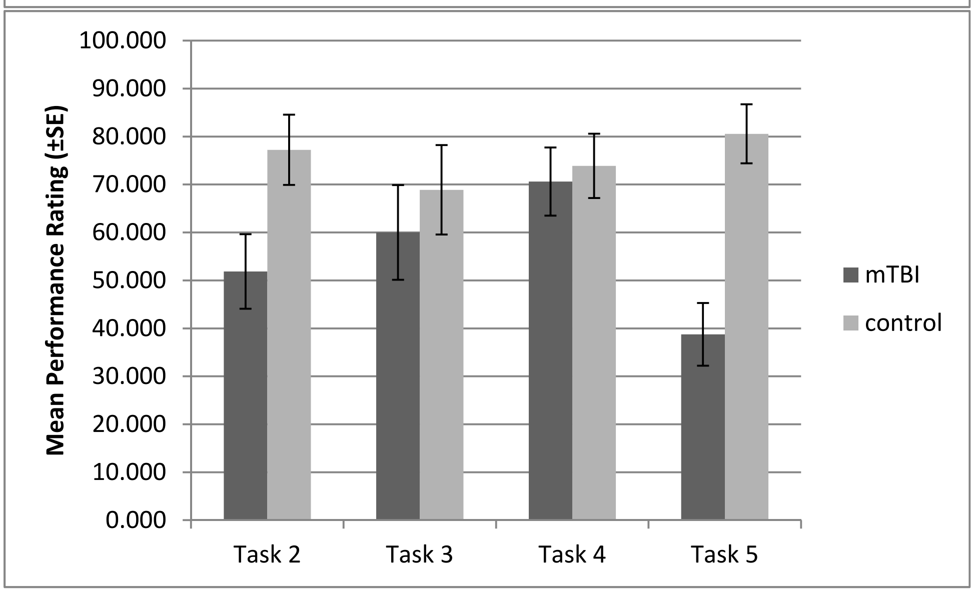
Appendix G.

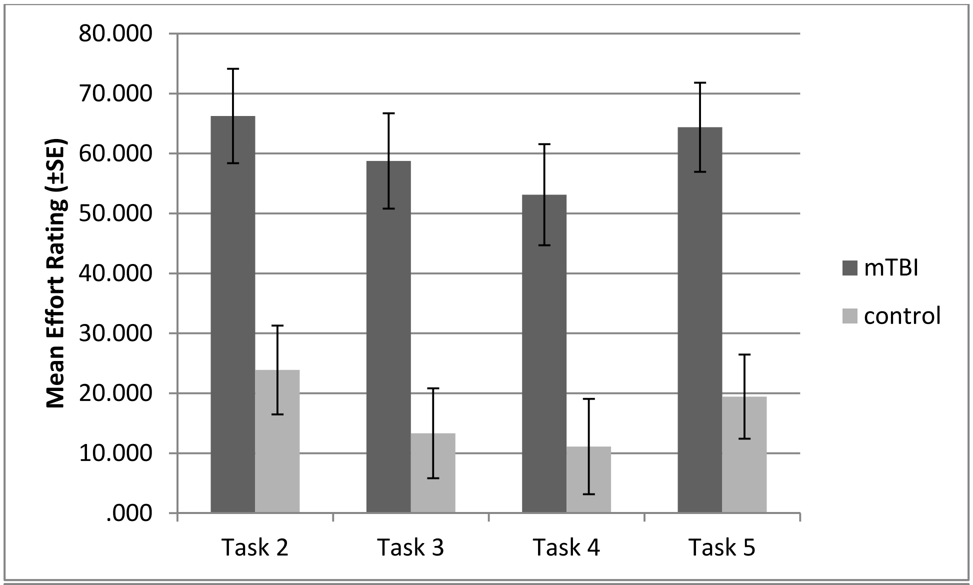
Mean ±SE Workload ratings by sample.

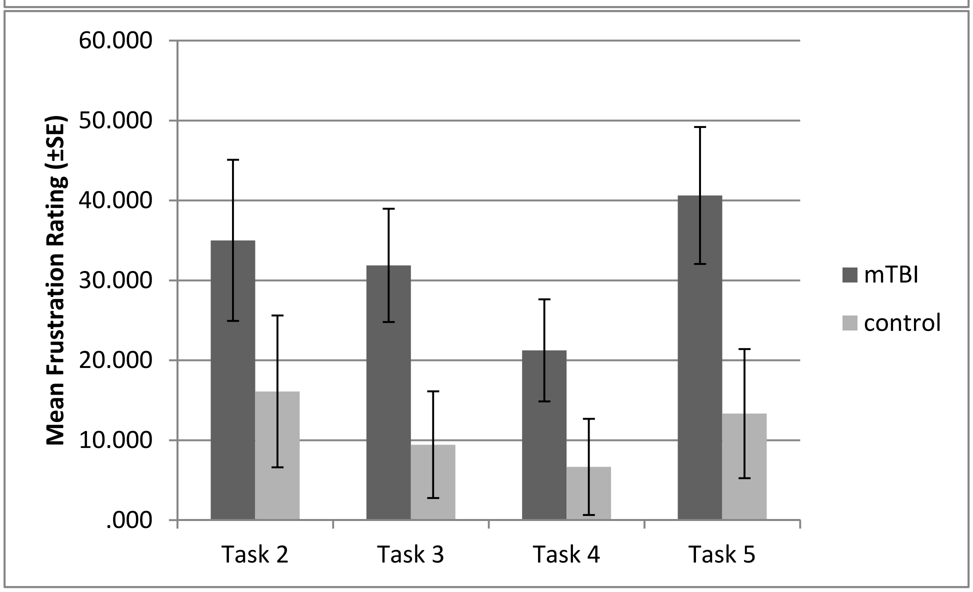





60.000
50.000
40.000
30.000
20.000
10.000
.000
Mean Temporal Demand Rating (±SE)
Task 2
Task 3
Task 4
Task 5
mTBI
control


100.000
90.000
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Mean Performance Rating (±SE)
Task 2
Task 3
Task 4
Task 5
mTBI
control


80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
.000
Mean Effort Rating (±SE)
Task 2
Task 3
Task 4
Task 5
mTBI
control


60.000
50.000
40.000
30.000
20.000
10.000
.000
Mean Frustration Rating (±SE)
Task 2
Task 3
Task 4
Task 5
mTBI
control

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