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Mild Traumatic Brain Injury and Dynamic Simulated Shooting Performance

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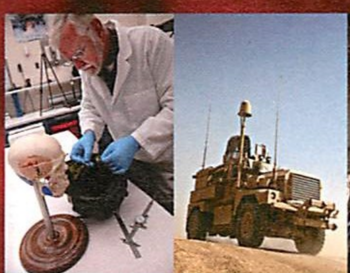

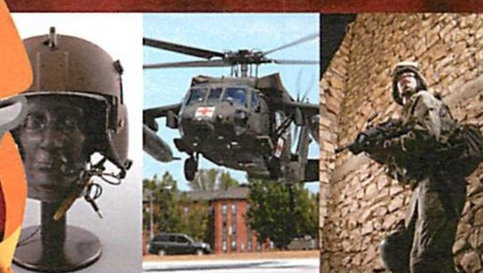

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14. ABSTRACT
Balance and coordination are disrupted by sensorimotor challenges, including pathologies resulting from blast overpressure or head acceleration/impact. Various vestibular and balance assessment tools are being developed for military use. This research evaluated simulated shooting tasks designed to be more dynamic and balance-intensive than current standard range marksmanship qualification tasks. Using a research-modified Engagement Skills Trainer, shooting performance and perceived workload were assessed during shooting tasks designed to challenge balance analogously to clinical gait assessments. Our first study established that we could detect shooting performance deficits caused by unusual vestibular stimulation. Our second study evaluated whether we could detect performance deficits associated with mild traumatic brain injury (mTBI). Our main findings were participants with mTBI were dizzier than healthy subjects and reported a higher perceived workload during the shooting tasks; however, we did not detect a decrement in their shooting performance. Further research is needed using healthy and control subjects from the same site.

15. SUBJECT TERMS
vestibular, mild traumatic brain injury, mTBI, concussion, marksmanship, shooting, balance, sensorimotor, psychomotor, workload, dizziness

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Introduction

Background Research Leading to the Current Study

Orientation, balance, and coordination during goal-directed activities can be affected adversely by a variety of disruptions to normal sensorimotor integration. Such disruptions can be caused by pathological central and peripheral vestibular conditions resulting from blast overpressure or head acceleration/impact (e.g., due to explosions or altitude barotrauma) (Lawson and Rupert, 2010; Grandizio et al., 2014). Novel vestibular and balance measurement tools are being developed for use by military and civilian communities to assess fitness for duty (Lawson and Rupert, 2010; Lawson, Rupert, and Cho, 2013). Improved tests could prove useful as initial screening procedures prior to assuming one's duties for the day (e.g., taking control of an aircraft). Such tools also could aid decisions concerning whether it is safe for a military service member to return to duty following a concussion or, conversely, if further clinical testing is warranted.[1] As new tests improve and mature, they will help answer longer-term medical questions as well, such as whether military personnel (e.g., Army Soldiers) or athletes can continue to serve in their chosen occupations (Lawson et al., in press), or whether sessions of vestibular rehabilitation are yielding benefits and returning patients to normal, healthy functioning (Lawson, Rupert, and Legan, 2012).

This research effort was sponsored by the U.S. Army Medical Research and Materiel Command to serve the goals of the Military Operational Medicine Research Program's Injury Prevention/Reduction Program, which include searching for evidence-based criteria for assessing the performance of military personnel after neurosensory (including vestibular) injury. This report describes the second stage of development and evaluation of several tasks that challenged fine goal-directed sensorimotor coordination during the maintenance of one's balance. The intention was to identify tests relevant to the assessment of neurovestibular injury. We shall briefly review the first stage of our research concerning the initial development of the tests using healthy participants (Grandizio et al., 2014) and then describe the rationale for the second stage of research entailing testing mild Traumatic Brain Injury (mTBI) participants, which is the subject of the current report.

During the first stage of research, we developed five candidate tasks that required simulated rifle shooting while balancing and moving in ways known to be challenging to vestibularly-mediated postural equilibrium (Grandizio et al., 2014). We sought to determine whether any tasks could be devised that have suitable test properties while being more *dynamic* than the current, relatively static range marksmanship qualification tasks employed by the U.S. Army. Once we evaluated the tests during normal performance by healthy participants, we evaluated whether any of them would be sensitive to deficits in balance and coordination caused by exposing healthy participants to a temporary/reversible vestibular challenge. Below, we briefly describe the tasks that were developed, the transient vestibular insult that was employed, and the findings that were obtained (and which motivated our second study).

[1] Such decisions are also required before returning an athlete to competition or an elderly person to unsupervised ambulation.

Rationale for development of the shooting tasks and key findings concerning them

The five simulated shooting tasks we explored in the first study were as follows:[2]

1) Kneel and Shoot (KS): entailing shooting at targets on the left and right side of the visual field while shooting from a narrow kneeling stance;

2) Pickup Rifle and Shoot (PURS): bending down to pick up a rifle from the floor, then rising to shoot;

3) Walk, Head Swivel, and Shoot (WHS): walking forward while swivelling one's head and body from side to side before shooting to the side;

4) Traverse Beam and Shoot (TBS): walking in a straight line while simultaneously shooting at targets to the side; and

5) Turn and Shoot (TS): turning 180 degrees to shoot at a target behind oneself.

Each of these tasks was specifically designed to be a *compromise* between the rifle handling behaviours required of a Soldier and the functional motor coordination activities that are known to be difficult for vestibular patients (and which they must attempt during clinical balance and gait assessment). In order to convey how this compromise was achieved, two specific examples from the literature are offered below.

Example 1 (Relevant to PURS Task #2, above): The established Berg Balance Scale (Berg, Wood-Dauphinée, Williams, & Maki, 1992; Berg, Wood-Dauphinée, and Williams, 1995) measures a balance patient's ability to pick an object up from the floor, which is similar to our PURS task #2, above. Similarly, as part of military duties, a Soldier should be able to pick up a rifle from a level lower than his/her head (albeit not necessarily the floor) and shoot quickly and accurately. Therefore, the PURS task can be viewed as a compromise between a military-relevant task and a clinically-relevant challenge used in balance and gait assessment.

Example 2 (Relevant to WHS Task #3): The established Dynamic Gait Index (Shumway-Cook & Wollacott, 1995) and the Functional Gait Assessment (Wrisley, Marchetti, Kuharsky, & Whitney, 2004) each contain a task that involves walking forward while swivelling one's head in yaw to the left and right. Similarly, the WHS task #3 above involved walking forward and pivoting into a shooting stance to the side, which is something a Soldier should be able to do efficiently.

[2] These five tasks are described in detail in Grandizio et al. and the first four down-selected finalist tasks employed in the present study are described further in the Methods section of this report (Table 1 and Figures 3-6). This brief introduction to the tasks is intended to help the reader to grasp the overall rationale we followed in developing simulated shooting tasks that were relevant to some of the same abilities assessed by established clinical gait/balance tasks.

Using the approach described, we devised a battery of clinically-relevant, balance-intensive tasks that also required rifle shooting. The tests were modified enough from the clinical balance tasks (from which they were derived) so as to be more similar to military duties than simply requiring participants to shoot while performing the original clinical tasks *exactly* as published. For example, a Soldier would probably never walk forward without interruption while simultaneously swivelling only his/her head (as in the Dynamic Gait Index) to each side and shooting with a rifle. Rather, the Soldier would do something more similar to our WHS task, i.e., naturally turn and assume a rifle shooting stance if he/she needed to engage a target to one side while walking. The resulting clinical-military hybrid tasks developed with this approach can be considered by military clinicians to be clinically-relevant vestibular balance challenges that should yield additional face validity for decisions concerning military readiness.[3] Below, we briefly summarize the key findings we obtained concerning these candidate tests.

The goal of our first study (Grandizio et al., 2014) was to characterize the properties of the different tests during normal performance by healthy participants and eliminate the least suitable test (or tests) so that subsequent research could employ the most promising tests in the least amount of time. We determined that the most reliable tasks were the Kneel and Shoot (KS) task (explained above) and the Traverse Beam and Shoot (TBS) task (also explained above). KS and TBS were also sufficiently challenging, i.e., they elicited the highest perceived workload ratings from the participants. These findings imply that these two tasks should be included in future research explorations intended to develop an assessment battery. Conversely, the Turn and Shoot (TS) task (entailing turning 180 degrees before shooting the target in semi-darkness) was not sufficiently reliable (as currently designed) to merit inclusion in the next study.[4] These findings helped us to develop and refine our tests, which we then evaluated during a transient vestibular challenge.

The vestibular challenge employed in the first study and its implications for the second study

The transient vestibular insult in Grandizio et al. (2014) consisted of a brief period of rotation at constant velocity, followed by a sudden stop. This stimulus elicited predictable, controlled vestibular (predominantly semicircular canal) aftereffects that we utilized as a proxy for a transient episode of active dizziness or vertigo, such as might be associated with vestibular pathology. We found that some aspects of the shooting performance were disrupted by inducing transient dizziness. Specifically, the KS and the TBS tasks were most sensitive to the effects of the transient vestibular insult, further corroborating the need to preserve these tasks during subsequent research on balance-compromised persons in Study #2. These findings also

[3] While these tasks incorporated the advice of several service members serving at our laboratory, military combatant command personnel should not infer that these tests were designed to realistically simulate military combat or military tasks described formally in military manuals.
[4] Note that this task could potentially be redesigned and reevaluated in a third study, however. It is probable that the suboptimal performance of TS in Study #1 had more to do with visual difficulty using the iron sights under low light conditions than with poor test properties inherently related to balance and coordination. Exploration of TS is advised under increased illumination, because the task has relatively few degrees of freedom, is easy to learn, is rapid to perform, and is clearly something a Soldier may need to do.

confirmed that when a sufficient vestibular perturbation is present, it can reasonably be expected to disrupt dynamic shooting performance.

Our first study evaluated a proxy of clinical pathology in healthy normal participants. The primary reason for not studying injured personnel in the first experiment was that we first needed to understand the basic properties of the candidate tests during normal performance and identify the most suitable ones. The secondary reason for studying healthy personnel initially was logistical, i.e., we had no ready access to a pool of injured volunteers (such as concussion/mTBI victims) at our home location in Fort Rucker and we wished to have our procedures refined before attempting an offsite study recruiting injured participants. Having worked out our procedures and determined the most suitable tests in Study #1, we commenced the current study #2, which is the subject of this report.

Rationale for the Current Study

This experiment focused on pathologically-induced dizziness, rather than experimentally-induced dizziness. We recruited participants reporting episodes of dizziness following a diagnosis of mTBI. Some researchers estimate that approximately 90 percent of acute mTBI patients and 80 percent of chronic mTBI patients exhibit evidence of vestibular pathology (Balaban & Hoffer, 2009). Such pathology should not be surprising, since there are several anatomical and neurological reasons why the events that cause mTBI also tend to disrupt central and peripheral vestibular structures (Lawson and Rupert, 2010).

Common signs and symptoms of mTBI include vertigo, dizziness, disequilibrium, and gaze instability. Postural sway is a common problem among Soldiers with mTBI (McNamee, Walker, Cifu, & Wehman, 2009). In addition, dizziness is one of the most common symptoms that distinguish mTBI patients from healthy persons (Paniak et al., 2002). Such findings are disturbing, since problems with balance could represent a more direct threat to individual safety than some of the other common sequelae of mTBI (e.g., headache). Of further concern is the fact that recovery from vestibular disorders due to concussion often takes longer than recovery from vestibular disorders attributable to other causes (Shumway-Cook, 2007). In fact, dizziness has been found to last as long as two years in 18% of concussion cases; a few patients cannot return to their pre-accident duties even five years after mTBI (Lawson and Rupert, 2010).

Occupational and physical therapists working in the military setting have observed that Soldiers who experience mTBI have observable difficulties with weapon usage (Grandizio et al., 2014). These clinical observations imply that weapons handling performance may be worth evaluating more formally during clinical balance assessments of military personnel. This inference is corroborated by the recent recommendations of a group of balance experts advising the military (Lawson et al., 2012), who recommended the inclusion of tests incorporating weapons handling into future balance test batteries designed for military applications. The cumulative advice of rehabilitation specialists and balance experts supports our rationale for attempting the present study of dynamic shooting performance of military participants recovering from mTBI.

Besides shooting obviously being relevant to Soldier survival, shooting tasks are clinically interesting because they are likely to place a demand on postural equilibrium similar to that placed by a cognitive task, with similar potential for increased test sensitivity to emerge (Shumway-Cook, 2007). The military benefit of adding shooting to a clinical balance assessment is that if a hybrid balancing/shooting test is identified that detects a post injury deficit in the ability to engage targets with an M-16 series rifle (Department of the Army, 2009), medical considerations concerning the relevancy of that deficit to military readiness will be more straightforward than would be the case for tests whose relation to critical Soldier skills is less direct. For this and the other reasons discussed above, we executed a study of dynamic shooting performance among mTBI participants.

Methods

To determine if there were differences between healthy and mTBI-affected participants, we studied the four best-performing shooting tasks selected from the dynamic marksmanship battery (of five original tasks) developed by Grandizio et al. (2014). Participants were scored on their shooting performance, defined as the number of accurate shots per second (shot throughput). They also were asked to provide ratings of dizziness, cognitive workload, and other relevant variables. The participants, variables, and methods are described below.

Participants

Sixty healthy control participants (without history of head injury) were recruited from Fort Rucker, Alabama,[5] comprised of 56 men and 4 women[6] whose mean age[7] was 27 years (*SD* = 5.4). Another forty participants from Fort Benning, Georgia completed the study (38 men and 2 women). The 40 Fort Benning participants had a mean age of 33 years (*SD* = 6.9). Thirty of the Fort Benning participants were recruited from mTBI patients of the Martin Army Community Hospital (MACH) traumatic brain injury treatment center, the majority of who were assigned to the Fort Benning Warrior Transition Battalion. The patients had a documented past diagnosis of mTBI confirmed by their medical history (DD Form 2807) and via interview with our study physician. To ensure that some healthy participants from Fort Benning were included in the control group, 10 (of the aforementioned 40) participants from Fort Benning were healthy and had no history of head injury. The mean age of the Fort Benning participants, split by mTBI (n = 30) versus healthy (n = 10) volunteers, was 33 years (*SD* = 6.9) and 28 years (*SD* = 19.6), respectively.

All participants completed a weapons qualification task prior to learning our novel dynamic test battery (using the same device, the Engagement Skills Trainer [EST] 2000). A participant's qualification score (Figure 1) was based on the number of target hits on the standard

[5] These participants are described in Grandizio et al.; their data comprised the bulk of our healthy control group for the logistical reasons already described.
[6] There were no gender restrictions to participation other than a pregnancy test; nevertheless, it is common to have a smaller pool of female volunteers available for recruitment at a military post (than in the population at large).
[7] Participants in our Forts Rucker and Benning studies were required to be of age 19 to 45, or 18 to 45, respectively. These age ranges were based on local definitions of the age of majority and the need to avoid excess variability due to sensory degradation associated with aging.

40-target marksmanship task, with “Experts” correctly hitting 36 to 40 targets, “Sharpshooters” hitting 30 to 35 targets, “Marksmen” hitting 23 to 29 targets, and “Did not Qualify (DNQ)” hitting 22 or less targets (Department of the Army, 2008). Standard qualification score was then used as a covariate during subsequent analyses of healthy versus mTBI participants completing our novel dynamic shooting test battery.

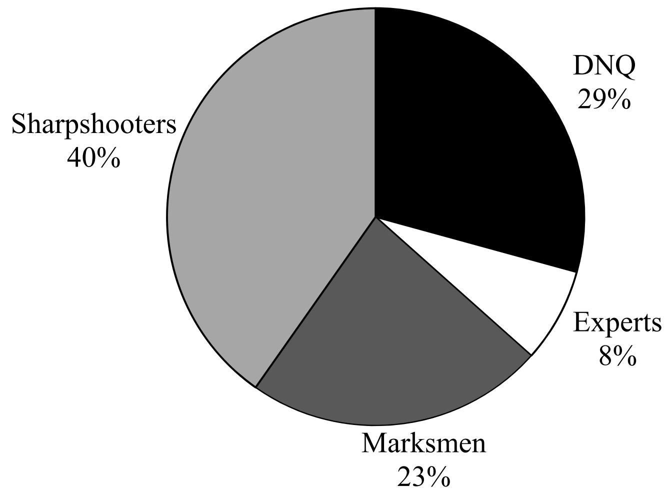

Figure 1. Distribution of marksmanship qualification scores.

The study population was limited to U.S. Army active-duty Soldiers, National Guard/Reserve Soldiers, or civilians with recent military experience. These limitations were adopted to ensure that participants were familiar with basic military weapons utilization. The healthy participants were required to have visual acuity correctable to 20/40 or better, to not be using medications that would increase subject risk or preclude participation, and to have no history of head/brain injury (due to blast, penetrating trauma, or blunt force, e.g., concussion due to participation in combative full contact sports).[8] They also had no known history of certain types of diseases affecting vestibular function (vestibular neuritis, vestibular schwannoma, Ménière’s), and no known history of unexplained sensorineural hearing loss, cerebrovascular disorders or stroke, whiplash injury, or other musculoskeletal/systemic conditions that would preclude participation (e.g., knee injury preventing them from assuming the stance required for the KS task). To minimize the potential for the simulated shooting tasks to induce psychological distress, the participants were confirmed to be free of symptoms indicative of significant PTSD (Grandizio et al., 2014; Prins, et al., 2004).

The mTBI volunteers met the same criteria as above for healthy volunteers, except that instead of being excluded due to a history of head/brain injury, there were required to have a previous diagnosis of mTBI (American Congress of Rehabilitation Medicine, 1993), which was confirmed via participant self-report, participant interview with the study physician, study physician review of the participant’s medical records (DD Form 2807), and, when needed, study

[8]The criteria in this section were confirmed via visual testing, participant self-reporting, medical records, and an interview with the study physician. Decisions were made case-by-case, at the discretion of the study physician.

physician review of the participants' Armed Forces Health Longitudinal Technology Application records.

Materials

Engagement Skills Trainer 2000 and its modifications for the current research

The EST 2000 is a small arms simulator training device. This device is used during U.S. Army Infantry Schools' Basic Rifle Marksmanship (BRM) training. As can be seen in Figure 2, the shooter fires from a lane at virtual targets which appear on a projection screen at a distance of 26 feet and 3 inches from the firing line. Demilitarized M4 carbines have been modified to use with the EST 2000 to maintain a realistic feel and function.

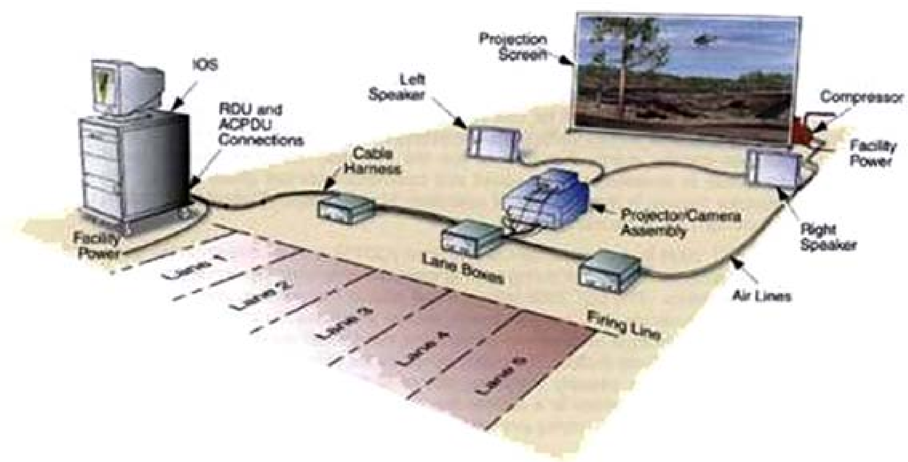

Figure 2. EST 2000 set-up (Anthony, 2006).

The EST 2000 is intended as a small arms *training* device, but the USAARL EST 2000 has been modified for *research* applications. It possesses specialized software to allow for the collection of many channels of data concerning performance (Jones, King, & Gaydos, 2011). Targets and target engagement procedures for the novel battery were developed through an iterative trial-and-error process; for example, some initial ideas we had concerning target size, location, timing, or engagement were not feasible within the limits of the training software. Moreover, the EST was physically modified from the standard Army configuration shown in Figure 2. This was done via the addition of 13-foot cables (purchased from the manufacturer) to allow more room for participant locomotion and by reconfiguring the equipment so that there were fewer floor obstructions caused by the system's air lines, lane boxes, or speakers (Figures 3 through 6).

The standard and dynamic marksmanship batteries

Participants completed two marksmanship batteries utilizing the EST 2000: a standard (relatively static) marksmanship qualification, and our newly-developed dynamic marksmanship battery (Grandizio et al., 2014). In the standard marksmanship qualification task, participants shot with a rifle at 40 targets presented sequentially. The targets varied in virtual distance (from the shooter), from 50 to 300 meters. The participants fired from three positions: prone supported, prone unsupported, and kneeling (Department of the Army, 2009). The key dependent variables for these standard and dynamic tasks were accuracy and reaction time, which were used to calculate each shooter's mean *shot throughput* (accurate shots per second).

The development of the dynamic marksmanship tasks and the final four tests used in this study were presented in the Introduction. The participants performed all shooting tasks using a demilitarized M4 rifle. The rifle partially mimicked the behavior of a rifle when fired via (pneumatic) simulation of recoil and noise (a much-reduced speaker playback confirming that simulated discharge of the weapon has occurred). Dynamic marksmanship battery tasks are described further in Table 1 and shown in Figures 3 through 6.

Table 1. Dynamic Marksmanship Battery Tasks.

Task	Description	EST Scenario and Instructions
1. Kneel and Shoot (KS) (Fig. 3)	Shoot at targets to the left and right of the visual field while in a narrow kneeling stance	--1 target at a time, 10 targets total, virtual targets appear at 75 m --Targets appear at extremes of lane width and require yaw swivel of head and rifle to engage --Each target up for 2 s; 2 s between targets --Kneel at location (90 in. from screen) with feet aligned and rear knee near the front heel --Stay aimed at last target until next target appears (don't anticipate)
2. Pickup Rifle and Shoot (PURS) (Fig. 4)	Pick up weapon from floor, shoot at target at top of screen	--1 target at top of screen, 2 shots --Targets appear at 40 m --Pick up rifle with 2 hands; --Start facing perpendicular to screen; --Include natural pitch head motion, bending at the waist, and looking at rifle during pickup and replace (don't perform squats with head upright) --After firing, place weapon back on ground; await instructions to pick up and shoot again
3. Walk, Head Swivel, and Shoot (WHS) (Fig. 5)	Walk with 180° horizontal plane (yaw) head/rifle turns on every 2 steps Fire at target whenever facing screen (every other turn).	--1 target, 2 shots total --Target appears at 15 m --Start facing perpendicular to screen --Start walking with left foot --Sequence: 2 steps, fire at screen to left, 2 steps, point at wall to right, 2 steps, fire at screen to left

Table 1 (cont.).

4. Traverse Beam and Shoot (TBS) (Fig. 6)	Walk on narrow path parallel to screen; shoot at targets	--4 targets from left to right --Targets appear at 25 m --Goal is to walk across the beam quickly (without stopping) while hitting all targets --The side-to-side limits of the walking path are cued tactually by the edges of 8-inch-wide wooden planking, of which the top is slightly elevated above the floor (plank is 0.8-in. thick). The planking is 96-in. long (walking distance).

Figure 3. Task 1: Kneel and shoot.

Figure 4. Task 2: Pickup and shoot.

Figure 5. Task 3: Walk and shoot.

Figure 6. Task 4: Traverse beam and shoot (Note: during actual experiment, wire was kept clear of participant's feet).

Questionnaires[9]

Perceived workload ratings (NASA TLX)

In addition to shooting performance, we measured how difficult the participant felt each shooting task was. The National Aeronautics and Space Administration Task Load Index (NASA TLX) provides a workload assessment based on ratings for six dimensions, viz., mental demands, physical demands, temporal demands, own performance, effort and frustration. For the present study, it was used to assess perceived workload immediately after performing each shooting task. Detailed instructions can be found in the test administration guide (NASA, n.d.). A raw TLX scoring procedure was used (Cao, Chintamani, Pandya, & Ellis, 2009; Hart, 2006).

Dizziness Handicap Inventory (DHI)

Participants completed the Dizziness Handicap Inventory (DHI). The DHI is a validated questionnaire that estimates general disabilities related to vestibular dysfunction (Jacobson & Newman, 1990). The questionnaire consists of 25 items related to the effects of dizziness, including 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 effects (e.g., *Because of your problem, are you embarrassed in front of others*?). Answers are scored as *no* = 0, *sometimes* = 2, and

[9]The main questionnaires incorporated into data analysis are briefly reiterated here. Full copies of many of the questionnaires are provided in Grandizio et al., 2014

yes = 4. The highest score possible is 100, with higher scores indicating a greater impairment. This data allowed us to characterize the participants' general daily problems with dizziness.

Additional estimates of dizziness or imbalance

The DHI tracks general handicaps related to dizziness during everyday life. To provide more specific temporal information concerning dizziness immediately around the time of our study, the participants also were asked whether they experienced any dizziness during the week leading up to the experiment (*yes* or *no*), or *during* the performance of the shooting tasks (where their debriefing comments were scored from 0 = *no dizziness* to 3 = *severe dizziness*).

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, after which the participants filled out questionnaires concerning daily dizziness, PTSD, etc., before being introduced to the EST weapons simulator. Participants first zeroed their weapon, calibrating the laser sensor to the direction the rifle was pointing. They then completed the standard marksmanship qualification already described. 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 prior to obtaining baseline performance data. The ultimate purpose of the shooting tests was to detect abnormal vestibular/balance function, while avoiding sensitization or adaptation of balance patients. It was deemed important to limit head movement among mTBI participants during the practice sessions, to avoid triggering unwanted symptoms. Therefore, three sessions of practice were used but the first was done at slower speed and with conscious limitation of head movement amplitude and speed. Upon completing the practice sessions, participants performed the dynamic marksmanship tasks. NASA TLX workload ratings were collected immediately following each of the shooting tasks. The order of performance of the tasks in the dynamic battery was balanced. Finally, the participants completed the debriefing questionnaire to provide subjective feedback on the dynamic battery of tests.

Results

Basic Characteristics of the Shooting Data

Of those participants who completed the dynamic marksmanship battery ($N = 102$), 21 from the Fort Rucker sample were not included in the present data analysis because too much data was missing to permit meaningful analysis of their shooting performance. This was partly due to computer data collection problems. Such problems were observed at times while recording data with the EST system, and were probably associated with our use of the system in a much more dynamic way than intended (it is designed for routine marksmanship training). For example, it appeared that when the rifle was moved too quickly (e.g., to turn 180 degrees rapidly and then shoot), rifle position data acquisition could become lost or unreliable. However, since shooting data loss was not a significant problem in Study #2 at Fort Benning, it is probable that human error was an additional factor in data loss in Study #1. Study #1 was more lengthy and complicated than Study #2, involving an additional shooting test and sessions of rotation (the transient vestibular challenge). By the time Study #2 was executed, the team was more experienced and also executing a simpler experiment. For these reasons, one would expect more data loss in Study #1.

Preliminary analyses were run to evaluate whether the participants differed with respect to marksmanship ability between the sites. This analysis did not detect differences in basic marksmanship qualification ability (defined as number of hits in qualification task) between sites, $t(79) = -1.57$, $p = 0.121$. A z-test for the difference between two proportions was conducted on the prevalence of DNQ qualification scores between Fort Benning and Fort Rucker participants. The *z*-test statistic comparing the proportion of DNQ outcomes between sites demonstrated that there was a significantly lower proportion of DNQ outcomes for the Fort Benning site ($z = -2.15$, $p = .03$). To account for this difference between sites, where appropriate, data collection site was included in subsequent analyses.[10]

A case breakdown of the analyzable participants ($N = 81$) is provided in table 2, showing the mean baseline for standard marksmanship qualification scores of the injured (mTBI) and uninjured (healthy) groups. (Number of participants at each site is shown also.)

Table 2. Cases by injury condition and data collection site.

Injury condition	No. of participants from Fort Rucker, AL	No. of participants from Fort Benning, GA	Mean qualification score ± SD
Injured (mTBI)	0	30	28.2 ± 6.1
Uninjured (no mTBI)	41	10	24.5 ± 10.8

Analysis of Dizziness Between Injury Conditions

Prior to comparing marksmanship performance of mTBI-injured versus healthy participants, DHI scores were analyzed to ascertain whether the two groups differed in their perceived levels of vestibular impairment. A one-way analysis of variance (ANOVA) demonstrated that DHI scores were significantly higher in the injured group than in the uninjured group [$F(1, 79) = 161.56$, $p < .001$]. Mean and standard error[11] values for both groups are represented in Figure 7 (note that the values are too small in the uninjured group to be visible in the Figure). The findings confirmed that the injured group was experiencing significantly greater dizziness-related handicaps during their daily activity, according to an established clinical instrument (viz., the DHI).[12] In the uninjured group, participants' DHI scores suggested no impairment (scores equal to 0, n = 50) or mild impairment (n = 1), whereas those for the injured group suggested no (n=1), mild (n=19), or moderate (n=10) impairment.

[10] In addition, an alternate analysis was conducted (see Appendix) which excluded DNQ participants. The results were consistent with those for the entire sample, but the small sample resulting from the exclusion rendered it more difficult to interpret minor differences in findings. For these two reasons, this report discusses the original analysis including the DNQ participants.

[11] Standard Error of the Mean (SEM).

[12] However, based on clinical cut-off scores in Whitney, Wrisley, Brown, & Furman, 2004, mean values for DHI implied a mild handicap was present in the injured group.

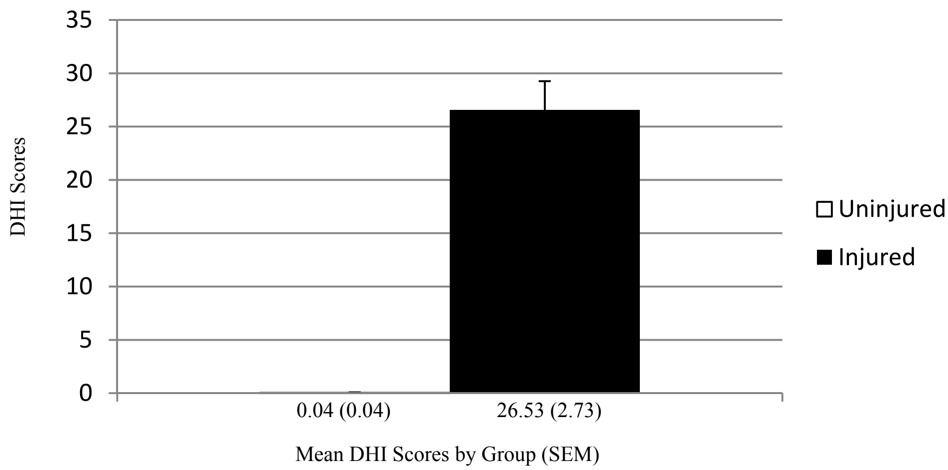

Figure 7. Mean and standard error for dizziness handicap index (DHI) scores by injury condition. The DHI characterizes general dizziness-related impairment during various activities of daily living.

The DHI tracks general dizziness-related functional handicaps in one's daily life. In order to estimate self-reported dizziness more closely associated with the time of study, participants also were asked to provide a binary response (*yes* or *no*) concerning whether or not they had experienced dizziness during the seven days prior to participating in the experiment. Twenty-three participants reported feeling dizzy in the week prior to the experiment, while 55 participants did not report any dizziness (four participants chose not to answer the question). All 23 positive responses were collected from the injured (mTBI) participant sample. A z-test for the difference between two proportions was conducted on the prevalence of *yes* responses between injured and uninjured participants. The *z*-test statistic comparing proportion of positive responses between the injured and uninjured group demonstrated that there was a significantly lower proportion of positive responses in the uninjured group ($z = -12.68$, $p < .001$).

During debriefing, participants were asked if they experienced dizziness during participation in any of the shooting tasks. An ordinal score ranging from 0 (*no dizziness*) to 3 (*severe dizziness*) quantified the participants' reports. Differences between injured and uninjured participants were then analyzed using a Mann-Whitney U test. There was a significant main effect of injury on observed dizziness ratings [$U = 229.00$, $p < .001$; Excluding DNQ, $U = 695.00$, $p < .001$], confirming that the participants with mTBI had more vestibular/balance impairment events than the uninjured controls. Mean score and standard error values for each group are represented in Figure 8.

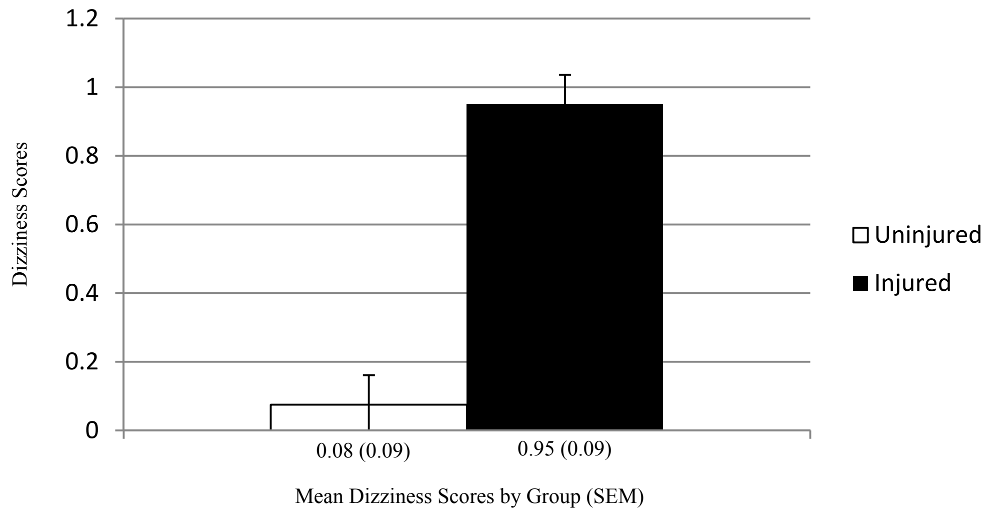

Figure 8. Mean and standard error for dizziness experienced during the shooting tasks.

Analysis of Shooting Performance Between Injury Conditions

Marksmanship performance on each of the tasks was represented by shot throughput (defined as the number of accurate hits per second), a measure that incorporated both accuracy and speed (Kane & Kay, 1992). Qualification scores (the number of accurate hits recorded during a standard or non-dynamic qualification task) were included as a covariate in each analysis to account for the observed variability in individual marksmanship ability among the participants.[13] Preliminary analyses of the data found that when correcting for marksmanship ability, a significant effect [($F(7, 68) = 3.07$, $p = .007$)] remained for the site at which the data was collected (Fort Rucker versus Fort Benning).[14]

Large between-shooting-task differences in the average time to fire each shot made a reliable repeated-measures analysis of throughput data unwarranted across all shooting tasks. Therefore, a one-way multivariate analysis of covariance (MANCOVA) was conducted to determine injury-specific differences between throughput measures recorded for each task in the modified battery [Kneel and shoot (KS); Pick up rifle and shoot (PURS); Walk, head swivel, and shoot (WHS); and Traverse beam and shoot (TBS)]. Throughput measures for the three existing standard qualification battery positions [prone-supported, prone-unsupported, and kneeling] were included for comparison to modified task performance. After correcting for variance accounted for by qualification scores and site differences, the overall main effect for injury on task performance was not significant [$F(7, 68) = 1.42$, $p = .213$], indicating that there was no consistent pattern detected concerning whether injured or uninjured participants were the better performers for any given shooting task.

[13] We have no evidence that MTBI affects static qualification shooting performance; nevertheless, it should be noted that this analysis method may be somewhat conservative, in that it possibly incorporates some variability in static performance due to MTBI.
[14] Therefore, the data collection site was included as a covariate in each analysis.

Alternatively, correlations between performance on the dynamic shooting tasks and the three measures of dizziness (overall DHI score, dizziness the week prior, and dizziness during the study) were explored. The results suggested significant relationships between one of the dynamic tasks and dizziness. Specifically, performance (throughput) on the Pick up rifle and shoot (PURS) task was inversely related to: 1) observed dizziness scores, $r(78) = -0.344$, $p = 0.002$, and 2) DHI scores, $r(78) = -0.338$, $p = 0.002$, both suggesting that as dizziness increased, performance decreased.

To further explore the relationship between dizziness and performance, participants were divided into two categories based on responses to the three measures: 1) no dizziness suspected (*not dizzy*) and 2) likely to be dizzy (*dizzy*). The first category was defined as having scored a *0* on the DHI, no observed dizziness (*0* observed rating), and not having reported any episodes of dizziness in the past week. Alternatively, the *dizzy* category was defined as having scored greater than *0* on the DHI, a low to high observed dizziness rating, and reported at least one episode of dizziness in the past week. This resulted in 46 *not dizzy* participants, 18 *dizzy* participants, 13 uncategorized given conflicting/contradictory results on the 3 measures of interest, and 4 with missing data on at least one measure. Next, to compare throughput on the four dynamic marksmanship tasks between *dizzy* and *not dizzy* participants, a MANCOVA including qualification scores as a covariate was conducted. The results suggest a significant main effect of dizziness on performance in the PURS task (Pick Up and Shoot; $F(1, 59) = 6.91$, $p = 0.011$) such that *dizzy* participants performed worse than *not dizzy* participants ($M_{dizzy} = 0.09$, $SE_{dizzy} = 0.01$; $M_{not\ dizzy} = 0.13$ $SE_{not\ dizzy} = 0.01$).

Analysis of Subjective Workload Between Injury Conditions

It is possible for different participant groups to perform indistinguishably, but for one group to have to work harder to reach similar performance to the other group. Therefore, in addition to measuring actual marksmanship performance, perceived exertion was measured using the NASA TLX. This instrument provides numerical estimates of subjective workload on six sub-scales: Mental demand (MD), Physical demand (PD), Temporal demand (TD), Performance (P), Effort (E), and Frustration (F). Each sub-scale has a possible range of scores from 0 to 100. Scores for each sub-scale were collected following each individual task. Scores were analyzed using a 2 by 4 by 6 mixed model factorial MANOVA. There was a significant overall between-subjects effect on subjective workload by condition demonstrating that, in general, injured participants reported significantly higher subjective workload scores than uninjured participants [$F(1, 78) = 14.77$, $p < .001$]. The main effect for condition is represented in Figure 9. In addition, there were a number of significant within-participants main effects and interactions between tasks and workload categories, which are summarized briefly in the next section.

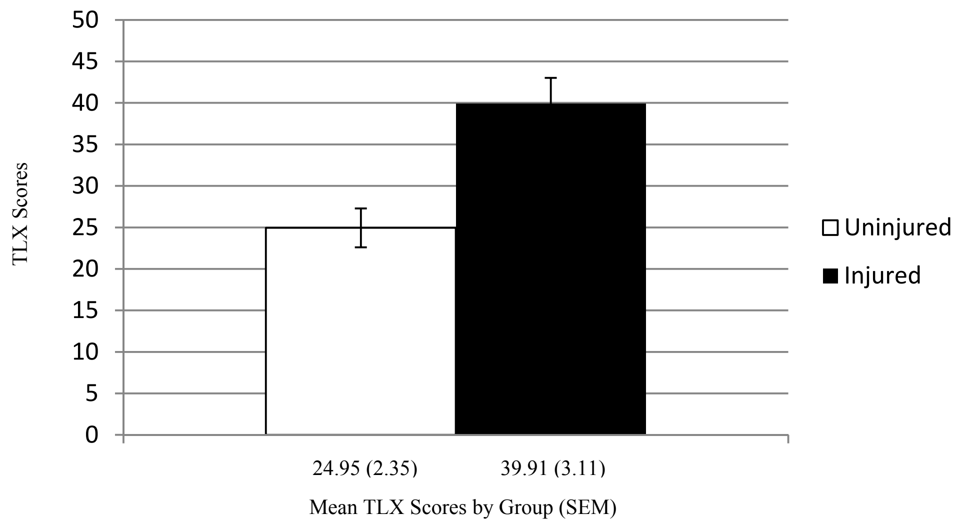

Figure 9. Estimated marginal means for overall NASA Task Load Index workload ratings by injury condition.

Dynamic shooting task effects on subjective workload ratings

Repeated-measures data for marksmanship task were determined (via Mauchley's test) to meet the assumption for sphericity, so uncorrected degrees of freedom were used in the analysis. A significant main effect of marksmanship task on reported TLX scores was identified within participants [$F(3, 234) = 16.34$, $p < .001$]. Estimated marginal mean TLX scores and standard error values for each task are presented in Figure 10.

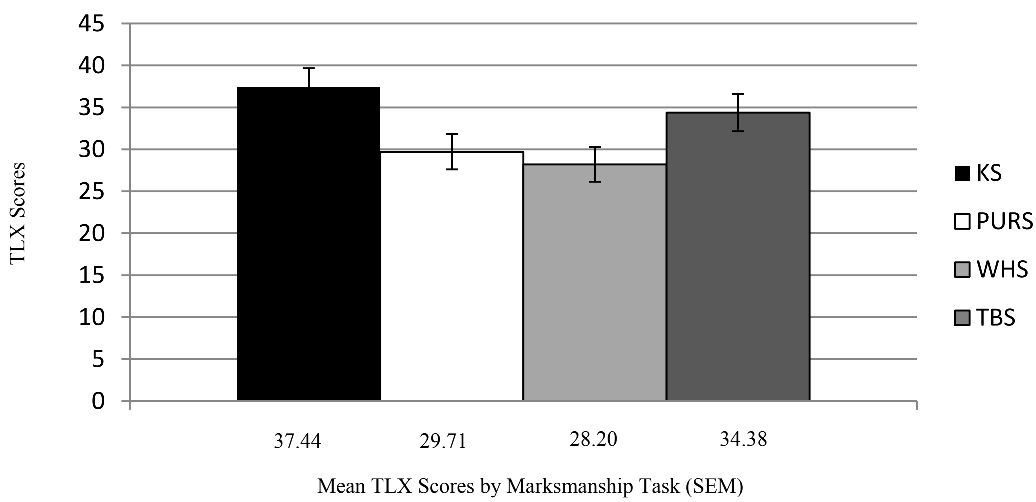

Figure 10. Estimated marginal means for overall workload ratings by task. [Kneel and Shoot (KS); Pickup Rifle and Shoot (PURS); Walk, Head Swivel, and Shoot (WHS); & Traverse Beam and Shoot (TBS)]

There were several significant pairwise differences between tasks. All pairwise comparisons were adjusted with a Sidak correction for multiple comparisons. TLX scores reported for KS were significantly higher than PURS and WHS ($p < .001$ for both). TLX scores for the TBS task were also significantly higher than PURS and WHS ($p = .013$ and .001, respectively). TLX scores for KS and TBS were not significantly different from one another, and there was no significant interaction for task effects between the mTBI and uninjured control groups. These findings indicate that all shooters, regardless of injury group, found that the KS and TBS tasks were the most difficult.

Workload rating differences among TLX sub-scales

Repeated-measures data for ratings between the six different workload sub-scales on the NASA TLX were determined (by a Mauchley's test) to not meet the assumption for sphericity. As the Greenhouse-Geisser ratio was below 0.75 (0.57), the Greenhouse-Geisser correction was applied to the degrees of freedom for within-participants analysis. After this correction, a significant main effect for sub-scale on TLX scores was identified within participants [$F(2.86, 222.66) = 11.87$, $p < .001$], with no significant interaction effect of injury. This effect is presented in Figure 11. Perceived level of effort was the highest source of workload overall ($\bar{x} = 39.97$), and had significantly higher scores than MD, TD, and F[15] ($p \leq .001$). PD ($\bar{x} = 35.65$) was also ranked significantly higher than MD, TD, and F, while P ($\bar{x} = 34.71$) was ranked significantly higher than F. However, it is important to note that there was a significant interaction effect of marksmanship task and TLX subscale [$F(10.09, 222.66) = 8.02$, $p < .001$]. This interaction was not significantly affected by injury condition. A summary of workload ratings by TLX subscale and marksmanship task are presented in Figure 12.

The scores indicated that participants found the KS task to require a larger physical demand ($\bar{x} = 48.53$) and entail more effort ($\bar{x} = 47.96$) than the other tasks, regardless of injury condition (healthy versus mTBI). The TBS task had higher ratings for P ($\bar{x} = 40.28$), indicating that participants (regardless of injury) believed they were the least successful in accomplishing this task as compared to the others. Overall, the KS and TBS tasks consistently had the highest subjective workload rating scores across all six TLX sub-scales. Collectively, the findings implied that perceived level of effort and physical demand were the factors contributing to the perceived workload of the dynamic shooting tasks, with workload sub-scale ratings interacting with the aforementioned tasks but not with injury condition.

[15] Acronyms were defined on page 15 (Results).

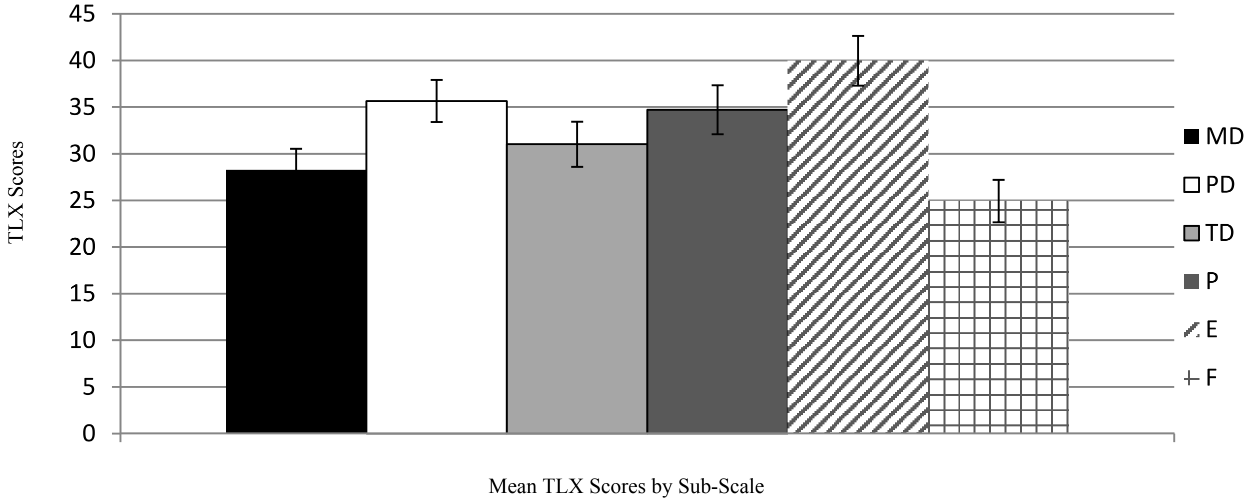

Figure 11. Estimated marginal means for workload ratings by sub-scale. [Mental Demand (MD); Physical Demand (PD); Temporal Demand (TD); Performance (P); Effort (E); & Frustration (F)]

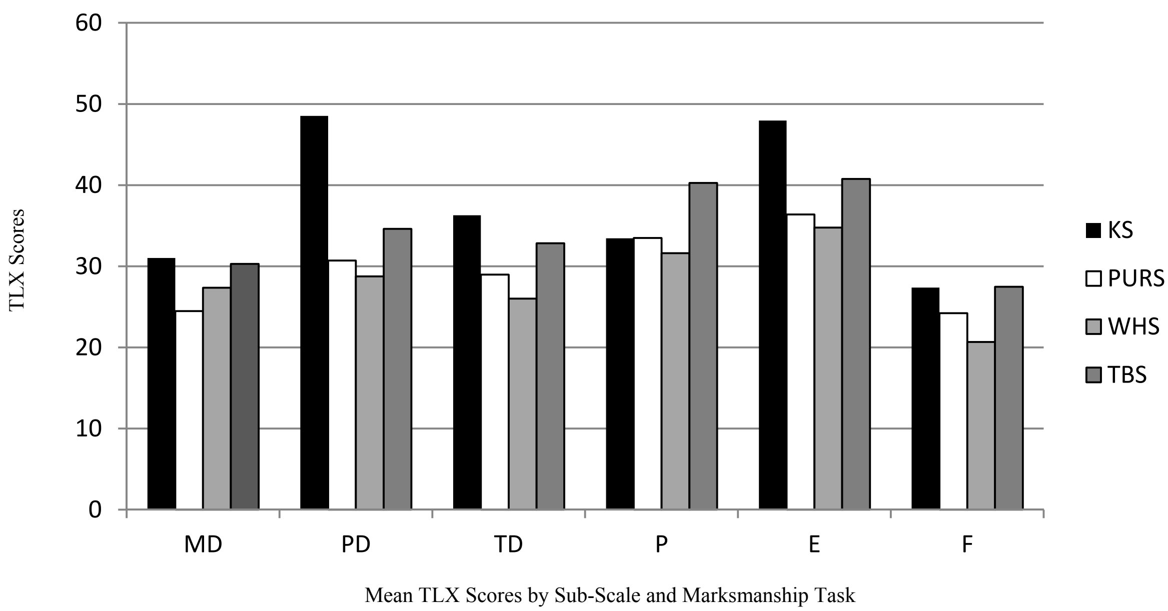

Figure 12. Estimated marginal means for workload ratings by TLX sub-scale and marksmanship task. [[Kneel and Shoot (KS); Pickup Rifle and Shoot (PURS); Walk, Head Swivel, and Shoot (WHS); & Traverse Beam and Shoot (TBS)]

Discussion

The Key Implications of This Study

The main inference to be drawn from this second study of simulated dynamic shooting performance is that the participants in our mTBI group did not shoot significantly worse than the healthy participants in our control group. However, the evidence implies that the mTBI-affected participants may have had to work harder to achieve a level of dynamic shooting performance that was indistinguishable from the healthy participants. Since potential site-of-recruitment confounds-to-interpretation exist, future research is recommended to determine whether differences in shooting performance can be detected when participants are all recruited from one site.

Overall Findings from This Line of Research

Summarizing the cumulative findings from our initial study of normal performance on the various dynamic shooting tests (Grandizio et al., 2014) and the present study of dynamic shooting by mTBI-affected participants, we infer the following:

a) One of the dynamic simulated shooting tasks (TS) would require modification and further evaluation before it could be suitable for inclusion in an assessment battery of dizziness and/or mTBI.

b) Spinning healthy participants to simulate mTBI-related dizziness/vertigo affected dynamic shooting. This finding confirmed that dynamic shooting performance was sensitive to the presence of dizziness/vertigo and, therefore, is worth exploring as a potential assessment technique for Soldiers suffering from dizziness and/or vertigo.

c) The mTBI participant group was confirmed to be more dizzy (on average) than the healthy participant group, which supports the assertion that it is worthwhile to determine if they also have a more difficult time with dynamic shooting tasks where strenuous balance demands are present.

d) Participants with mTBI reported a higher perceived workload during the dynamic simulated shooting tasks, inferentially supporting the assertion that they are working harder cognitively and/or physically than healthy Soldiers.

e) Dynamic shooting performance was too variable for us to be able to detect a group difference between healthy and injured participants in this effort.

Conclusions, Limitations, and Recommendations

This study found that participants who had experienced a past mTBI reported a greater daily handicap due to dizziness (versus non-injured participants), had more observable idiosyncrasies of coordination during dynamic shooting, and reported a higher workload during dynamic shooting. The study failed to detect poorer dynamic shooting performance among mTBI participants. This could be because mTBI participants were working harder to achieve the same level of shooting performance as healthy participants, or it could be because our mTBI participants came mostly from the infantry community at Fort Benning, whereas our uninjured participants were mostly from the aviation community at Fort Rucker. Further research is recommended comparing healthy and mTBI participants from the same site or from military posts which heavily overlap in terms of the military occupational specialties of their personnel. During the reported study, we gathered a small sample of data from 10 healthy Soldiers at Fort Benning, and the data suggested that site of recruitment may matter, i.e., the descriptive data trend implied that healthy Soldiers at Fort Benning tended to shoot better on average than the healthy Soldiers at Fort Rucker[16]. Therefore, research is recommended using only participants from a single installation and serving in more comparable occupational specialties. If the recommended single-site experiment also fails to detect dynamic shooting differences between healthy and mTBI participants from similar occupations, this will bode poorly for the application of these dynamic shooting tests to the detection of mTBI.[17] On the other hand, it should be recognized that continued negative findings would tend to bode well for the ability of mTBI-affected Soldiers to continue to defend themselves and their unit with a rifle. In other words, continued failure to find an mTBI versus healthy shooting performance difference in future research would be bad news for the development of a clinical shooting test of mTBI, but potentially good news for injured military personnel.

This general line of research could have future implications beyond the assessment of injured Service members. Our clinical-military hybrid tests were not designed to simulate realistic military shooting tasks; nevertheless, they may prove useful as augmentations of weapons training and qualification tasks, by making them more dynamic. The current shooting tasks are often relatively static, requiring participants to fire from one of three shooting positions at a time without rapidly changing positions or targets. It has long been recognized that much of small arms combat does not occur at long ranges and is not static in nature (e.g, shorter-range urban, hedgerow, or jungle fighting). Therefore, it could be argued that dynamic shooting tasks involving balancing, walking, and moving while shooting may constitute a useful future addition to marksmanship training or testing.

One limitation of studies of this kind is the fact that, while the Army finds the EST to be useful for marksmanship training, it was not designed to serve research. Much time was spent making sure the hardware and software were working correctly for a purpose outside the original design goals of the device. We were sometimes constrained by the training design of the scenarios when modifying the stimuli for research. It was also difficult at times to be sure that automated data collection was happening properly. Finally, the EST is relatively expensive to purchase[18] and maintain and requires considerable space to house. Future development is recommended to devise and evaluate dynamic shooting tests that are more robust, portable, easy to learn, and capable of sensitively quantifying balance-related body sway during testing in a variety of settings. Balance and coordination during goal-directed activities could be disrupted by reactions to (and aftereffects of adaptation to) a wide variety of sensorimotor challenges of

[16] The small sample size made a more formal statistical assessment of any site differences in the control group unreliable.
[17] Although the tests might still prove useful for other applications.
[18] Albeit, for the Army, the EST represents a "sunk cost," since it is available at many installations.

relevance to military and aerospace operations, including: prolonged exposure to microgravity; rhythmic alterations in G-force (e.g., parabolic flight, terrain-following flight, turbulent flight, or travel by sea); real and apparent motion; altered visual-vestibular integration (e.g., during simulator or virtual environment training); angular acceleration stimuli such as occur in centrifuge trainers or spinning space capsules (examples include incidents or concerns associated with Gemini and Orion space operations); and vectored-thrust aircraft or dynamically-manoeuvring rotorcraft (Lawson & Riecke, 2014; Lawson, 2014). It may prove useful to develop portable dynamic shooting tests that are relatively inexpensive and are integrated with (similarly portable) systems designed to quantify postural sway (Lawson et al., 2012; Lawson et al., 2013). Further research could then be carried out to determine the utility of such systems in the aforementioned, operationally-relevant settings or to develop comprehensive databases concerning performance in a given setting via research at multiple sites. Specific to the question of MTBI-related balance, we recommend that future studies seek, when feasible, to quantify body sway, dynamic shooting performance, and workload using MTBI and non-MTBI participants from the same site.

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Appendix. Alternate Analyses Excluding Participants Who "Did Not Qualify" During the Initial Static Army Marksmanship Qualification Task.

As explained on page 13, an alternate analysis was carried out which excluded participants whose qualification scores during the initial static, simulated Army marksmanship qualification test resulted in a score that "did not qualify" them. This analysis yielded results that were mostly consistent with the main analysis described in the body of this report (which included "did not qualify" participants). Consistencies and discrepancies versus the main results are discussed in this section.

A case breakdown of the analyzable participants ($N = 58$) is provided in table 3, showing the mean baseline for standard marksmanship qualification scores of the injured (mTBI) and uninjured (healthy) groups. (Number of participants at each site is shown also.)

Table A1. Cases by injury condition and data collection site excluding DNQ.

Injury condition	No. of participants from Fort Rucker, AL	No. of participants from Fort Benning, GA	Mean qualification score ± SD
Injured (mTBI)	0	27	29.70 ± 4.11
Uninjured (no mTBI)	25	6	32.13 ± 3.84

Analysis of Dizziness Between Injury Conditions

As described in the body of the report, three measures of dizziness were taken including scores on the DHI, self-reported dizziness in the past week, and observed dizziness scores. Each measure was separately analyzed with respect to condition and collectively suggested that the uninjured participants experienced and exhibited a lower degree of dizziness than injured participants. Specifically, a one-way analysis of variance (ANOVA) demonstrated that DHI scores were significantly higher in the injured group than in the uninjured group ($F(1, 56) = 87.69$, $p < .001$; $M_{healthy} = 0.00$, $SD_{healthy} = 0.00$; $M_{mTBI} = 25.96$ $SD_{mTBI} = 2.93$). The findings confirmed that the injured group was experiencing significantly greater dizziness-related handicaps during their daily activity, according to an established clinical instrument (viz., the DHI). Twenty participants reported feeling dizzy in the week prior to the experiment, while 36 participants did not report any dizziness (two participants chose not to answer the question). All 20 positive responses were collected from the injured (mTBI) participant sample. A z-test for the difference between two proportions was conducted on the prevalence of *yes* responses between injured and uninjured participants. The *z*-test statistic comparing proportion of positive responses between the injured and uninjured group demonstrated that there was a significantly lower proportion of positive responses in the uninjured ($z = -5.78$, $p < .001$). Finally, differences between injured and uninjured participants were analyzed using an independent samples *t*-test. There was a significant main effect of injury on observed dizziness ratings ($t(56) = -5.87$, $p < .001$; $M_{healthy} = 0.05$, $SD_{healthy} = 0.27$; $M_{mTBI} = 0.94$ $SD_{mTBI} = 0.80$), confirming that the participants with mTBI had more vestibular/balance impairment events than the uninjured controls. These findings are consistent with those from the analyses with all participants.

Analysis of Shooting Performance Between Injury Conditions

As described above, a one-way multivariate analysis of covariance (MANCOVA) was conducted to determine injury-specific differences between throughput measures recorded for each task in the modified battery [Kneel and shoot (KS); Pick up rifle and shoot (PURS); Walk, head swivel, and shoot (WHS); and Traverse beam and shoot (TBS)]. Throughput measures for the three existing standard qualification battery positions [prone-supported, prone-unsupported, and kneeling] were also included for comparison to modified task performance. After correcting for variance accounted for by qualification scores and site differences, the overall main effect for injury on task performance was not significant [$F(7, 45) = 1.05$, $p = 0.411$], indicating that there was no consistent pattern detected concerning whether injured or uninjured participants were the better performers for any given shooting task.

Results of the correlational analyses between performance on the dynamic shooting tasks and the three measures of dizziness (DHI score, observed dizziness score, and binary response to having felt dizzy the week prior) are consistent with those from the analyses with all participants. In fact, the results show a slight increase in the strength of the correlational relationships. Performance (throughput) on the "Pick up rifle and shoot" task was inversely related to: 1) observed dizziness scores, $r(55) = -0.442$, $p = 0.001$, and 2) DHI scores, $r(55) = -0.389$, $p = 0.003$, both suggesting that as dizziness increased, performance decreased.

As described in the body of the paper, an analysis comparing *dizzy* and *not dizzy* participants was conducted. However, this particular analysis was not possible to run on the subset of data including only participants who qualified on standard marksmanship between it reduced the sample size for the *dizzy* group to 3. Thus, no reliable results are presented here corresponding to that in the body of the text.

Analysis of Subjective Workload Between Injury Conditions

Findings from analyses of perceived exertion and workload scores, analyzed using a 2 by 4 by 6 mixed model factorial MANOVA, were consistent with the findings from all participants. There was a significant overall between-subjects effect on subjective workload by condition demonstrating that, in general, injured participants reported significantly higher subjective workload scores than uninjured participants [$F(6, 50) = 3.21$, $p = 0.01$]. Findings specific to task and workload were nearly identical to those reported above and are thus not repeated here.

Conclusions from the Alternate Analysis

Alternate analyses of the subset of participants who qualified during their initial, static range test yielded similar results as the main analyses reported in the body of the paper. The mTBI participants in the alternate analyses demonstrated more evidence of dizziness and higher ratings of perceived workload. In addition, the alternate analyses yielded some preliminary evidence of shooting performance decrements associated with dizziness. This finding should be evaluated further with a larger sample wherein greater variation in the dizziness ratings data exists.

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