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Feasibility of TBI Assessment Measures in a Field Environment: A Pilot Study for the Environmental Sensors in Training (ESiT) Project

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14. ABSTRACT <p>The present study compared a variety of TBI assessment methods to determine their feasibility for use in a military training field environment. Participants (N = 47) were assigned to one of two conditions. Condition 1 included neurocognitive performance tests (Continuous Performance, Symbol Digit Coding, Stroop and Four-Part Continuous Performance) and oculomotor tests (Pupillary Light Reflex and King-Devick). Condition 2 included the Integrated Display Enhanced Testing for Cognitive Impairment and mTBI (iDETECT), which includes neuropsychological performance, balance/sensory integration, and vestibular/oculomotor integrity tests within a multimodal system. Both conditions included the Military Acute Concussion Evaluation (MACE) and an Ease-of-Use survey. Mean scores for the Ease-of-Use survey and mean test administration times for each measure were compared. Administrative feedback was also considered for qualitative analysis. Results suggest that of the measures tested, the iDETECT is deemed most appropriate for use in the field environment. Therefore, the iDETECT will be used in a follow-up, correlational study.</p>						
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Introduction

Traumatic brain injury (TBI) has been labeled the “signature injury” of Operation Iraqi Freedom and Operation Enduring Freedom (OIF and OEF) for soldiers. Defined as damage to the brain caused by a sudden outside force, it is estimated that over 20% of Service members deployed to Iraq or Afghanistan have sustained at least one TBI (Terrio et al., 2009). Traumatic brain injuries range in severity, with mild TBIs (mTBIs) characterized by less than 1 hour (hr) of loss of consciousness, less than 24 hr of a confused or disoriented state and of memory loss, and normal results from structural brain imaging scans (Computed Topography [CT] or Medical Resonance Imaging [MRI]) afterwards. More severe TBI symptoms may last from a few days to multiple years following the injurious event, and repeated TBIs may result in more life-altering and long-term consequences. The Defense and Veterans Brain Injury Center (DVBIC), in conjunction with the Armed Forces Health Surveillance Center (AFHSC), tracks TBI diagnoses for all U.S. Military personnel (deployed and nondeployed). Most recently, the DVBIC reports that 352,619 TBI diagnoses were made between 2000 and 2016- Q2 (Defense and Veterans Brain Injury Centers, 2016). Of the diagnosed TBI cases, 82% (290,214) were classified as mild in severity (also referred to as a concussion). Research suggests that incidences of concussion in a nondeployed (garrison) setting have occurred at a rate higher than would be expected (Helmick et al., 2015). In 2013, it was recognized that at least 80% of TBI diagnoses were made in a nondeployed (garrison) setting (Department of Defense, 2013). TBI diagnoses in the nondeployed setting may be the result of vehicle crashes (private or military owned), falls, sports and recreational activities, and military training (Defense and Veterans Brain Injury Centers, 2013; Helmick et al., 2015). Regardless of the setting, many TBIs go unreported and do not receive proper treatment for recovery. Due to the prevalence of TBIs and the difficulty of consistently diagnosing them, a high priority has been placed on developing an objective method for accurate and timely identification of a potentially injurious exposure and subsequent diagnostic evaluation. Early and accurate diagnosis of a TBI can provide clinicians with a better picture of the injuries requiring treatment and with information that will be useful for evaluating a return-to-duty status after recovery (Defense Centers of Excellence, 2010).

Currently, the process for assessing whether a Soldier has suffered a TBI begins following exposure to a potentially concussive event. The Soldier may be ordered by a medic or supervisor to be assessed within 12 hr of an event if there was a loss of consciousness (LOC), an obvious alteration of consciousness (e.g., memory loss, confusion, dizziness), or based on other specified criteria (e.g., the Soldier was within 15 meters [m] of the blast) (Headquarters, Department of the Army, 2013; Department of Defense, 2012). In addition to this process, a Soldier may self-refer based on symptoms and/or involvement in a possible TBI-inducing incident. After a Soldier reports for an assessment, a combat medic or a clinician administers the Military Acute Concussion Evaluation (MACE) or other comparable medical evaluation (Headquarters, Department of the Army, 2013; Department of Defense, 2012). The MACE is a screening tool used to evaluate for mTBI, or acute concussive symptoms, immediately or soon after suspected head trauma (Center of Excellence for Medical Multimedia, 2013; Defense and Veterans Brain Injury Center, 2016). It includes several screening questions (i.e., incident description, assessment for LOC, alterations in consciousness, injury to the head, and concussion history), scoring of a cognitive exam, and a neurological exam (Defense Centers of Excellence, 2010). This evaluation is heavily reliant on self-report for initiation and completion, and can be difficult to complete immediately following an event due to its length and involvement. Because

the MACE exam can be challenging to administer and interpret in an operational or training environment, a clinician or combat medic often must determine if a Soldier has suffered an mTBI either at the time of the event (rapid evaluation) or at some point following medical evacuation when situational factors will not interfere (full evaluation). Both scenarios are not ideal for diagnosing a TBI and may result in undiagnosed or misdiagnosed mTBIs due to accidental omission of symptoms or a change in symptoms before diagnosis. Without an accurate assessment of mTBI, Soldiers may go untreated and be allowed to return to duty (RTD) while still affected by and vulnerable to damaging secondary effects. Thus, it is critical to be able to assess for an mTBI as quickly and accurately as possible after a suspected injury in order to monitor symptom progression.

The consequences of late or no identification of a head injury can have a severe impact on the individual. Prematurely returning to physically or mentally demanding tasks—be it on the battlefield or the playing field—after head injury increases the risk and likelihood for physical injury and/or for more catastrophic brain injury if a second injury were to occur while still symptomatic from the first (Barr, 2006; Saunders & Harbaugh, 1984). In a study on Australian football players, those who had suffered from a concussion showed significantly slowed attentional performance, fine dexterity, response, and movement times 48 hr post-concussion compared to non-concussed individuals (Pearce et al., 2015). Attentional performance continued to be notably slower at 96 hr and 10 days after the event, as well. Other research has also found cognitive changes to last up to 10 days (Barth et al., 1983; Collins et al., 1999). Over time, exposure to multiple blows to the head can reduce the threshold for future brain injury, which highlights the need for accurate identification when an event occurs (Kutcher & Giza, 2014). In one study, athletes with a history of TBI were found to be three times more likely to have a concussion than those without a history (Guskiewicz et al., 2003). Research on high school athletes has found a correlation between brain wave alterations and depression, anxiety, and aggression in those with a history of concussion (9+ months prior) compared to those with no history, suggesting that mood changes are a possible long-term consequence of TBI as well (Moore, Sauve, & Ellemberg, 2015). Thus, the possible negative outcomes and complications of returning to high levels of activity prematurely include sustaining another concussion, experiencing severe or prolonged symptoms, permanent neurologic deficits, or injurious effects from second impact syndrome (Cantu & Voy, 1995; Kelly et al., 1991; Saunders & Harbaugh, 1984; Echemendia & Cantu, 2003; Malhotra, 2014).

Multiple sports guidelines exist for determining both the severity of a TBI and when it is safe for an athlete to return to play (e.g., Barr, 2006). The occurrence of LOC is regarded by many as an automatic disqualifier from immediate return to play, yet LOC is only reported with approximately 10% of sports-related head traumas across a range of experience levels (Field, Collins, Lovell, & Maroon, 2003; Guskiewicz et al., 2003; Pellman et al., 2004). Pearce and colleagues (2015) determined that recovery rates vary across individuals and functional areas impacted, suggesting that a multi-modal method of measuring TBIs and subsequent recovery is most appropriate given the multiple areas of functioning that can be impacted across individuals. General consensus exists in the sports world that a player who is objectively displaying symptoms of a head injury should not be allowed to play until asymptomatic.

In the military context, research has tended to focus on “return-to-duty” measurements of when it is safe for an injured Service member to go back into the field (Radomski et al., 2013);

however, there is a lack of research aimed at improving the detection and assessment of a head injury in a timely and accurate manner. Because of the limitations to administering and interpreting the MACE, it is critical to explore other methods of identifying brain trauma as soon after the incident as possible. Promising tests of timely and accurate detection of head injury include the neuropsychological measures Continuous Performance, Symbol Digit Coding, Stroop, and Four-Part Continuous Performance, as well as oculomotor measures such as the King-Devick (KD) and Pupillary Light Reflex (PLR). All of these measures are practical, relatively short, and simple to administer in addition to having demonstrated validity in detecting symptoms of TBI. See Table 1.

Table 1. Methods of TBI Detection

Domain	Test	Construct/ Measurement	Support	Reference(s)
Neuropsychological	Continuous Performance Test	Vigilance and sustained attention	Sensitive to poor performance (ADHD, learning disabilities, epilepsy, schizophrenia); sensitive to drug effects (stimulant medications, alcohol, nicotine); Medium to large test-retest reliability	CNS-Vital Signs, 2016; Rosvold & Delgado, 1956; Gualtieri & Johnson, 2006; Epstein, Johnson, Varia, & Connors, 2001; Lindsay, Tomazic, Levine, & Accardo, 2001; Mirksy & van Buren, 1965; Vadhan, Serper, Harvey, Chou, & Cancro, 2001; Barkley, 1977; Dougherty, Marsh, Moeller, Chokshi, & Rosen, 2000; Levin, Connors, Silva, Canu, & March, 2001
Neuropsychological	Symbol Digit Coding Task	Information processing speed, visual-perceptual speed, and complex attention	Provides useful information on changes in attention and persistence; sensitive to acute and chronic cerebral dysfunction	CNS-Vital Signs, 2016; Gualtieri & Johnson, 2006
Neuropsychological	The Stroop Test	Simple and complex reaction time, executive function, information processing speed, and cognitive flexibility	Strong convergent validity with the Neurobehavioral Evaluation System (NES2)	CNS-Vital Signs, 2016; Gualtieri & Johnson, 2006
Neuropsychological	4-Part Continuous Performance Test	Executive functioning and working memory	Distinguishes between baseline changes in cognitive performance; demonstrate validity in discriminating TBI from other conditions	McAllister, Flashman, McDonald, & Saykin, 2006; Gevins & Smith, 2003
Oculomotor	King-Devick (KD)	Saccadic eye movement	Successful as a rapid sideline screening tool for sport-related concussion. Sensitive to mTBI/concussion as well as neurological status; Sensitive to Parkinsonism, multiple sclerosis, and sleep deprivation; Resilient to false positives; Can be administered by nonmedically trained personnel	King & Devick, 1976; Galetta et al., 2011; Balcer & Galetta, 2013; Galetta et al., 2013; Munce et al., 2014; Leong, Balcer, Galetta, Liu, & Master, 2014; Dziemianowicz et al., 2012; Rosenberg et al., 2013; Lin et al., 2014; Davies, Henderson, Balcer, & Galetta, 2012
Oculomotor	Pupillary Light Reflex (PLR)	Neurological function; responsiveness of pupil to light stimulus	Evidence that mTBI delays temporal aspects of PLR. Distinguishes between samples with mTBI history and those without.	Chesnut, Gautille, Blunt, Klauber, & Marshall, 1994; Hults, Knowlton, Oliver, Wolfson, & Gamst, 2006; Manley & Larson, 2002; Lieberman et al., 2003; Wilhelm, 2011; Capo-Aponte, Urosevich, Walsh, & Tarbet, 2013

Although the aforementioned measures show efficacy in assessing the neurological function impacted by a head injury each in themselves, multiple types of measures used together within an assessment battery can yield more accurate and reliable results. Resch et al. (2016) compared the sensitivity and specificity of three individual evaluations as well as a combination of all three to this end: a computerized neurocognitive test, a vestibular/balance test, and a symptoms scale. The findings showed that subjects were correctly classified as injured/concussed 80 to 100% of the time when all three evaluations were used whereas individual assessments misclassified subjects up to 47.5% of the time when used in isolation. Therefore, when considering methods of detecting head injury in the field, a multimodal assessment capable of measuring different types of performance deficits for the detection of mTBI may be preferred.

One such multimodal assessment system is the Integrated Display Enhanced Testing for Cognitive Impairment and mTBI (iDETECT). The assessment software of the iDETECT utilizes a systems approach to identifying mTBI. The tools within the iDETECT system cover three broad modalities of injury: neuropsychological performance, balance/sensory integration, and vestibular/oculomotor integrity. Clinical tests for each of these modalities were modified to truncate and adapt the test for incorporation into a computer-based assessment tool. The iDETECT has been utilized in the assessment of mild cognitive impairment (MCI) related to dementia. In an elderly (>65 years old) cohort of 405 subjects not previously known to have cognitive impairment, the iDETECT was able to discriminate between normal and demented subjects with a 99% sensitivity (85% specificity). Additionally, use of the iDETECT was shown to classify normal versus any MCI impairment with 85% sensitivity (85% specificity) when compared to a gold standard battery of neuropsychological tests within the same cohort (Wright, et al., 2011). In a study evaluating the iDETECT with a population of high school and collegiate football players, the iDETECT was 93% sensitive and 67% specific for cognitive impairment when compared to clinical diagnosis of concussion using current reference standards (e.g., symptoms checklists, clinical assessment, and computer-based neuropsychological [NP] tests) (Gualtieri & Johnson, 2006). Further, the majority of users who gave feedback found the visual display comfortable to wear (76%), felt the display blocked out all visual distractions (91%), found the earphones comfortable to wear (89%) and blocked out all outside noise (80%), felt they could concentrate while taking the test (87%), and thought the iDETECT tool was as “user friendly” as other computer-based neurocognitive assessment tools (89%). Importantly, 70% of respondents stated they would prefer to use the iDETECT device over other cognitive assessment tools. Thus, early qualitative and quantitative data suggests iDETECT may offer a substantive advancement in field triage and objective assessment of neurologic impairment during the acute and subacute periods after a suspected mTBI.

The aforementioned measures have support to suggest their effectiveness in detecting possible mTBI. Some are even designed specifically for use on the sidelines of sporting events. However, to our knowledge, none of the measures have been evaluated to determine if they are appropriate for field use in a military training setting. The present study explored the feasibility of using the aforementioned assessment methods in the military field-training environment. Specifically, we considered the feasibility of four cognitive performance tests (Continuous Performance, Symbol Digit Coding, Stroop, and Four-Part Continuous Performance), two oculomotor tests (King-Devick and Pupillary Light Response), and a multi-modal test (the iDETECT). The tests included in our study are by no means an exhaustive selection of measures

suitable for mTBI detection. Rather, during the development of this study, these tests met initial criteria for feasibility and were supported by the literature. Further, these tests were selected for inclusion in the present study based on input provided by Army leaders and subject matter experts. Since these measures have not been evaluated in a military field-training setting, it is imperative that they should not only be tested to see if they are capable of detecting deleterious effects of a head injury, but they should also be deemed possible to properly administer in a field environment where resources are limited. Further, as our target setting for this study is the military training environment, it is essential that the administration of the measures do not interfere with military training. This requires the measures to be relatively short in length (goal of 15-20 min total), administered and interpreted by personnel with minimal training, and easily administered on the training site. Therefore, to determine feasibility, we considered the amount of time required to administer the assessment, responses to participant's self-reported, user-friendliness ratings, test administrator feedback, and observations made by the lead investigators about the measures' appropriateness in the environment. The findings from the feasibility evaluation will also determine the measures that will be used in a larger, follow-up study aimed at correlating the selected measures with environmental sensor data collected in a military field training-environment.

Methods

Participants

Fifty-seven Soldiers undergoing training at the U.S. Army Basic Airborne Course (N = 27) and the U.S. Army Combatives Course (N = 30) at Fort Benning, GA, volunteered as participants. Eligibility criteria required that participants be Service members on active-duty orders, to include National Guard and Reserve, who are at least 17 years old, currently completing either Airborne or Combatives training, and have conversational fluency in English. There were no exclusions based on gender, ethnicity, or health beyond the health requirements of the training course. Demographic information such as gender, age, ethnicity, and rank was not collected. Because of a technological advancement in one of the measures used in our study during the course of data collection, data from 10 early participants was not used in the final analysis. Therefore, our final analysis included data for 47 participants (17 Airborne and 30 Combatives).

Procedure

Potential volunteers were briefed on the study in groups during idle times (breaks or transition periods) of their training program. Individuals that were interested were escorted to the study area away from their leadership to meet with a research team member to ensure their participation was not due in any part to perceived pressure from leadership. Written informed consent was obtained from volunteers prior to beginning the study at which time research team members highlighted the voluntary and anonymous nature of the study and participant responses. No compensation was provided to participants for their involvement. The study protocol was reviewed and approved by the U.S. Army Medical Research and Materiel Command Office of Research Protections Institutional Review Board and conducted according to institutional ethical standards.

There were two conditions of testing for both of the training activity groups (Table2). Measures used in Condition 1 consisted of the MACE, the KD, four cognitive performance tests (Continuous Performance, Symbol Digit Coding, Stroop Test, and Four-Part Continuous Performance), the PLR, and the Ease-of-Use survey. Condition 2 included the MACE and the iDETECT. Data collection stations for the measures were set up to maximize the study team's ability to efficiently collect data from multiple participants at the same time. This was crucial in order to prevent disruptions in the participant's training activities due to the research. For Condition 1, there were 5 stations consisting of: (1) MACE, (2) KD, (3) cognitive performance tests, (4) PLR, and (5) the Ease-of-Use survey. Condition 2 had three data collection stations consisting of (1) MACE, (2) iDETECT, and (3) the Ease-of-Use Survey. The MACE and KD were administered at a table outside covered by a canopy if required by weather. The PLR and cognitive performance tests were administered inside of a climate controlled mobile data collection vehicle (see Figure 1) as these measures required control for lighting and/or a power source provided by the vehicle's generator. All measures were completed in the intended manner, according to their original instructions. However, no personally identifiable information was collected. Rather than recording performance data, the research team members recorded the amount of time it took to administer each of the measures completely and accurately for each participant.

Table 2. Conditions, Constructs, and Tests

	Construct measured	Tasks/Tests
Condition 1	Oculomotor Testing	Pupillary Light Reflex (PLR)
		King-Devick (KD)
	Neurocognitive Performance Testing	Continuous Performance, Symbol Digit Coding, Stroop, & Four-Part Continuous Performance
	Comprehensive Exam	MACE
	Survey	Ease-of-Use Survey
Condition 2	Neuropsychological performance, Vestibular/Oculomotor Integrity, and Balance/Sensory Integration	Integrated Displayed Enhanced Testing for Cognitive Impairment and mTBI (iDETECT) Systems
	Comprehensive Exam	MACE
	Survey	Ease-of-Use Survey



Figure 1. Interior of data collection vehicle.

Measures

Military Acute Concussion Evaluation (MACE).

The MACE is a comprehensive evaluation consists of three components, namely, symptom assessment, cognitive exam, and neurological screening. Symptom assessment is composed of a description of head injury and event conditions, history of concussion, and medical symptoms accompanying a head injury/blow to the head. The cognitive exam is a series of tests measuring memory, concentration, and orientation. Finally, the neurological screening consists of a clinical investigation of pupil response, eye tracking, speech fluency, and gait. In the present study, research team members used the MACE pocket card (Defense and Veterans Brain Injury Center, 2012). Participants were only given List A within the MACE cognitive exam to ensure consistency. See Figure 2.

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The figure displays eight pages of the MACE (Military Acute Concussion Evaluation) manual, organized into four columns and two rows. Each page contains specific sections of the evaluation protocol.

- Page 1 (leftmost):** MACE - Military Acute Concussion Evaluation. Includes patient information fields (Name, DOB, Unit, Date of Injury, Examiner, Date of Evaluation) and the CONCUSSION SCREENING section with questions about alteration of consciousness and loss of consciousness.
- Page 2 (second from left):** MACE - Military Acute Concussion Evaluation. Continues the CONCUSSION SCREENING section with questions about post-traumatic stress and a witness, followed by the CONCUSSION SCREENING RESULTS table.
- Page 3 (third from left):** MACE - Military Acute Concussion Evaluation. Contains the COGNITIVE EXAM section, including Orientation (score 1-5) and Immediate Memory (score 1-5) tests.
- Page 4 (rightmost):** MACE - Military Acute Concussion Evaluation. Contains the NEUROLOGICAL EXAM section, including Eyes (score 1-5), Speech (score 1-5), Motor (score 1-5), and Balance (score 1-5) tests.
- Page 5 (leftmost):** MACE - Military Acute Concussion Evaluation. Contains the COGNITIVE EXAM - Continued section, including Concentration (score 1-5) and Delayed Recall (score 1-5) tests.
- Page 6 (second from left):** MACE - Military Acute Concussion Evaluation. Continues the COGNITIVE EXAM - Continued section with Concentration Alternate Word Lists and Delayed Recall Alternate Word Lists.
- Page 7 (third from left):** MACE - Military Acute Concussion Evaluation. Contains the SYMPTOM SCREENING section, including a list of symptoms and a summary table for Cognitive, Neurological, and Symptom results.
- Page 8 (rightmost):** MACE - Military Acute Concussion Evaluation. Contains the ADDITIONAL INFORMATION ABOUT MACE COGNITIVE SCORES section, including a table for Coding Tips for Concussion and a table for References.

Figure 2. MACE pocket card.

King Devick (KD).

The KD requires eye-movement coordination, attention, information processing, and language abilities. Test-takers are asked to rapidly read aloud numbers written on three different test cards without error after a brief practice session on a demonstration card (Oride, Marutani, Rouse, & Deland, 1986). Scores are calculated from the cumulative time it takes for a participant to read from left to right 120 single-digit numbers printed on three test cards. The number of errors made (that are not immediately corrected) is also counted. The standardized instructions provided with the published versions of the KD were used. When using the measure to assess for concussion, post-incident scores are compared to premorbid, individual baseline scores; for the purposes of our current research, the test only needed to be administered once. See Figure 3.

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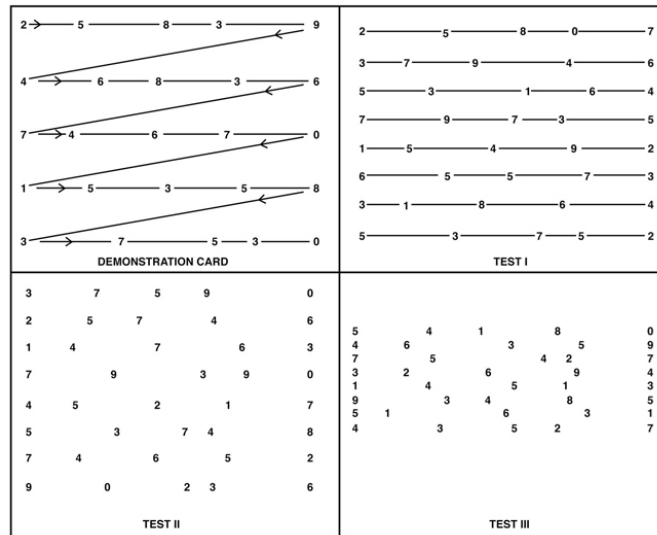


Figure 3. King Devick (KD).

Pupillary Light Reflex (PLR).

The PLR is a measure of the size of the eye's pupil over time in response to a brief flash of light. The PLR is measured with a Neuroptics PLR-200 monocular pupillometer that records a 5-s, infrared video image of the pupil and uses image analysis software to calculate the pupil diameter to within fractions of a millimeter at a frame rate of 30 Hertz (Hz). The Neuroptics PLR-200 monocular pupillometer includes a light flash stimulus to drive the pupillary reflex; the intensity and duration of the flash stimulus are adjustable to calibrated values. The light flash stimulus driving the pupillary reflex is in the visible spectrum whereas the infrared light used for recording the pupil diameter is invisible to the eye (extraspectral) and does not have any effect on the pupil diameter. See Figure 4.



Figure 4. Pupillary Light Reflex (PLR).

Neurocognitive performance tests.

The neurocognitive performance tests used in this study are Continuous Performance, Symbol Digit Coding, Stroop, and Four-Part Continuous Performance. To minimize the time required for data collection, participants were semi-randomly selected to complete one of the four tests. All of the tests were administered via computer using the commonly used neurocognitive test battery software, CNS-Vital Signs (CNSVS) (CNS-Vital Signs, 2016; Gualtieri & Johnson, 2006). See Figure 5.

Continuous Performance.

The Continuous Performance Test is a computerized task measuring choice response time, sustained attention and performance accuracy. The test presents 200 letters randomly for approximately 5 minutes (min) and asks participants to press a computer space bar in response to a specified target letter presented at random (the letter “B” in this version). Reaction times and the number of correct and incorrect responses are recorded (CNS-Vital Signs, 2016).

Symbol Digit Coding.

The Symbol Digit Coding Test is modeled after the Symbol Digit Modalities Test and the Wechsler Digit Symbol Substitution Test (Gualtieri & Johnson, 2006). In this test, participants are presented with eight symbols above eight empty boxes. The participants are required to type in numbers on a computer keyboard that correspond with a symbol key presented on the screen. Subjects must correctly key in as many corresponding numbers as they can in a period of 4 min. The number of correct responses and incorrect responses are summed into two overall scores (CNS-Vital Signs, 2016).

Stroop Test.

The Stroop test includes three parts that assess for simple and complex reaction time (Gualtieri & Johnson, 2006). Participants are asked to identify colors when they are paired with both congruent and incongruent color words for approximately 150 s. In the first part of the test, participants press the space bar when presented with a word on the screen that represents the name of a color. In the second part of the test, participants press the space bar only when presented with the name of a color that is written in the color that matches the word (e.g., the word “red” written in a red font). Finally, in the third part of the test, participants are asked to press the space bar only when presented with the name of a color that is written in a color that does not match the word (e.g., the word “red” written in a green font) (CNS-Vital Signs, 2016).

Four-Part Continuous Performance.

The Four-Part Continuous Performance Test measures working memory and sustained attention. The test builds on the structure of the standard Continuous Performance Test (see above) by including an N-back component. The four-part continuous performance test uses a random series of various shapes in various colors throughout. In the first part of the test, participants press the space bar when presented with any shape. The second part requires that participants press the space bar when a specific shape of a specific color is presented. In the third part of the test, participants must press the space bar only when a shape matches the shape

presented immediately before it. Finally, the fourth part of the test asks participants to press the space bar only when a shape matches the shape presented two times back. The test takes approximately 7 min to complete (CNS-Vital Signs, 2016).

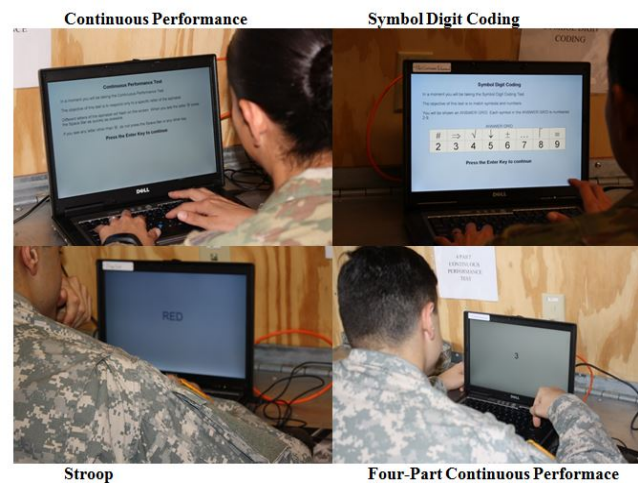


Figure 5. Neurocognitive Performance Tests.

Integrated Display Enhanced Testing for Cognitive Impairment and mTBI (iDETECT).

The iDETECT system is a rapid, autonomous system for identification of neurological impairment in a field setting or any setting where traditional NP testing is impractical for use. The system hardware is comprised of a self-contained touch-screen tablet computer that provides administrative capabilities to the tester, a virtual reality goggle visor with motion detection (see Figure 6), noise-reduction headphones, and a hand-held input device for subjects to enter input via two buttons. The system design allows for an immersive testing experience that reduces distractions, reduces test administration time, and provides objective scoring for mTBI regardless of the surrounding environment (Barker et al., 2007). A key feature of the iDETECT system is that it incorporates a number of assessment tools into a single system in order to take advantage of each tool as well as more comprehensively screen for mTBI given the complex nature of injury presentation.

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Figure 6. Integrated Display Enhanced Testing for Cognitive Impairment and mTBI (iDETECT).

The iDETECT software is designed to automatically score each test measure producing values for reaction time, number of correct responses, number of errors, and the number of missed responses. For the present study, the platform consisted of four test modules (see Figure 7): NP performance, reaction time, balance/sensory integration, and vestibular/oculomotor integrity.

The NP performance module is comprised of a series of tests that evaluate information processing speed, reaction time, episodic memory, and working memory of the test subject. A description of each test is presented below.

- 1) **Selective Reminding Memory Test:** This module tests the immediate and delayed recognition memory. Participants are given brief instructions then shown 12 target words individually for 3 s each to memorize. The module then presents 24 words to the participants (12 target words and 12 distractor words), requiring the participant to indicate when a target word is presented. This immediate recognition memory test is conducted first and then followed by the Simple and Complex Attention Test to induce a period of delay. Upon completion of the attention tests, participants are once again shown 24 words (the original 12 target words and 12 new distractor words) and must indicate if each word is one of the target words.
- 2) **Simple and Complex Attention Test:** The attention tests determine the information processing ability of the participant. Each participant engages in two versions: a simple and complex test. In both tests, an object with one to three characteristics consisting of shape, color, and internal line orientation is presented to the participant. Participants must respond within 2 s if the object matches the specified criteria for the test. For the complex attention tests, the procedure is the same as above except objects will contain all three characteristics and participants must identify objects that correctly match all three stated characteristics. The system records mean reaction time for each test.
- 3) **Conditional Choice Reaction Test:** In this module, the participant is asked to react to a series of 10 arrows pointing either left or right. Instructions tell the participant

if the arrow is blue, then click the button that indicates the direction the arrow is pointing. If the arrow is red, then click the button that indicates the opposite direction the arrow is pointing. The arrows are displayed for 2 s. The test measures a participant's reaction time.

- 4) N-back Test: This module tests working memory through continuous presentation of visual stimuli. The test consists of two conditions (1-back and 2-back) that employ black and white photographs of faces as the stimuli. In the 1-back, the participant is shown a series of faces and must indicate if the face being shown is identical to the previous face. The format for the 2-back condition is the same, except that the participant must indicate if the face displayed is identical to the face shown two images prior. In this condition, participant responses begin when the third face image is shown.

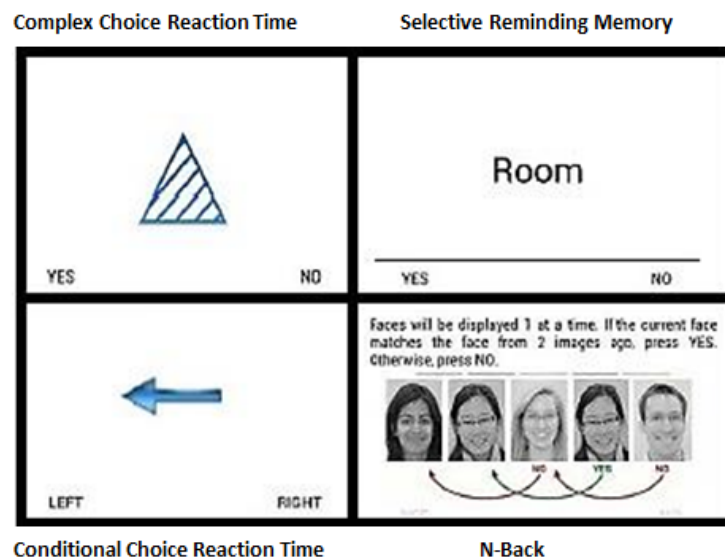


Figure 7. Tests within Neuropsychological Performance Module.

The second module in the iDETECT is the Reaction Time Test. Due to advancements and additions to the iDETECT platform, the Reaction Time Test is featured separately from the other neuropsychological performance tests. This simple test measures the reaction time of the participant. A timer appears in the field of view set to 0.0 s with instructions to wait for the timer to begin counting upwards. The timer is randomly set for a delay of up to 6 s before starting for each trial. After the timer begins, the participant clicks a button on the handheld device to stop the timer and record the reaction time.

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Figure 8. Reaction time test.

The balance/sensory integration module evaluates the balance of the participant using a Non-Postural Balance Test. This test measures the ability to process and integrate vestibular and sensory information in order to maintain balance that can be disrupted following a head injury (Guskiewicz et al., 2003). To begin the Non-Postural Balance Test, participants calibrate the system by sitting in a comfortable straight up position to establish the baseline for the horizontal axis. The test module consists of a horizontal platform balanced on the apex of a semicircular base depicted as a seesaw on a playground. A green cube that sits above the apex creates a target zone in the middle of the platform. For each trial, a ball is placed on the platform that is in a tilted position. A red line appears to indicate to the participant which side to tilt their head to begin moving the platform in order to roll the ball into the target area. Participants continue to move their head from side to side in an order to place the ball inside the target zone. Once the ball is inside the target zone, the color of the target bars and ball change to green to indicate the ball is successfully in the target zone. Once inside, a 3 s countdown appears on the ball and participants must keep the ball in the target zone during that time in order to register the trial as a successful attempt. See Figure 9.



Figure 9. Non-Postural Balance test.

The vestibular/oculomotor integrity module assesses the ability of the visual and

vestibular system to maintain gaze stability for coordination of eye and motor movements in response to moving stimuli (Peterson, 2010). The oculomotor function of the participant is tested with two similar modules that utilize target tracking. In the simple Target Tracking Test, a black arc appears in the visual field on the iDETECT screen with a blue ball centered on the line of the arc near the bottom of the visual field. At a different location on the circle is a dashed red outline of a ball to indicate a target zone. A single trial consists of the ball moving around the arc at a constant speed during which the participant must track the ball along the course of the arc and indicate through the handheld device when the ball enters the target zone. The module lasts approximately 4 min and includes several trials with the ball moving at varying speeds. See Figure 10.

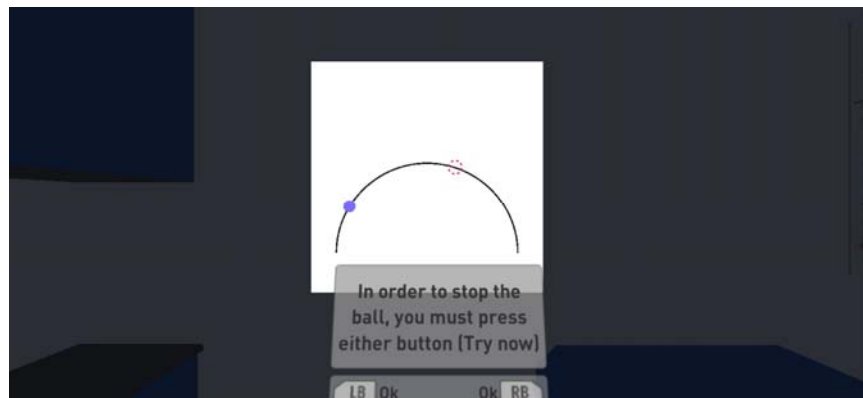


Figure 10. Target Tracking test.

Ease-of-Use survey.

The paper-and-pencil survey was developed by the U.S. Army Aeromedical Research Laboratory (USAARL) research team and consisted of a 10-point Likert-type scale ranging from “Very Poorly” (=1) to “Very Well” (=10). The questions addressed the participants’ perceived performance on each test, their level of distraction, and how “smoothly” they felt each test performed. For the Condition 2 Ease-of-Use survey, the questions were specific to each of the testing modules they completed on the iDETECT. Therefore, the Ease-of-Use survey asked questions pertaining to NP tests, reaction time, balance/sensory tests, and vestibular/oculomotor tests. Because the reaction time test was in a separate testing module from the other NP tests, it was necessary to consider participant’s responses to this specific test separately from the neuropsychological tests module. See Figure 11.

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Figure 11. Soldier completing Ease-of-Use survey.

Results

Due to training schedules and an intent to not interrupt Soldiers' training, we were unable to collect complete data from four participants. The missing data includes three of the participant Ease-of-Use surveys and completion times for the PLR, MACE, and iDETECT. However, the remainder of the data for these participants were still used in the analysis. In order to assess feasibility of the included assessments and instruments, descriptive statistics were calculated. Independent-samples *t*-tests were conducted using participant survey scores to compare reported perceptions of the instruments between Combatives and Airborne groups (see Table 3). To simplify interpretation, the scores for the neurocognitive tests were combined before calculating means and standard deviations. For all other measures, average time of completion for each was calculated. Research team members reported their observations of how well measures performed in the military training environment and the measures' ease of administration. Lead investigators also took note of basic observational data to include the environmental demands and the overall effectiveness of each measure in the military training field environment. This information was considered for subjective, qualitative analysis. Details of these results are below.

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Table 3. Summary of Participant Survey Results

	Performance		Distraction		Ease of administration	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Condition 1						
MACE	26	7.81 (1.89)	26	5.77 (2.94)	26	8.85 (1.49)
Cog. Tests	26	8.38 (1.44)	26	6.54 (2.64)	26	8.81 (1.88)
KD	26	8.92 (1.29)	25	6.24 (3.38)	26	8.85 (2.17)
PLR	26	8.69 (1.41)	26	5.19 (3.48)	26	9.35 (1.06)
Condition 2						
MACE	18	8.06 (1.77)	18	7.94 (2.21)	18	8.67 (1.41)
iDETECT – RT	18	7.33 (2.59)	NA	NA	18	8.33 (1.85)
iDETECT – NP	18	7.61 (1.88)	18	7.83 (2.20)	18	8.17 (1.79)
iDETECT – SI	18	7.78 (1.96)	18	7.78 (2.02)	18	8.50 (1.51)
iDETECT – VO	18	8.17 (1.58)	18	7.44 (2.01)	18	8.39 (1.72)

Participant Survey Scores

Participants in Condition 1 completed the MACE, KD, PLR, and one of four computerized neurocognitive tests. Each rated their perceived levels of performance, distraction, and ease of administration on a scale from 1 (very poor) to 10 (very well) across tests. Overall, participants' ratings in the Airborne group were similar to those in the Combatives group with the exception of distraction ratings (Independent-samples *t*-tests, $p < 0.05$). Airborne tended to rate their level of distraction as higher than the Combatives participants (see Figure 12).

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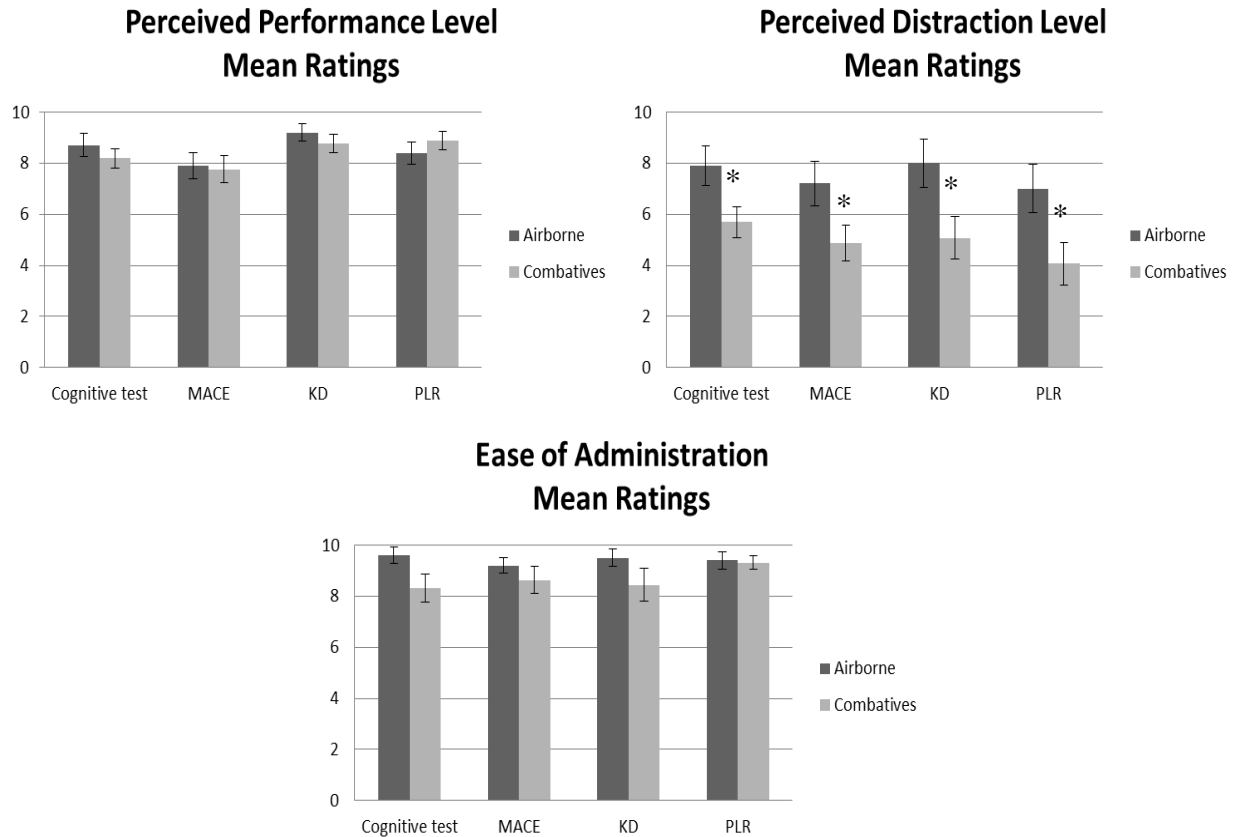


Figure 12. Mean ratings in Condition 1 by Group and Test/Instrument. * denotes significant difference at $p < 0.05$. Error bars represent standard error of the mean.

Participants in Condition 2 completed the MACE and four modules on the iDETECT system: neuropsychological (NP), balance/sensory integration (SI), vestibular/oculomotor (VO), and reaction time (RT) tests. Identical to Condition 1, participants also rated their perceived levels of performance, distraction, and ease of administration on a scale from 1 (very poor) to 10 (very well) for each test completed. Unlike in Condition 1, participants' ratings were comparable across the Airborne and Combatives groups ($p > 0.05$; see figure 13).

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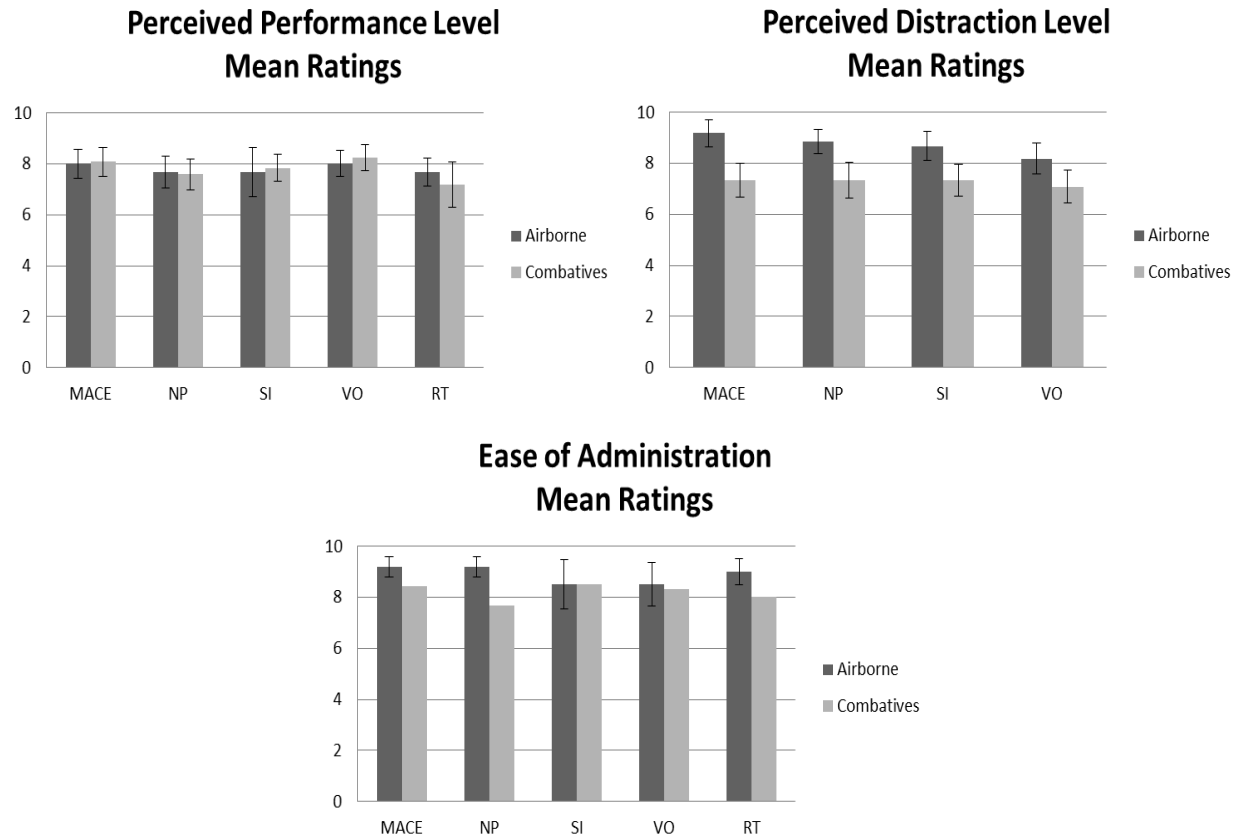


Figure 13. Mean ratings in Condition 2 by Group and Test/Instrument. Error bars represent standard error of the mean.

Test Administration Time

For Condition 1, participants completed one semi-randomly selected neurocognitive performance test, the MACE, KD, and PLR. For each of the neurocognitive performance tests, the average time for completion was 6 min for the Continuous Performance, 4 min for Symbol Digit Coding, 5 min for Stroop Test, and 9 min for Four-Part Continuous Performance. Collectively, a neurocognitive battery would take approximately 24 min to administer based on the summation of these separate scores. The MACE for this condition on average took 6 min for administration. For about 16 participants in condition 1, there was a recording error for KD. However, based on the complete data collected from the other participants in this condition it is estimated that administration time is approximately 3 min. The PLR took just over 1 min for administration. .

For Condition 2, participants completed the MACE and all tests on the iDETECT. Administration time was recorded for all tests collectively for the iDETECT. On average, participants completed the iDETECT in approximately 22 min and the MACE for this condition in approximately 5 min.

Research Team Feedback – Subjective Report

Feedback from the research personnel administering the tests in Condition 1 indicated that Airborne participants appeared distracted during the MACE and KD. Feedback also indicated that the MACE seemed time consuming and may be best for a one-on-one clinical environment. For Condition 1 Combatives participants, feedback indicated a fairly smooth process for test administration. In Condition 2, feedback for both groups indicated that the task instructions included in the iDETECT system were lacking clarity and could be improved. Feedback also indicated that the iDETECT system seemed easy for participants to navigate. See Table 4.

Investigator’s Observations – Subjective Report

Military Acute Concussion Evaluation (MACE).

The MACE pocket card is designed for field settings and can be used in most any environment. Because it is a comprehensive exam, it has the capability to assess for multiple symptoms. The main challenge with the MACE is that it requires extensive training for administration and interpretation. Typically, it is administered by medics and other medical personnel that have received specific training. However, the availability of trained medics or medical personnel at the training site can be limited.

King Devick (KD).

The KD was designed for use on the sidelines for sporting events, which make it a promising choice for successful use in the military training environment. It is very quick and easy to administer. The test administration and interpretation requires little expertise and training. This would allow most anyone to make a decision on the spot whether he or she requires further evaluation for head injury or if they can continue training. However, for the purpose of this study, the KD was not desirable on its own because it only assesses for one type of performance, oculomotor. It would do well if included within a battery of tests that can assess for multiple aspects of brain function.

Pupillary Light Reflex (PLR).

With regard to administration time, the PLR was most quickly completed. It is also easy to administer, however, while most anyone can administer the test, only trained individuals can interpret the results. Therefore, immediate, on-the-spot decision-making using this test is limited. Further, because the test measures for a pupil’s reflex to light, lighting in the environment must be controlled. For this study, we provided a research vehicle with the capability of controlling light. In the general field environmental for military training, resources used to control lighting are likely to be more limited, particularly for Airborne training where most of the activities occur outside.

Neurocognitive performance tests.

Because the software used for the neurocognitive performance tests is self-guided after initial set-up, these test were easy to administer and required little effort from the research team

members. The software also provides immediate interpretation of results. This will allow for most anyone to administer the test and make on-the-spot decisions. Individually, the tests are quick to complete. However, collectively as a battery, they may be considered lengthy given that they only assess for neurocognitive functioning. Because these tests are administered by laptop computer, environmental controls and resource availability are also issues (e.g., necessary power source, subject to weather conditions). These outside factors make the Neurocognitive Performance tests less than ideal for training events that occur outside.

Integrated Display Enhanced Testing for Cognitive Impairment and mTBI (iDETECT).

Like the neurocognitive performance tests, the iDETECT is also self-guided after initial set-up and therefore is easy to administer. The iDETECT is also easy to interpret as the software has the capability to provide immediate results. Like the KD, it was designed to be a sideline tool for sporting events, making it likely appropriate for most any environment. The virtual reality goggles and noise cancelling headphones allow for a true assessment with minimal distraction. The iDETECT includes multiple options for assessing for possible brain injury within one platform, which is highly desirable for preventing delays between measurement methods. For this study, we included NP performance (including reaction time), vestibular/oculomotor integrity, and balance/sensory integration tests to create a multimodal battery that could assess several types of dysfunction in approximately 20 min. The drawback of the iDETECT is that it is subject to changes in technology. The iDETECT platform changed while this study was being conducted, requiring us to extend our data collection period in order to gather enough data for the new platform. As virtual reality technology advances, it is likely that the iDETECT platform will change in the future. Although technological and psychometric advances are generally beneficial, improvements to the iDETECT that significantly change its structure could create discrepancies when comparing baseline data for participants that have completed assessments on older models.

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Table 4. Summary of Investigator's observations – Subjective report

Tasks/Tests	Average Duration	Observational Performance
Pupillary Light Reflex (PLR)	Just over 1 min	Pros: Very quick, easy to administer Cons: Interpretation may require extensive training, environmental controls (lighting), only provides one type of assessment (oculomotor)
King-Devick (KD)	Under 5 min (estimated)	Pros: Quick, easy to administer, easy to interpret, little adjustment to environment Cons: Only provides one type of assessment (oculomotor)
Continuous Performance, Symbol Digit Coding, Stroop, OR Four-Part Continuous Performance	CP: 6 min SDC: 4 min Stroop: 5 min 4PCP: 9 min	Pros: Easy to administer, easy to interpret, most individual tests are quick to administer (but not collectively) Cons: Environmental controls (requires laptops and power source), only provides one type of assessment (cognitive)
iDETECT	20 min	Pros: Easy to administer, easy to interpret, multimodal system, good for most any environment Cons: Changes in technology
MACE	6 min	Pros: Comprehensive exam, good for most any environment, does not require baseline Cons: Interpretation may require extensive training

Discussion and Conclusions

Traumatic brain injuries are a predominant and severe issue within the U.S. Military. Because successful treatment strongly relies on a quick and accurate diagnosis, the process through which diagnoses are made is critical in managing the frequency and severity of TBIs. In the present study, we sought to explore the feasibility of several methods used for identifying a traumatic brain event in the military training environment. Our overall goal was to determine which tests based off of the recommendations of Army leaders and subject matter experts as well as from evidence of efficacy in this study would be best suited for a brief, field-administrated battery that could be used in a follow-up field study.

During our analysis, we considered participant's responses on the Ease-of-Use survey, administration time, and reported observations by research team members. For the Ease-of-Use survey, we found that Airborne participants in Condition 1 reported significantly higher perceived distractibility on all assessments as compared to Combatives participants in the same condition. This was also corroborated by the research personnel administering the tests, who similarly reported the Airborne participants in Condition 1 appeared more distracted during the MACE and KD. Although the source of this increased distractibility is unclear, it is suggestive that the measures in Condition 1 may not be best suited to the Airborne training environment due to an increased chance of distraction during administration. For all other outcome variables in Condition 1 (e.g., perceived performance and ease of use), we did not observe significant group differences between Airborne and Combatives participants. This lack of difference between groups suggests that conditions specific to group membership did not differentially influence the outcomes. Similarly, there were no group differences in ratings between the Airborne and Combatives groups in Condition 2. This confirms that both environments were appropriate and comparable testing fields for this pilot study.

Analysis of administration times provided support for all of the tests individually. However, based on recommendations in the literature (Resch et al., 2016), we sought to establish a battery consisting of multiple methods for assessing for head injury (neurocognitive, oculomotor, and balance/sensory). The individual measures that we tested, such as the KD, PLR, MACE and Neurocognitive performance tests, could have been combined in different arrays as a battery of assessments. However, based on the analysis of the observational reports, many of these measures are not appropriate for the military training field environment because of the need for environmental controls and/or trained professionals that could not be circumvented in the field. Of the single-modality measures, the KD is the only test that met our standard of feasibility for field use. However, this measure alone is not sufficient for assessing head trauma from a multi-modal approach.

The iDETECT was also deemed appropriate for the military training field environment due to its portability, diminished need for environmental controls, and ability to be administered and interpreted by individuals with little training. Our findings also indicated that the iDETECT system was well received by participants and test administrators due to its innovative virtual reality capabilities. The virtual reality goggles and noise canceling headphones show promise for minimizing distraction in vivo. This is pivotal for environments such as Combatives and Airborne where fellow trainees are engaging in attention-grabbing activities such as hand-to-hand combative bouts and parachuting out of planes. To effectively assess for potential head injury, full and complete attention is required. Thus, it would appear as though the iDETECT system is the most promising tool for in field use.

There are several limitations worth noting with our study. First, our sample was drawn only from soldiers in Airborne and Combatives training, and our sample method was one of convenience. Although this limits the generalizability of our findings, we believe the results likely would be demonstrative of Soldiers in training with higher risks of a head injury given the standardization of these training courses. Also, our sample size of 47 soldiers is arguably small, but sufficient in this study to provide pilot data to inform the next phase of this project. There were technological errors in recording the administration times for the KD in Condition 1 which we addressed by approximation; however, we cannot be certain of the actual average completion

time from this test. Although all of our research assistants were trained extensively and required to practice administration beforehand, there are likely some unmeasured differences in subjective reporting and administration times that are due to researcher differences. Finally, the validity of the Ease-of-Use survey responses is unclear. Because the items on the questionnaire refer to each measure specifically by name, it is possible that some participants may not have remembered each name and may have given blanket answers for each measure specified or answers that tended towards the mean. This speculation is suggested by some responses being consistently repeated across each measure indicating careless or inaccurate responding.

Recommendations

The clearest recommendations from this study are that the iDETECT system shows promise as an easy-to-use, relatively brief (approximately 20 min), reliable method of assessing functional changes after a potential head trauma. Thus, we recommend that the iDETECT be used in our follow-up study. This follow-up study will examine the relationship between head impact, as measured by environmental sensors, and the resulting performance on the NP performance, vestibular/oculomotor, reaction time, and balance/sensory integration test modules after head impact.

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