2017-06

Oculometric screening for traumatic brain injury in veterans

Wagner, Christinea M.

Monterey, California: Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

OCULOMETRIC SCREENING FOR TRAUMATIC BRAIN INJURY IN VETERANS

by

Christinea M. Wagner

June 2017

Thesis Advisor:	Quinn Kennedy
Co-Advisor:	Lee Sciarini
Second Reader:	Maheen Adamson

Reissued 21 Aug 2017 with correction to thesis advisor's name.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 2017	3. REPORT TYPE AND DATES COVERED Master's thesis

4. TITLE AND SUBTITLE
OCULOMETRIC SCREENING FOR TRAUMATIC BRAIN INJURY IN VETERANS

5. FUNDING NUMBERS

6. AUTHOR(S) Christinea M. Wagner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number: NPS.2017.0002-IR-EP7&4-A.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

A collaborative project between Naval Postgraduate School (NPS), Veterans Affairs Palo Alto Health Care System (VAPAHCS), Defense and Veterans Brain Injury Center (DVBIC), and neuroFit Inc., was developed to: 1) assess the efficacy of the Comprehensive Oculometric Behavioral Response Assessment (COBRA) as a screening method for mild-to-moderate Traumatic Brain Injury (TBI) in veterans, and 2) evaluate the usability of the neuroFit Oculometric Neurological Examination (ONE) device in military medical facilities. COBRA metrics used to characterize oculometric signs associated with TBI came from two published samples: a 41-subject control sample and a 34-subject civilian TBI sample comprised of mild (loss of consciousness (LOC)<30 min), moderate (30 min<LOC<24 h), and severe (LOC>24 h) TBIs. The control sample was compared to the eight-subject veteran TBI sample (age range: 27–55 years; 8 males) from the VAPAHCS, comprised of mild (n=7) and moderate (n=1) TBI diagnoses and posttraumatic amnesia (PTA) (n=4). Results demonstrated a significant ($p = .02$) difference between the control and veteran TBI samples. COBRA metrics accurately detected TBIs at a rate of 77%. Results indicate the COBRA method is viable for TBI screening in military medical facilities and may be suitable for diagnosing chronic visual problems related to mild and moderate TBI.

14. SUBJECT TERMS
traumatic brain injury (TBI), screening, oculomotor, eye tracking, Comprehensive Oculometric Behavioral Response Assessment (COBRA), veterans, Veterans Affairs (VA)

15. NUMBER OF PAGES
85

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OCULOMETRIC SCREENING FOR TRAUMATIC BRAIN INJURY IN VETERANS

Christinea M. Wagner
Captain, United States Army
B.A., Seattle University, 2008

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN HUMAN SYSTEMS INTEGRATION

from the

NAVAL POSTGRADUATE SCHOOL
June 2017

Approved by: Quinn Kennedy
Thesis Advisor

Lee Sciarini
Co-Advisor

Maheen Adamson, Defense and Veterans Brain Injury Center
Second Reader

Patricia Jacobs
Chair, Department of Operations Research

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ABSTRACT

A collaborative project between Naval Postgraduate School (NPS), Veterans Affairs Palo Alto Health Care System (VAPAHCS), Defense and Veterans Brain Injury Center (DVBIC), and neuroFit Inc., was developed to: 1) assess the efficacy of the Comprehensive Oculometric Behavioral Response Assessment (COBRA) as a screening method for mild-to-moderate Traumatic Brain Injury (TBI) in veterans, and 2) evaluate the usability of the neuroFit Oculometric Neurological Examination (ONE) device in military medical facilities. COBRA metrics used to characterize oculometric signs associated with TBI came from two published samples: a 41-subject control sample and a 34-subject civilian TBI sample comprised of mild (loss of consciousness (LOC)<30 min), moderate (30 min<LOC<24 h), and severe (LOC>24 h) TBIs. The control sample was compared to the eight-subject veteran TBI sample (age range: 27–55 years; 8 males) from the VAPAHCS, comprised of mild (n=7) and moderate (n=1) TBI diagnoses and posttraumatic amnesia (PTA) (n=4). Results demonstrated a significant ($p = .02$) difference between the control and veteran TBI samples. COBRA metrics accurately detected TBIs at a rate of 77%. Results indicate the COBRA method is viable for TBI screening in military medical facilities and may be suitable for diagnosing chronic visual problems related to mild and moderate TBI.

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LIST OF ACRONYMS AND ABBREVIATIONS

CDC	Centers for Disease Control and Prevention
COBRA	Comprehensive Oculometric Behavioral Response Assessment
DVBIC	Defense and Veterans Brain Injury Center
DOD	Department of Defense
GCS	Glasgow Coma Scale
HSI	Human Systems Integration
ICU	Intensive Care Unit
IED	improvised explosive device
IRB	institutional review board
LOC	loss of consciousness
MACE	Military Acute Concussion Evaluation
MRI	magnetic resonance imaging
mTBI	Mild Traumatic Brain Injury
DTI	diffusion tensor imaging
MHS	Military Health System
NPS	Naval Postgraduate School
ONE	Oculometric Neurological Examination
OEF	Operation Enduring Freedom
OIF	Operation Iraq Freedom
PTA	Posttraumatic Amnesia
PTSD	Post Traumatic Stress Disorder
QR	Quick Response
ROC	Receiver Operating Characteristic
RPG	Rocket Propelled Grenade
TBI	traumatic brain injury
VAPAHCS	Veterans Affairs Palo Alto Health Care System
VA	Department of Veterans Affairs
WOC	Without Compensation
WRIISC	War Related Illness and Injury Study Center

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EXECUTIVE SUMMARY

The Defense and Veterans Brain Injury Center (DVBIC) reported that first-time traumatic brain injury (TBI) diagnoses in service members reached 347,962 in 2016. Attributed to the wide use of improvised explosive devices (IEDs) in the Iraq and Afghanistan wars, this number is staggeringly high compared to rates reported in previous conflicts. Combat experiences also contribute to the number of TBIs that occur post deployment when service members return home. In 2016, researchers Regasa, Thomas, Gill, Marion, and Ivins found that this transition period is often coupled with engagement in high-risk behaviors and that TBI diagnoses that occur shortly after the return from a deployment could potentially represent a late diagnosis for TBI that actually occurred during a deployment.

The occurrence of late diagnoses is partially due to challenges related to diagnosing TBIs. TBI is a complex injury due to its various causes and symptoms. Oftentimes, TBI goes undetected in the presence of other, more life threatening injuries or, conversely, TBI symptoms may not occur until a few days after the injury event. Service members may be unaware they have symptoms or they may choose not to disclose symptoms of TBI because they believe it may affect military or future employment. Therefore, screening measurements used presently that rely on patient feedback may not accurately or reliably capture TBIs.

According to a technical review completed for the U.S. Army Medical Research & Materiel Command, the U.S. Armed Forces is considering the use of an oculomotor tracking device that can be used as a detection method for neurological dysfunctions related to TBI (Barker et al., 2013). A specific example of such a device available is the Comprehensive Oculometric Behavioral Response Assessment (COBRA) method. The COBRA method quantifies 10 eye-performance metrics by using recorded eye movements of an individual from an oculomotor tracking device. Researchers Liston, Wong and Stone demonstrated in a 2017 study that the COBRA method reliably screens for TBI in injured civilian subjects. Compared to surveys and neurological scans,

COBRA is a non-invasive, inexpensive, quantitative, and objective screening method for TBI.

A collaborative project between Naval Postgraduate School (NPS), Veterans Affairs Palo Alto Health Care System (VAPAHCS), Defense and Veterans Brain Injury Center (DVBIC), and neuroFit Inc., a small business developing technology to support eye-movement-based metrics of neural function, was developed to: 1) assess the efficacy of the COBRA as a screening method for mild-to-moderate Traumatic Brain Injury (TBI) in veterans, and 2) examine the usability of the Oculometric Neurological Examination (ONE) device (neuroFit, Inc.) for use by operational units, military treatment facilities, or VA hospitals.

COBRA metrics used to characterize oculometric signs associated with TBI came from two samples included in the published study (Liston et al., 2017). These samples consisted of: a 41-subject control sample and a 34-subject civilian TBI sample comprised of mild (loss of consciousness (LOC)<30 min), moderate (30 min< LOC< 24 h), and severe (LOC>24 h) TBIs. These samples were compared to an eight-subject veteran TBI sample (age range: 27–55 years; 8 males; 7 mild, 1 moderate TBI diagnoses) recruited from the VAPAHCS. The usability assessment consisted of an evaluation of requirements related to training, transportation, and resourcing the neuroFit ONE device, and an overall performance evaluation.

Results demonstrated a significant ($p = .02$) difference between the control and veteran TBI samples. COBRA metrics accurately classified TBIs at a rate of 77%. These results indicate the COBRA method could be used for baseline assessment during intake physicals as a detection method for acute injury and for management of brain health in military and VA hospitals. An immersive evaluation of the neuroFit ONE device demonstrated the hardware usability, and that it will integrate well into military medical facilities. Functions relating to training, operating, and transporting the system fall within the required set of skills, abilities, and knowledge of military medical personnel and field medics. Resource requirements can also be met. Further research is recommended regarding the use of the COBRA method with the neuroFit ONE device as well as further

exploration of the implementation of the neuroFit ONE in emergency clinics and Role 1 military medical treatment facilities.

References

Barker, F., Ciuffreda, K., Jacobs, J., Kardon, R., Scheiman, M., Schuchard, R., & Walsh, D. (2013). Traumatic brain injury detection using oculomotor and eye movement tracking: A technical working group critical review. *Group OTW. Version 1.3*, Fort Detrick, MD: Combat Casualty Care Research Program 2013.

Defense and Veterans Brain Injury Center. (DVBIC). (2016). DOD Wworldwide Nnumbers for TBI. Retrieved from http://dvbic.dcoe.mil/DOD-worldwidenumbers-tbi

Liston, D., Wong, L., & Stone, L. (2017). Oculometric assessment of sensorimotor impairment associated with TBI. *Optometry and Vision Science, 94*(1), 51–59.

Regasa, L., Thomas, D., Gill, R., Marion, D., & Ivins, B. (2016). Military deployment may increase the risk of traumatic brain injury following deployment. *Journal of Head Trauma Rehabilitation, 31*(1), 28–35.

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ACKNOWLEDGMENTS

Many thanks go to my thesis advisor, Dr. Meghan Kennedy, for her continuous support throughout the phases of this study and to LCDR Lee Sciarini for his valuable insight. The NPS IRB was also very helpful and I am thankful for their support. Thank you to the NPS Operations Research Department Chair, Dr. Patricia Jacobs, for funding this research. This work was also supported by the Office of Naval Research Code 30.

I would like to extend a special thank you to those at the VAPAHCS. Thanks to Dr. Maheen Adamson for her expertise, guidance, and especially for establishing a collaborative research relationship with NPS, VAPAHCS, and DVBIC. Thanks also to Dr. Molly Timmerman and her staff for going out of their way to help with patient recruitment. Lastly, thanks to Dr. Joy Taylor for her support and for providing workspace to carry out the study.

Additionally, I would like to thank Dr. Dorion Liston for providing the instructions and use of the neuroFit ONE and COBRA method, and for advice throughout the planning and execution of this study.

Finally, for supporting me throughout this process, I would like to thank my family: my parents, for encouraging me to pursue my interests; Brandon, for always being there, regardless of distance or time zone; and Zosma, for her patience and companionship.

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I. INTRODUCTION

A. BACKGROUND

Traumatic brain injury (TBI) is a physical injury caused by an acute traumatic injury such as an outside force or blow to the head, a violent jolt, or a penetrating head injury (CDC, 2016). TBI often results from falls, car accidents, or from impacts that occur in sports activities. The Centers for Disease Control and Prevention (CDC) reports an estimated 2.5 million civilians sustain a TBI in the United States each year (2016). Within the military, instances of TBI also could occur from combat related events or training that is unique to service members. This thesis will focus on TBI in military personnel and will include TBI from both their military and civilian experience.

Attributed to the wide use of improvised explosive devices (IEDs) in the Iraq and Afghanistan wars, reported first-time TBI diagnoses in service members reached 347,962, a number that is staggeringly high compared to rates reported in previous conflicts (Defense and Veterans Brain Injury Center [DVBIC], 2016). The increased incidences of brain injury on the contemporary battlefield may also be due to higher chances for survival following injury, as compared to the chances of survival with previous wars in American history (Gean, 2014). Current improvements made to protective equipment and medical procedures are more apt to mitigate head injuries, but there is still difficulty with identifying a TBI, specifically closed TBI in which there is no obvious wound. Difficulty in identifying closed TBIs leads to an unknown number of unrecognized and unreported TBI incidences.

Combat induced injuries are not the only cause for TBIs in service members. In fact, research indicates that "non-deployment related TBIs accounted for 85 percent of all TBIs reports to the DoD between 2001 and 2011," (Farmer et al., 2016, p. xi). Common noncombat sources of TBI injuries are related to training accidents, accidental falls, sporting events, and motor vehicle accidents (Farmer et al., 2016). However, it is necessary to consider the possibility that TBI incidents with service members have job specific characteristics that differ from the wider civilian population. For instance,

service members transitioning to home life after a deployment are more likely to engage in high-risk behaviors that frequently lead to TBI injuries (Regasa, Thomas, Gill, Marion, & Ivins, 2016). Furthermore, an injury that occurs shortly after returning from deployment that is diagnosed as a TBI could potentially represent a late diagnosis of TBI that occurred during a deployment (Regasa et al., 2016). The occurrence of late diagnoses is partially due to challenges related to diagnosing TBIs.

TBI is a complex injury due to its various causes and symptoms. Oftentimes, TBI goes undetected in the presence of other, more life-threatening injuries or closed injuries. Some symptoms occur immediately while others can go unnoticed for days or weeks after the injury, or until the injured person resumes regular or stressful activities, making early detection difficult (CDC, 2016) Military and sports personnel are also known to withhold information about their TBI symptoms, as some believe that a diagnosis could hinder their career progression (Gean, 2014). Therefore, the U.S. Armed Forces is seeking an accurate and readily available TBI detection method for military medicine that can be employed in an operational environment (Barker et al., 2013).

One such method is oculometric screening. Research indicates that TBI affects eye movement function (Glass, Groswasser, & Grosswasser-Reider, 1995). Eye-movement assessment tests offer a non-invasive, inexpensive, quantitative, and objective method to measure abnormalities in oculomotor functions that are indicative of brain injury. A specific example is the Comprehensive Oculometric Behavioral Response Assessment (COBRA) method. The COBRA method quantifies 10 eye-performance metrics by using recorded eye movements of an individual from an eye-tracking device. Researchers have demonstrated that the COBRA method reliably screens for TBI in injured civilian subjects (Liston, Wong, & Stone, 2017). Additionally, COBRA has been shown to be sensitive to the severity of TBI by detecting and characterizing oculomotor deficits associated with TBI in a civilian sample (Liston & Stone, 2014). Because service member injuries have the possibility to stem from military specific activities such as combat or associated training events, this study will determine if the results that occurred with COBRA in a civilian sample can be replicated in a military sample. The data collection and the resultant analysis will inform policy and procedures on a feasible

method to immediately and objectively screen service members for TBI, ensuring the requisite treatment is provided.

B. PURPOSE

The primary purpose of this study was to test the validity of the COBRA method and the neuroFit Oculometric Neurological Examination (ONE) eye-tracking device for use as a screening method for TBI with veterans. If the results support the efficacy and utility of the COBRA method and neuroFit ONE eye-tracker as a TBI detection tool, then this method can potentially be implemented for use. Potential environments in which the neuroFit ONE can be operated include permanent military hospitals and temporary field units in operational environment to ensure TBI is identified early. Early screening of TBI in a deployed environment could consequently, improve the treatment and approach for chronic TBI conditions while also ensuring that service members receive immediate care.

C. HUMAN SYSTEMS INTEGRATION CONSIDERATIONS

This study will address the Human Systems Integration (HSI) domains of occupational health, safety, and personnel. The concept of the occupational health domain is to promote and maintain the "highest degree of physical, mental and social well-being of workers in all occupations by preventing departures from health, controlling risks and the adaptation of work to people, and people to their jobs," (Agius, 2010, para. 1). Screening for TBI is relevant to occupational health because the known symptoms and comorbidities that are often associated with TBI pose serious health related risks that require immediate treatment. TBI is known to impact cognitive, behavioral, and whole body functions. Immediate or delayed symptoms may include dizziness, blurry vision, confusion, and difficulty with memory or concentrating. Psychiatric symptoms could include depression, anxiety, or Post Traumatic Stress Disorder (PTSD), which is known to be associated with TBI due to the traumatic nature of combat related injuries (Bagalman, 2013). Identification of TBI with a screening process helps to ensure that a necessary treatment program is implemented immediately to reduce symptoms and improve the wellbeing of service members with TBI.

Furthermore, retention rates may improve as service members become aware of the implementation of a screening method for TBI. TBI is recognized as a common health concern amongst service members serving in combat environments (Bagalman, 2013). Therefore, a screening method may ease service members' concerns about the varying effects of TBI if they know that their health and recovery is a priority to their command and military medical providers.

Similar to occupational health is the safety domain, which emphasizes the use of design and operational principles to reduce the possibility of accidents or mishaps (Boehm-Davis, Durso & Lee, 2015). Service members with mild to moderate TBI may be unaware of having TBI symptoms (Bagalman, 2013); consequently, their TBI does not get diagnosed or they will not seek the immediate treatment that is needed. Mild forms of TBI can result in symptoms that persist for weeks or months, or in some cases, years after injury if post-concussive syndrome occurs (Barker et al., 2013). Immediate treatment requires accurate detection methods; therefore, implementing a reliable and valid TBI screening method could help to reduce instances of missed TBI diagnoses and potential long-term health and safety risks.

The personnel domain refers to human knowledge, skills, and abilities required to be placed in a specific job or to operate, maintain and support a specific system (Boehm-Davis et al., 2015). This study is relevant to the personnel domain because the results of the screening assessment may indicate that an injured service member is temporarily or permanently disqualified for their military specialty due to the TBI injury. Changes in brain function can impact how an individual interacts with their work associates, peers, family members, and the wider community. Therefore, identifying the injury and applying a recovery plan is essential to helping injured individuals regain their previous function, if possible, and their sense of self.

The findings of this study will inform U.S. Armed Forces of a potential method to screen service members for TBI, ensuring immediate treatment. The findings also will support recommendations on occupational health, safety, and personnel requirements to help mitigate risks associated with TBI.

D. OBJECTIVES

This study will assess the efficacy of an oculometric screening method for TBI in veterans with mild to moderate TBI. The primary research objective is to determine if the COBRA method can be used to detect and characterize TBI in a veteran sample. The hypothesis is that veteran subjects with diagnosed TBI show the same oculomotor characteristics as published civilian samples diagnosed with similar levels of TBI. Additionally, this study also will assess the usability of the COBRA method and neuroFit ONE device in operational units, military treatment facilities, or VA hospitals. This question will be answered through an immersive qualitative evaluation of the hardware used to run COBRA, specifically regarding training, operating, and transporting the system. Lastly, exploratory questions to determine if the COBRA method can be used to assess effects associated with the number of TBI events and the elapsed time since the initial injury will be investigated.

E. THESIS ORGANIZATION

The following chapter provides a literature review on TBI, screening for TBI in the military, and the use of eye-tracking methods to accomplish this. This study was informed by previous studies conducted on the COBRA and was developed by applying the research concepts from the previous studies to consider military veterans. A review of the COBRA studies is included in Chapter I. The methodology, variables, and piloting for this research will be discussed in Chapter III. Chapter IV presents the results of the research and the discussion of the findings is provided in Chapter V.

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II. LITERATURE REVIEW

A. TRAUMATIC BRAIN INJURY

DVBIC defines a Traumatic Brain Injury (TBI) as "a blow or jolt to the head that disrupts the normal function of the brain," (2017b, para. 2). Associated causes of TBI include incidents where someone hits his or her head or a force is applied to the head such as through falling, physical assault, or incidents related to sports or traffic accidents. TBIs generally cause compression in brain tissue that could cause neurodegenerative damage (Haddad & Arabi, 2012). Even with mild injury, damage can result in physical, psychological, and cognitive issues, which can occur immediately or develop over weeks to months after the initial injury (Barker et al., 2013). Due to the varying causes, TBI can result in a broad spectrum of symptoms depending on the cause and severity of the TBI. Cognitive symptoms of TBI can include difficulty concentrating or thinking clearly and memory loss. Physical symptoms include headache, dizziness, blurred vision, or feeling tired; and psychological symptoms can include mood changes such as increased irritability, sadness, or anxiety (CDC, 2016). Although it is more common for TBI patients to recover quickly and with minimal intervention, some may experience persistent symptoms that become chronic, lasting several months or longer (DVBIC, 2017a).

The classification of TBI depends on the injury mechanism and resulting effects of the injury. There are three classification types: focal vs. diffuse, injury mechanism, and level of severity (mild, moderate, and severe). Focal TBI refers to an injury that is localized to a small area of the brain while diffuse TBI covers a large area (Vital, 2002). Injury mechanisms include penetrating injuries (e.g., gunshot wounds), impact trauma (e.g., a blow to the head resulting from falls or auto accidents) and blast exposure (e.g., IED or other explosions). Penetrating TBI leads to an open injury. In the military, bullets and shrapnel often cause "open" head injuries. "Closed" head injuries result in an internal injury that is not externally visible, such as swelling of the brain and damage to brain tissue (Gean, 2014). Lastly, mild, moderate, and severe TBI classifications are

determined with the following measures: loss of consciousness (LOC), alteration of consciousness or mental state, posttraumatic amnesia (PTA), or by establishing a Glasgow Coma Scale (GCS) score (Jaffee et al., 2009). See Table 1 for criteria established by the Department of Defense (DOD) and the Department of Veterans Affairs (VA) to diagnose severity levels of TBI. Medical professionals use the GCS to classify the severity of a patient's head injury and level of consciousness by observing behaviors that could indicate an injury level (Teasdale & Jennett, 1974).

Table 1. DOD/VA Classification of TBI Severity

Mild TBI	Moderate TBI	Severe TBI
Normal structural imaging, CT scan	Normal or abnormal structural imaging, CT scan	Normal or abnormal structural imaging, CT scan
Loss of consciousness for less than 30 minutes	Loss of consciousness for more than 30 minutes and less than 24 hours	Loss of consciousness more than 24 hours
Alteration of consciousness for one moment up to 24 hours	Alteration of consciousness for more than 24 hours	Alteration of consciousness for more than 24 hours
Post-traumatic amnesia for 1 day or less	Post-traumatic amnesia for more than 1 and less than 7 days	Post-traumatic amnesia for more than 7 days
Glasgow Coma Scale = 13–15	Glasgow Coma Scale = 9–12	Glasgow Coma Scale = 3–8

Adapted from Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury (DCoE) and DVBIC (2010).

The presence of PTA is considered to be a significant behavioral indicator of head injuries; therefore, it is commonly used to determine the severity of a closed head injury and is opined by some to provide the most accurate prediction of the potential outcome (McMillan, Jongen, & Greenwood, 1996). PTA is defined by the time between LOC and the return of continuous and day-to-day memory, making it a retrospective assessment (McMillan et al., 1996). The PTA period is determined by a patient's response to orientation and identification questions to gauge the level of confusion and disorientation that occurs at this time (King et al., 1997).

B. MILITARY TBI

In comparison to the general population, the causes for TBI in military service members could stem from combat environments and related events. During Operation Iraqi Freedom (OIF) Operation Enduring Freedom (OEF), an increasing presence and consequent devastation of TBI was brought on by the use of improvised explosive devices, car bombs, and land mines. The frequency of deployments that occurred with OIF and OEF also exposed service members to the possibility of multiple TBI events, which, when left untreated, puts service members at risk for later onset of Alzheimer's, Parkinson's, or the even more debilitating neurodegenerative disease, chronic traumatic encephalopathy (McKee & Robinson, 2014). Initially, service members were not provided with equipment or vehicles that offered adequate protection against these threats, which contributed to the frequent occurrence of TBI. As these attacks became more prevalent, protective equipment and combat medicine were modified to reduce critical injuries, and healthcare professionals became more aware of the need to screen for TBI in service members (Bagalman, 2013).

DVBIC reports 347,962 of active-duty service members with a first-time TBI diagnosis since 2000 (2016). While the number of diagnoses is very high, it can only be considered an estimate of actual TBIs in service members due to the archaic screening methods that need to be updated. TBI can still go unnoticed, especially if a person appears to be uninjured after an accident.

Recognizing symptoms associated with TBI is further complicated by associated medical comorbidities. The occurrence of comorbid symptomology is prevalent with military service members (Mysliwiec et al., 2013). Military-related illnesses that are often present with mild TBI (mTBI) include anxiety disorders, depressive disorders, PTSD, and sleep problems sometimes associated with pain (Bagalman, 2013). Various studies have suggested that TBI is linked to increased alcohol or drug use while a report by the Institute of Medicine reported the opposite findings (Masel & DeWitt, 2010). This case represents an example of the challenges associated with comorbidity factors. A scientific review of “post-concussive computerized neurocognitive assessments,” completed by the

Defense Health Board (2016, p. 9) recognized that comorbidity factors associated with TBI have the potential to impact detection methods because they muddle the effects of TBI with compounding symptoms, requiring a multifaceted evaluation of assessment results. Therefore, a multidisciplinary approach for detection and treatment is suggested to reduce long-term or missed symptoms.

C. SCREENING

Proper screening is essential to the diagnosis and treatment of TBI. For instance, long-term neurological dysfunctions are greatly reduced if an individual with mTBI receives rest and reduces his or her cognitive activities shortly after the injury-event (Mayo Clinic, 2014). Similarly, individuals who receive immediate treatment for mTBI are less likely to be at risk of another brain injury.

Medical personnel assess brain injuries by checking the injured person's ability to follow directions and move their eyes and limbs by following the format of the GCS (Mayo Clinic, 2014). The GCS is a neurological scale used to categorize consciousness after a TBI by measuring eye, verbal, and motor responses to stimuli. Scores from the GCS are such that 13 to 15 represents mTBI, GCS 9 to 12 is a moderate TBI, and GCS 3 to 8 is severe TBI (DCoE & DVBIC, 2010). More sophisticated screening methods require trained medical professionals and highly specialized equipment. These methods include imaging tests such as magnetic resonance imaging (MRI) or a computerized tomography (CT) scan. Additionally, doctors can use an intracranial pressure monitor to probe the skull for areas of increased pressure or tissue swelling (Mayo Clinic, 2014). However, these methods are not common practice within DOD and VA guidelines for acute TBI. For instance, methods such as imaging and blood work are available but they are not used with initial acute TBI, which contributes to the occurrence of undiagnosed TBIs.

According to McMillan et al. (1996), PTA is an accurate and reliable assessment method of determining the severity of head injuries. Furthermore, a more recent study demonstrated that the length of PTA provides the most accurate indicator of behavior, memory, and executive functioning following a TBI (Guise, LeBlanc, Feyz, Lamoureux,

& Greffou, 2017). Therefore, PTA assessment is often used for diagnosis and treatment decisions. However, there is no standardized procedure used to measure PTA. An earlier study assessed the use of the Rivermead post-traumatic amnesia protocol and found that it demonstrated reasonably high reliability, but with a significant misclassification rate (King et al., 1997). The Westmead PTA scale has widespread use, but there is not enough empirical evidence to determine the reliability and validity of this specific assessment method (Marchman, Jakabek, Hennessy, Quirk, & Guazzo, 2013). Therefore, it would not be reasonable to only consider the use of a PTA assessment in clinical practice, but it would be useful as a supplemental assessment method.

Another tool used in military medicine to screen for mTBI is the Military Acute Concussion Evaluation (MACE), which is used to survey service members returning from combat. MACE includes a series of questions about head injuries (Gean, 2014). However, relying on self-reports and surveys to diagnose a TBI can make it difficult to pinpoint the mechanism and time of injury. A recent study indicated undiagnosed, unrecorded, and falsely diagnosed TBIs in service members due to inadequate description of injury causes (Regasa et al., 2016). This study also found that 90% of TBI diagnoses were made in non-deployed health clinics, which suggests that an overwhelming majority of service members with TBI were not diagnosed near the point of injury or at a forward operating clinic (Regasa et al., 2016).

Additionally, screening measurements that rely on patient self-reporting may not identify patients with TBI well (i.e., poor specificity), and may not have good test-retest reliability (Donnelly, Donnelly, Dunnam, & Alt, 2011). Some veterans and active duty members may be unaware that they have symptoms and will ultimately fail to provide an accurate report (Vanderploeg, Belanger, Duchnick, & Curtiss, 2007). According to Bagalman (2013), active duty service members and “veterans may choose not to disclose symptoms of TBI” (p. 11) because they believe it may adversely impact their military careers, future employability and benefits.

D. OCULOMOTOR AND EYE MOVEMENT TRACKING

In response to present concerns with current screening methods of TBI, the U.S. military has expressed interest in the use of eye-tracking methods to diagnose TBIs (Barker et al., 2013). Eye-tracking methods are relevant to TBI screening because oculomotor functions are dependent on a widespread network of brain regions disrupted in TBIs, such as the prefrontal cortex (Kraus et al., 2007), cerebellum (Moschner et al., 1999), brainstem (Thier, Bachor, Faiss, Dichgans, & Koenig, 1991), and motion-processing areas of the dorsal stream (Newsome, Wurtz, Dursteler, & Mikami, 1985). Therefore, oculomotor abnormalities provide objective and quantifiable signs of neurological dysfunctions (i.e. presence of TBIs). Oculomotor screening methods also are being considered by the military because it is a non-invasive and inexpensive method that does not require extensive technical knowledge to use or to interpret results. These features make it a viable option for operational units in field settings (Barker et al., 2013).

E. COBRA STUDY

The COBRA was used in a study to detect and characterize sensorimotor deficits associated with TBI (Liston & Stone, 2014). It consists of a simple eye-tracking task that is displayed on a computer monitor. The eye movement function of participants is assessed by a broad set of oculometric measures. In general, the metrics identify the speed, responsiveness, smoothness, and accuracy of tracking a moving target. Poor performance in these areas indicates TBI. Specific details are described below.

The COBRA method establishes the eye-performance task based on the Rashbass (1961) step-ramp target movement assessment. Rather than testing eye-performance with a predictable moving target that only moves left or right at a constant velocity, the step-ramp method consists of targets that move in random directions and speeds and start at random locations. This randomization helps to prevent the participant from anticipating the movement of the target. Using the step-ramp motion stimulus, 10 eye-movement metrics can be collected with the COBRA method. From this set of 10 metrics, a single index is determined for each participant. For those with TBI, the index is referred to as the TBI impairment, or severity index (Liston et al., 2017).

COBRA metrics from the two published samples (Liston & Stone, 2014; Liston et al., 2017) were used to characterize oculometric signs associated with TBI: a 41-subject control sample (age range: 20-56 years, median 27; 19 female; 35 naïve to eye-tracking tasks) and a 34-subject civilian TBI sample (age range: 20-61 years, median 34; 13 female; median time since injury: 9.1 years) comprised of mild (loss of consciousness LOC<30 min: 7), moderate (30 min<LOC<24 h: 1), and severe (LOC>24 h: 24) injury cases. In comparing civilian control and TBI samples, COBRA quantified sensorimotor impairments associated with TBI including: prolonged smooth pursuit latency, sluggish acceleration, diminished gain, increased catch-up saccade amplitude, a larger saccadic component during tracking, more directional noise, poorer responsiveness to speed, and more speed noise (all $p < 0.05$, Wilcoxon rank sum test) (Liston et al., 2017). Using a linear classifier, COBRA metrics detected the presence of brain injury at a rate of 81% (Liston et al., 2017).

Thus, COBRA demonstrates the ability to do the following: identify subtle neurological signs of subclinical neurological injuries indicative of chronic TBI, quantify the presence and severity of functional impairment, and monitor deterioration or recovery treatment efficacy (Liston et al., 2017). Compared to surveys, COBRA is a non-invasive, quantitative, and objective screening method for TBI (Liston et al., 2017). It also is much cheaper and more operationally feasible than neurological scans. COBRA could benefit both active duty and veteran service members by offering a screening method that provides early identification and has the potential to capture undisclosed TBI. Early identification will help to ensure that necessary treatment is provided immediately rather than contributing to prolonged treatment issues (Anderson, 2012).

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III. METHODOLOGY

Data collection for this study was conducted in collaboration with NPS, VAPAHCS, and DVBIC. Both the NPS Institutional Review Board (IRB) and the Stanford University IRB (the IRB of record for VAPAHCS research) approved the outlined methods to assess the efficacy of the COBRA method to screen for TBI in veterans. This process started at NPS with pilot testing, which was conducted to ensure proper use of the COBRA method and the device that houses this system, neuroFit ONE. Next, the methodological steps used in this study with VAPAHCS patients are presented.

A. PILOT TESTING

Pilot testing for this study was conducted to allow for familiarization with the operation of the neuroFit ONE device and interpretation of COBRA metrics. The designer responsible for the COBRA method provided a user guide and in-person instructions on the use and trouble shooting procedures necessary to operate the overall system independently. As such, this introductory instruction required one session and took approximately 45 minutes to complete. An additional 30 minute session was conducted upon request to monitor the learned use and provide additional trouble shooting procedures. It is also important to note that while one person can accomplish assembly and set up, the designer assembled the table made for the neuroFit ONE device.

The pilot sessions were conducted in an instructor office at NPS. These sessions entailed activities such as practicing COBRA calibration and testing, trouble-shooting procedures, finalizing experimenter instruction scripts, and practice providing informed consent. Fifteen volunteers (including members of the research team) completed the pilot sessions. The data that was generated by the COBRA during these pilot sessions was not retained.

An occasional issue with the eye tracker occurred when volunteers who wore bifocals, dark eye makeup, or had natural, darkly pigmented eyelashes. The research team was informed of these issues prior to the piloting sessions. In these instances, the eye tracker might have difficulty with distinguishing between pupils and similarly dark areas

around the pupil. System designers for neuroFit ONE confirmed efforts to correct for this issue. However, at the time of this study, this occurrence creates human parameters, such that individuals with dark and dense eyelashes may present a challenge for TBI screening with neuroFit ONE.

The neuroFit ONE system tracks the left pupil and provides indicators to the operator when the pupil is not being tracked. One indicator is that the live image provided by the monocular eyetracker shows a red circle over the pupil or red over the eyelashes of the participant's left eye set to a blue background. Another indicator is when the cross lines do not stay centered on the pupil as it moves, the eye movement is not being tracked. Images of eye movement not being tracked and tracked eye movement, respectively, are shown in Figure 1.

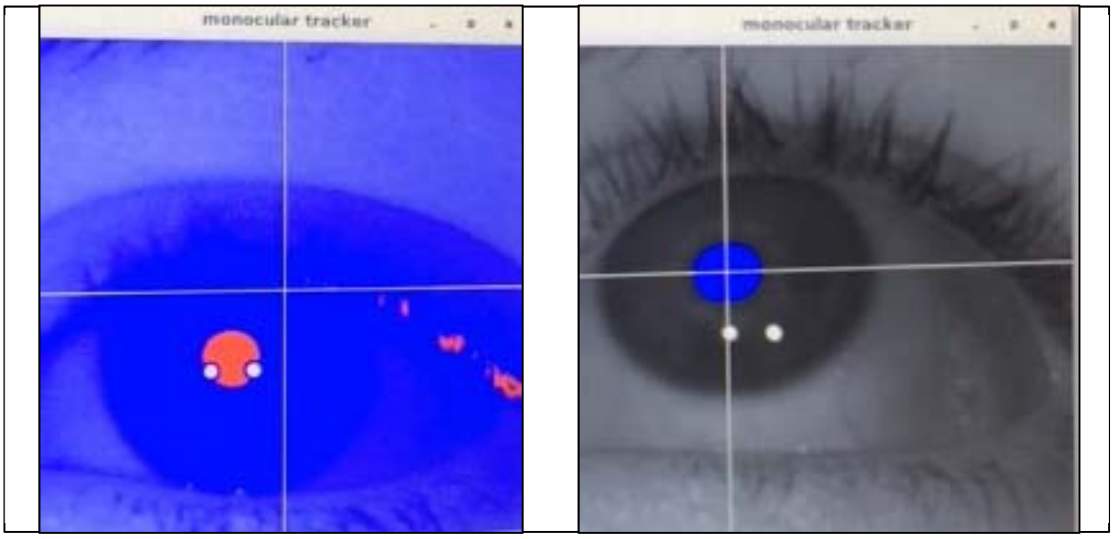


Figure 1. Non-tracked (left) and Tracked (right) Eye Movements

Regarding volunteers who wore eyeglasses, the neuroFit ONE user manual provides guidance to pitch the head of those volunteers down by 5 to 10 degrees (neuroFit Inc., 2016). However, a volunteer who wears bifocals indicated that this required looking through the upper portion of the lens, which is typically for viewing objects in the distance, rather than for looking at a computer screen. In this instance, the

volunteer completed the test without glasses without issue. Other volunteers with very strong eyeglass prescriptions also were able to complete the task without the use of their eyeglasses.

The piloting sessions also presented challenges with identifying height requirements for a chair that could accommodate a wide range of participant heights. Participants must adjust their seating and the chinrest with respect to the camera and the distance guidelines. The operator is responsible for ensuring that the participant is correctly centered on the focal plane using the live full-field image during the facial features check. The operator must also verify that the participant is seated in a natural position that can be held comfortably throughout the duration of the test session. The user manual provides guidance on the instruction of this; however, there are no guiding lines or visual overlays to assist the operator in identifying correct positioning.

Overall, pilot testing identified three key factors to consider with test sessions: 1) ensure that approximately 15–30 minutes is available for the COBRA test, 2) ensure that participants are able to clearly see images on the neuroFit ONE screen, and 3) ensure seating is available to accommodate participants with a minimum height of 58 inches. These considerations were incorporated with the test sessions conducted with VAPAHCS participants. The following sections provide the overview of this process.

B. PARTICIPANTS

The sample of interest for this study included veteran personnel aged 20–56 who are patients at the VAPAHCS. Given that the long-term goal is to implement the eyetracker for working-age adults, patients over the age of 56 were excluded. Exclusion criteria were selected on the basis of limiting additional factors that could augment TBI symptoms. The following lists inclusion and exclusion criteria:

Inclusion criteria:

- Veterans diagnosed with mild to moderate TBI following DOD and VA TBI diagnosis guidelines
- TBI event was caused from non-penetrating blast or impact trauma to the head
- Patient is able to make their own medical decisions and sign informed consent forms
- Patient is able to sit still for up to 20 minutes and fixate for several seconds at a time and track with the left eye while keeping their head still
- Patient is able to sit, stand, and walk without assistance
- Patient has better than 20/200 visual acuity

Exclusion criteria:

- Diagnosis of any of the following: psychosis, schizophrenia, bipolar, major depression (MDD), alcohol or drug addiction, suicide ideation, severe TBI, dementia, and mild cognitive impairment (MCI)
- The patient has suffered a stroke or brain damage resulting in severe cognitive problems
- The patient is taking drugs that affect cognitive function
- Facial injuries that would make using a chinrest uncomfortable
- Conditions that would make the left eye untrackable including eyelid occlusion, paresis, and/or cataracts in the left eye
- A TBI event in the last two months
- LOC greater than 24 hours
- Post traumatic amnesia greater than 7 days following a head injury
- A TBI even caused by a penetrating head injury or impact trauma to the head
- An injury to the eye involving a metallic object

1. Participant Recruitment

Medical doctors and staff treating TBI patients provided a by-name list to refer patients to participate in the study. A VAPAHCS Without Compensation (WOC) appointment status was obtained after two visits to the VAPAHCS human resources center located in Mountain View, California in order to access patient information. Potential participants from the list were screened for exclusion criteria using the clinical patient record system. Fifty-one patients from the referred list fulfilled the inclusion criteria based on searchable criteria and were sent a recruitment letter signed by a VAPAHCS physician supporting this study. The student researcher provided contact information and mailed the recruitment letters. Fliers also were posted at the VAPAHCS Rehabilitation and Physical Therapy Clinic and throughout the WRIISC. Additionally, medical and WRIISC research staff allowed for an in-person presentation of the flier to patients and research participants they referred for the study, resulting in 14 referrals. Potential participants were not directly approached without a referral.

Two interested participants responded to an email address included on the mailed recruitment letters. Forty-nine patients did not contact the researcher and were contacted via telephone two to three weeks after letters were mailed and were read a script to inquire on whether they were interest in participating in the study. See Appendix A for the phone script. Nine patients confirmed their interest in the study and were prescreened to determine their eligibility to participate. The prescreening questions included on the phone script addressed exclusion criteria, demographics, and medical history that could help characterize their TBI. Based on the responses provided for the screening questions, a determination was immediately made to either exclude the participant or to schedule a test session. Every effort was made to schedule test sessions on the same day as a participant's medical appointment at the VA. The experimenter made 17 visits from NPS to the VAPAHCS and stayed in Palo Alto for five days to conduct recruiting and data collection for this study. See Figure 2 for an overview of recruitment for this study.

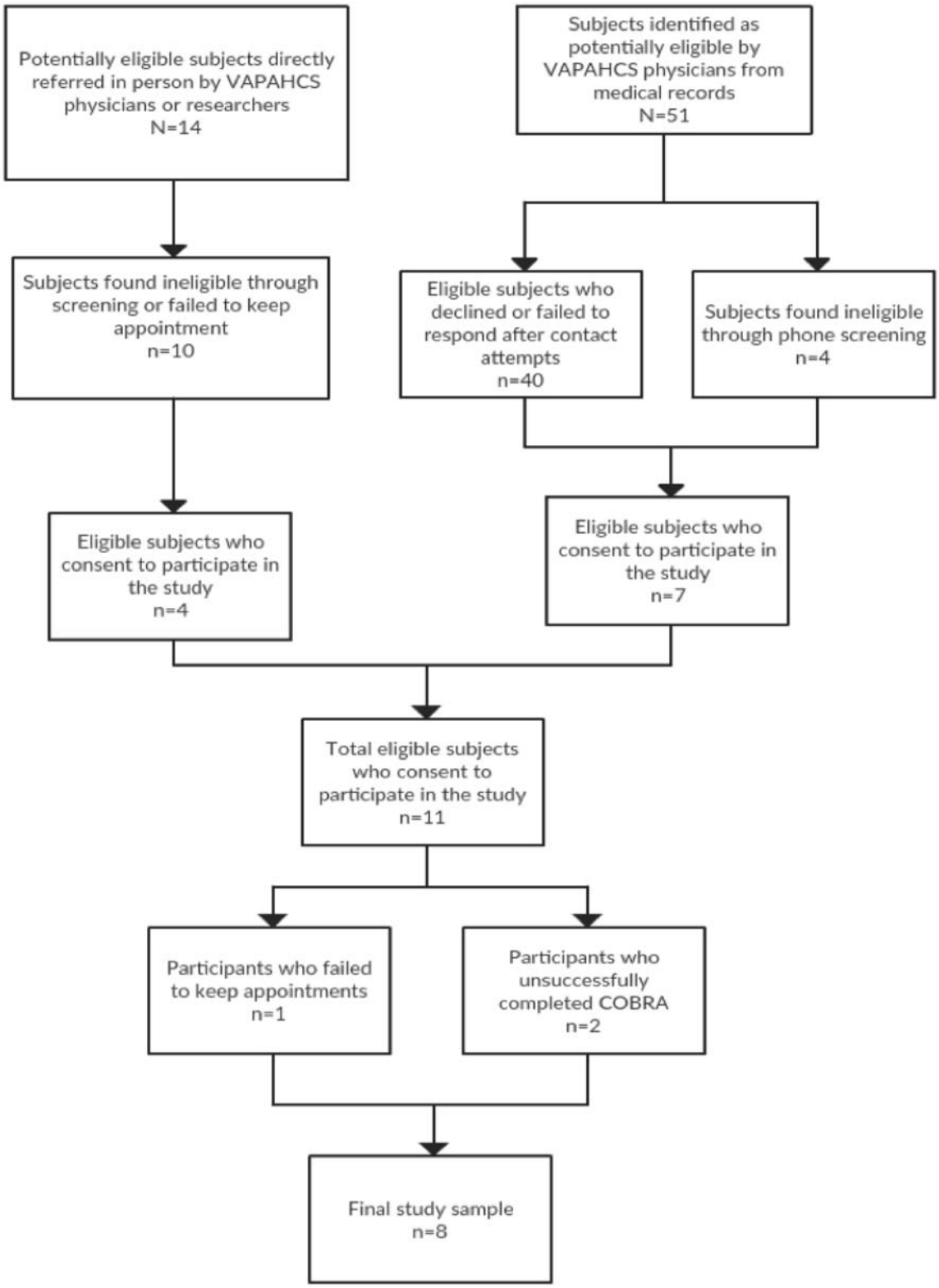


Figure 2. Overview of Study Recruitment

2. Demographics

A demographic summary of the eight male participants recruited from the VAPAHCS is shown in Table 2. As such, all participants were military veterans with varying military and civilian backgrounds. Information was collected with surveys, which is discussed in further detail below.

Table 2. Demographics

Descriptive Characteristics	Descriptive Statistic
Education Level (%)	
High school or less	0.00
Some college	0.38
College and/or beyond	0.63
Employment Status (%)	
Unemployed	0.00
Employed (includes homemaker)	0.63
Student/Volunteer/Retired	0.38
Deployments (%)	
OEF	0.63
OIF	0.38
Other	0.75
Military Occupation (%)	
Combat arms (e.g. Infantry, Armor, etc.)	0.25
Combat Support (e.g. Signal, Intelligence, etc.)	0.25
Combat Service Support (e.g. Medical, Logistics, HR, etc.)	0.50
Time since seperation (mean years (sd))	6.67 (4.9)
Handedness (%)	
Right handed	0.75
Left handed	0.25
Eye Problems (%)	
Wears glasses	0.38
General Health Factors	
Sleeping Problems (%)	0.50
Sleep per night (mean hours (sd))	6.13 (1.3)
Caffeine Use (mean cups of coffee (sd))	9.25 (8.6)
Alcohol Use per week (mean no. drinks (sd))	2 (2.2)
TBI Factors (%)	
Dazed/memory gap	1.00
Posttraumatic Amnesia	0.50
Loss of Consiousness (%)	
No LOC	0.13
< 30 min	0.75
> 30 min <24 hrs	0.13
Time since TBI (mean years (sd))	8.13 (5.4)

C. COBRA AND NEUROFIT ONE

This section provides a discussion on the collection of oculometric performance data, which is used to characterize visual signs of TBI. The process used by the COBRA and neuroFit ONE device is automatic and standardized for each participant. These systems and the their functions are presented below, followed by a description of the oculometric variables that are collected.

1. Apparatus

As a system, neuroFit ONE consist of a subject-response button, chinrest, a table 42 inches wide by 25 inches deep, power supply and cables, HDMI cable, keyboard, mouse, one standard computer monitor, and the device itself, which resembles an all-in-one PC monitor with a camera and eyetracking capability (see Figure 3).

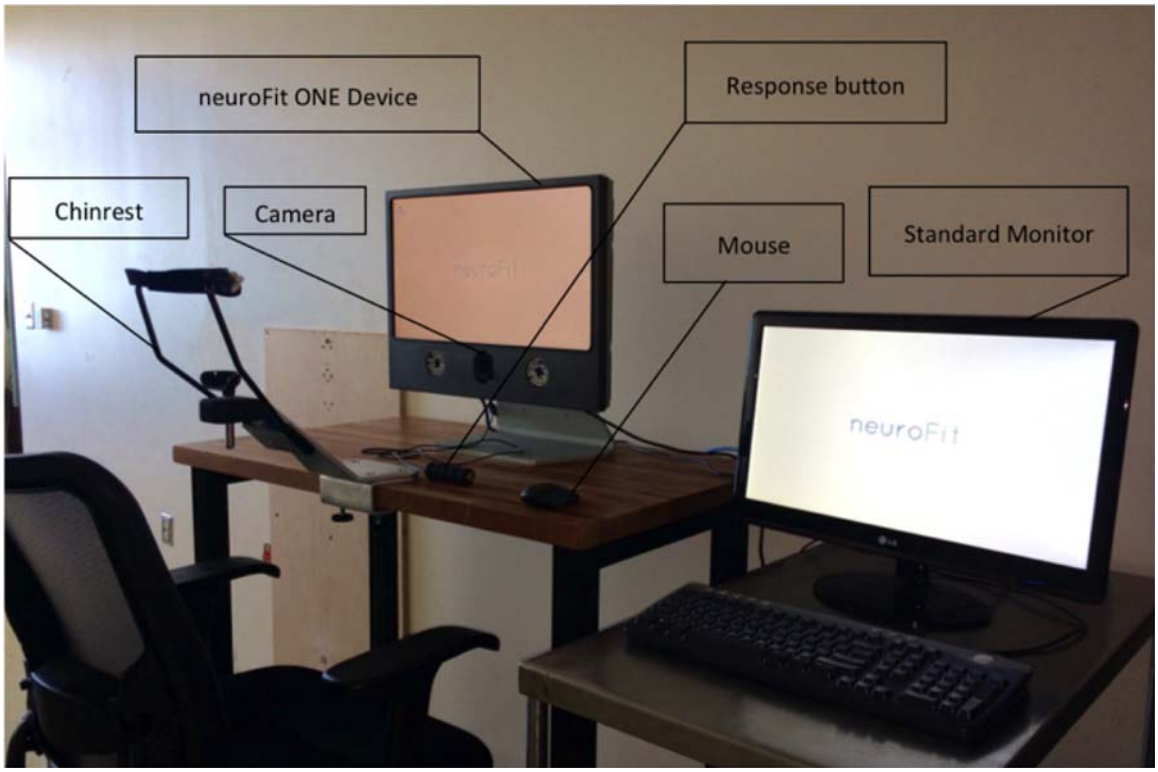


Figure 3. COBRA and neuroFit ONE Components

2. Usability

NeuroFit ONE was designed for use in a clinical setting and by users with no eye-tracking experience to support nearly completely automated functioning (neuroFit Inc., 2016). The design intent is to require the user to have no special skills or knowledge beyond the basic skills required to use a computer. Data collected from the test sessions are automatically analyzed and saved to a designated data folder on the device, which can be saved to an external hard drive.

Assembly and setup is supported with a neuroFit ONE setup manual. Instructions are provided to allow the operator to complete setup and initial tests of the camera, subject-response button, and Internet connection to ensure these three subsystems are satisfactorily setup and are properly operating (neuroFit Inc., 2016).

3. COBRA Setup

The pre-installed neuroFit ONE program runs the COBRA test session. Each test sessions can last up to 15 to 30 minutes and consists of three phases. This section describes the first phase, referred to as facial features (neuroFit Inc., 2016). When the neuroFit ONE program first opens it displays a live full-field image. This image is used to position the participant and the chinrest with respect to the camera so that the participant's eyes are centered on the focal plane (see Figure 4). The chinrest and the chair or stool used by the participant allows for height adjustment. Each session is initiated by scanning a quick response (QR) code from the operator's NeuroFit account after the participant's seating and chinrest are appropriately adjusted. When this is completed, the program will next verify that it can recognize facial features of the participant. The camera focuses on two sets of corneal reflections and two pupils (neuroFit Inc., 2016). Once the eyes have been located, the camera aligns to the participant's eye level. When the vertical alignment criterion has been achieved, the device will indicate it is ready with a visual check mark and moves on to the next stage.

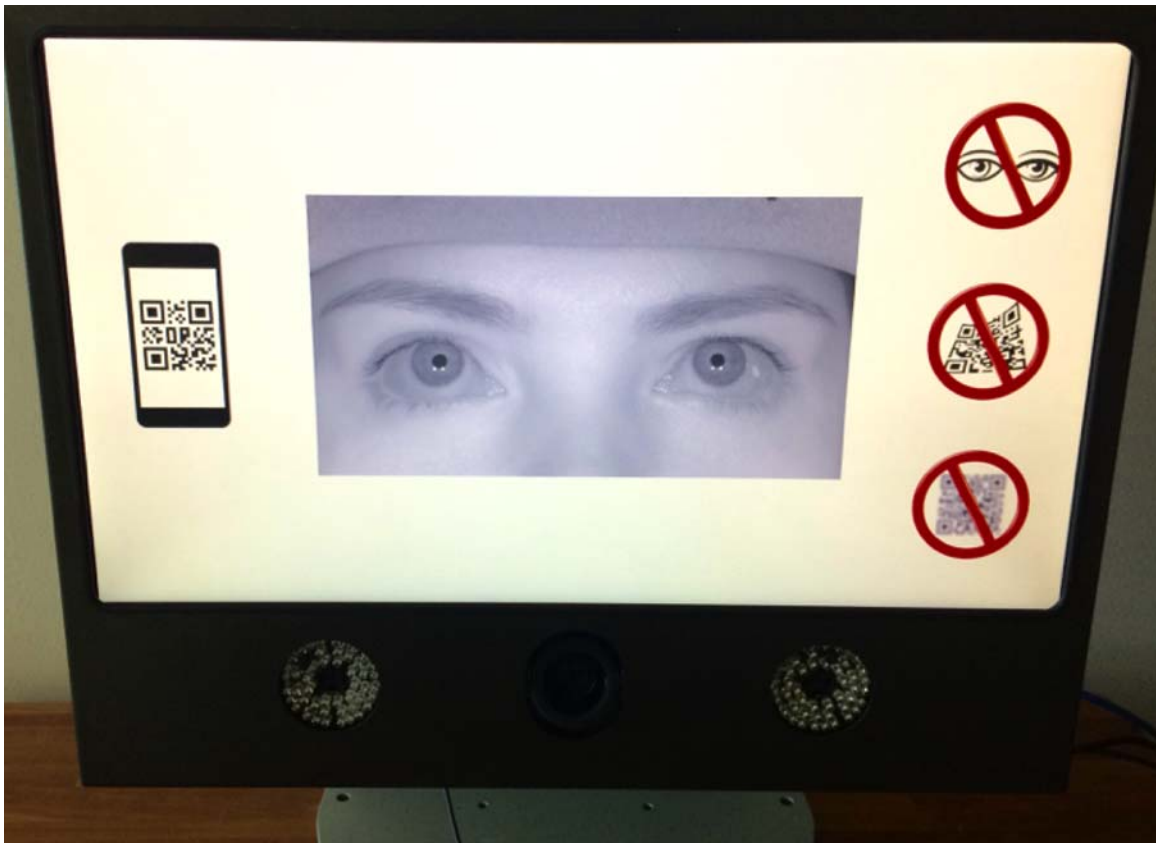


Photo is of the experimenter.

Figure 4. Live Full-Field Image

Attaching the additional monitor to the HDMI output of the device causes a separate window to appear, providing a live image of the patient's left eye via the monocular eyetracker (neuroFit Inc., 2016). This image will also help the operator to verify that the eye is being tracked as it moves. When the eye is properly tracked, the pupil will appear blue (red indicates that pupil is not being tracked). Occasionally the operator will have to adjust the appropriate grayscale threshold to isolate the pupil for dark-pupil tracking (neuroFit Inc., 2016). As described in the instructions, mouse clicks within this window are interpreted as commands to increase (right click) or decrease (left click) the threshold, allowing the operator to fine-tune the estimate given by this automated function (neuroFit Inc., 2016).

4. Calibration

The second part of the COBRA test session is a calibration phase. During calibration the participant fixates on a stationary target. The participant uses the handheld response-button to indicate steady fixation on target. By default, a button press will advance each of the nine points in the calibration (neuroFit Inc., 2016). The calibration data is automatically analyzed and displayed. Clicking the mouse allows the participant to advance past the calibration results. The device moves to the next stage if the precision criterion is met at the designated value of .4 degrees.

5. COBRA Test

The COBRA test follows successful calibration. The participant uses the supplied response-button to indicate that he or she is ready to begin. At the start of each trial, a static dot appears on the center of the screen (Figure 5). When the participant presses the button the dot will move in a random direction and speed. Initiation of the dot also is random such that sometimes the dot moves immediately after a button press and other times there is a delay before the dot moves. By default, a button press advances each of the ninety COBRA trials. The operator must monitor the monocular tracker live image during the experiment to ensure it is acceptable (e.g., the subject has not moved out of the window, the lighting conditions are still acceptable) (neuroFit Inc., 2016).

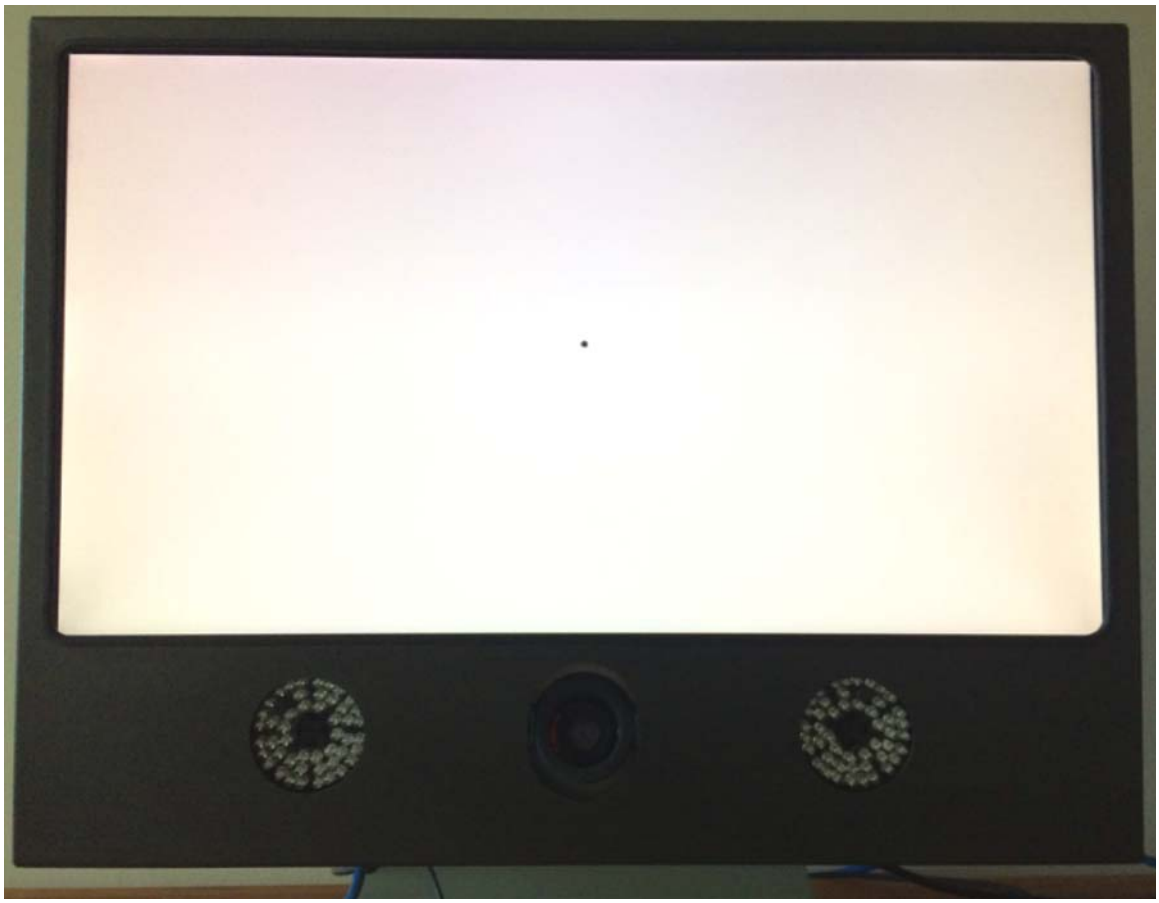


Figure 5. COBRA Test Starting Screen

COBRA results are computed automatically in approximately 10 seconds (neuroFit Inc., 2016). The summary and raw data is saved to a data file with a date-time stamp to name each participant's session. Pressing "ESC" closes the program.

6. Variables

COBRA variables include the following 10 eye-movement metrics: pursuit initiation (latency and open-loop pursuit acceleration), steady-state tracking (gain, catch-up saccade amplitude, and the proportion of the steady-state response consisting of smooth movement), direction tuning (oblique effect amplitude, horizontal-vertical asymmetry, and direction noise), and speed tuning (speed responsiveness and noise) (Liston & Stone, 2014).

Using methods described in Liston et al. (2017), the COBRA test characterizes ten metrics of sensorimotor performance for each veteran participant to compute a TBI severity index. These ten metrics are normalized with respect to data from a 41-subject control sample (Liston & Stone, 2014), essentially expressing each metric as a z-value with respect to the normal sample. In the civilian TBI sample, several of the ten metrics were shifted by more than one standard deviation when normalized to the variance in the normal sample (e.g., eye acceleration: -1.32; steady-state gain: -1.96; steady-state proportion smooth: -1.96; speed-tuning responsiveness: -1.78) whereas others were largely unchanged from the control sample (e.g., direction-tuning anisotropy: -0.15) (Liston & Stone, 2014). The level of these impairments is used to characterize the oculomotor signs observed in TBI samples, essentially giving an across-observer average of the severity of oculomotor signs indicative of TBI. To quantify the TBI severity index for an individual, that individual's vector of normalized metrics is compared to the characteristic TBI vector. For example, veteran TBI participants with oculomotor impairments (e.g., 1 to 2 standard deviations, at or below the 15th percentile, below the mean of the normal sample) will have large values for TBI impairment indices. If a TBI subject had metrics near the mean of the normal sample (e.g., normalized metrics near zero), the TBI impairment index would also be near zero.

D. SURVEYS

Each potential participant answered pre-screening questions included on the telephone recruitment script (Appendix A). These questions helped to determine eligibility for participation and gathered health information relevant to TBIs such as symptoms and health conditions. Each test session included a standard demographics form (Appendix B). These questions are meant to provide information on exploratory factors that could potentially impact TBI experiences or symptoms and will be explored given that enough variability is present in the data. The types of questions included on the demographics survey covered military occupation, number and location of deployments, age, gender, marital status, employment, education, caffeine consumption, and sleep quality. The Ohio State University (OSU) TBI Identification Method—Interview Form

(Appendix C) was used to collect TBI history and to document injuries that led to LOC. For the complete list of variables captured by these surveys, please see their corresponding Appendix.

E. PROCEDURES

Methods used to recruit participants included recruitment letters, flyers, and physician referrals. Those who expressed interest in participating in the study were pre-screened to verify inclusion and exclusion criteria. An appointment session was made in advance or for the same day, based on availability. The experimenter led individual participants to an interview room where they each received a verbal summary of the purpose of the study, procedures, potential risks, and their rights as a research participant. They were then provided with the consent forms to read and sign. Participants received a copy of the consent forms and the researcher retained the signed copies. The participants were then given the demographics survey to fill out and the experimenter used the OSU TBI Identification Method to ask questions and document each participants' TBI history. Once the forms were completed, the experimenter led participants to another room where the neuroFit ONE was located. The participants were given directions for each phase of the COBRA test session. Participants were given the opportunity to review the results of the COBRA task and were debriefed on the benefit of their participation in the study. Participants were advised to refer to their copies of the consent form should they have any questions and to use the provided contact information as needed. Data collected from the phone survey, demographics form, OSU TBI Identification Method, and each participant's TBI impairment index determined by the COBRA method was consolidated into one Microsoft Excel (2010) document for ease of analysis.

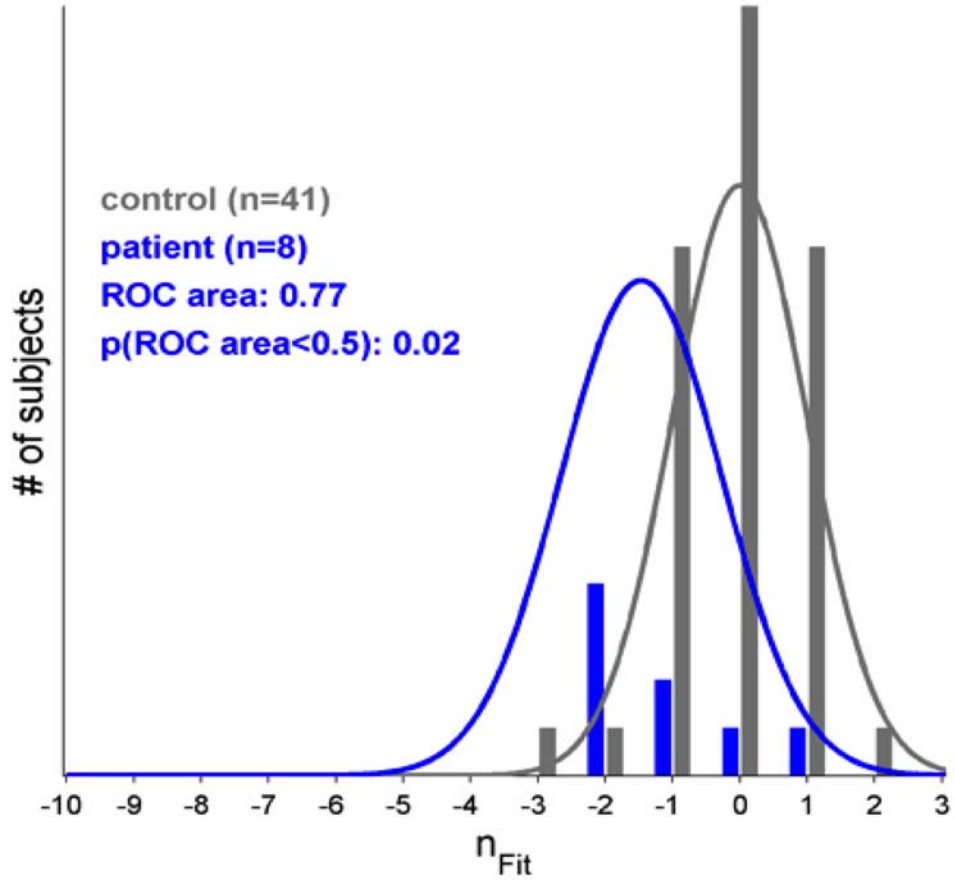
IV. RESULTS

The results section first focuses on the primary objective of this thesis, which is to verify that the COBRA method can accurately detect mild to moderate TBI in a veteran sample. The exploratory research objective of determining if the COBRA method can characterize head injuries based on the number of TBIs and time since the initial injury also is covered in the section below. It is important to note that results are constrained by the small sample size. A statistics professor at NPS who specializes in small sample sizes was consulted for the portion of this study that required statistical analysis. The final part of the results section provides the outcome of the usability assessment of the COBRA method and neuroFit ONE device with military medical facilities and personnel.

A. STATISTICAL FINDINGS

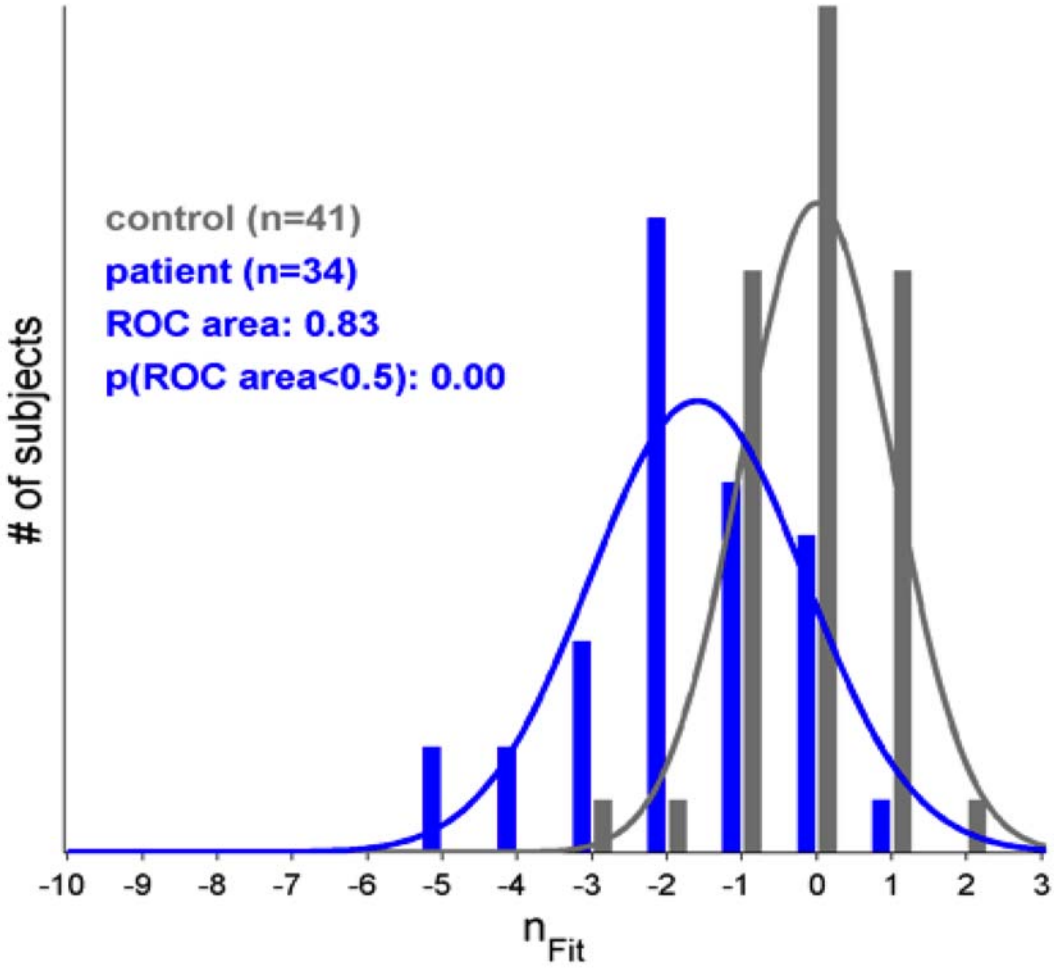
The preliminary analysis consisted of comparing the eight-subject veteran TBI sample to the published control sample and determining the accuracy rate of classifying TBIs (Liston & Stone, 2014). To quantify the COBRA method's detectability of TBI within the veteran TBI sample, the receiver operating characteristics (ROC) area between the veteran TBI and control sample distributions was computed using MATLAB version 9.2 (The MathWorks Inc., Natick, MA, 2017). This statistical approach follows the same analysis used in the previous COBRA study to compare the control sample with the TBI sample (Liston et al., 2017). The ROC comparison results are demonstrated in Figure 6, which displays a histogram plot of TBI impairment indices of the veteran sample (shown in blue) and the Control Sample (shown in gray) fitted with a normal distribution. The results indicate a significant difference between the veteran TBI and control samples (ROC = .77, p = .02) similar to the difference between the civilian TBI and control samples (Figure 7) from the previous COBRA study (Liston et al., 2017). The 77% classification rate indicates that use of the COBRA method and neuroFit ONE is a viable option for TBI screening and may be uniquely suitable for diagnosing chronic visual problems related to mild and moderate TBI.

As mentioned previously, a negative TBI impairment index indicates visual problems associated with TBI. Both figures show that resulting TBI impairment indices have overlap with the non-TBI control sample. With regard to the previous COBRA studies, this overlap is attributed to participants who were TBI patients but reported little-to-no residual impairment from their TBI incidences (Liston et al., 2017). Following this plausible conclusion, the two veteran participants in this study whose TBI impairment indexes did not indicate oculomotor impairment are considered outliers and this will be indicated in further analyses.



The Veteran Sample is shown in blue and the Control Sample is shown in gray.

Figure 6. Histogram Plot of TBI Impairment Indices Fitted with a Normal Distribution. Adapted from Liston (2017).



The civilian TBI sample is shown in blue and the control sample is shown in gray.

Figure 7. Histogram Plot of TBI Impairment Indices Fitted with a Normal Distribution. Adapted from Liston (2017).

The resulting TBI impairment indices collected from the COBRA method for each participant are listed in Table 3. Positive TBI index values represent normal eye movement functioning and negative values indicate degraded eye movement functioning and consequent signs of a head injury.

Table 3. TBI Impairment Index of the Veteran Sample

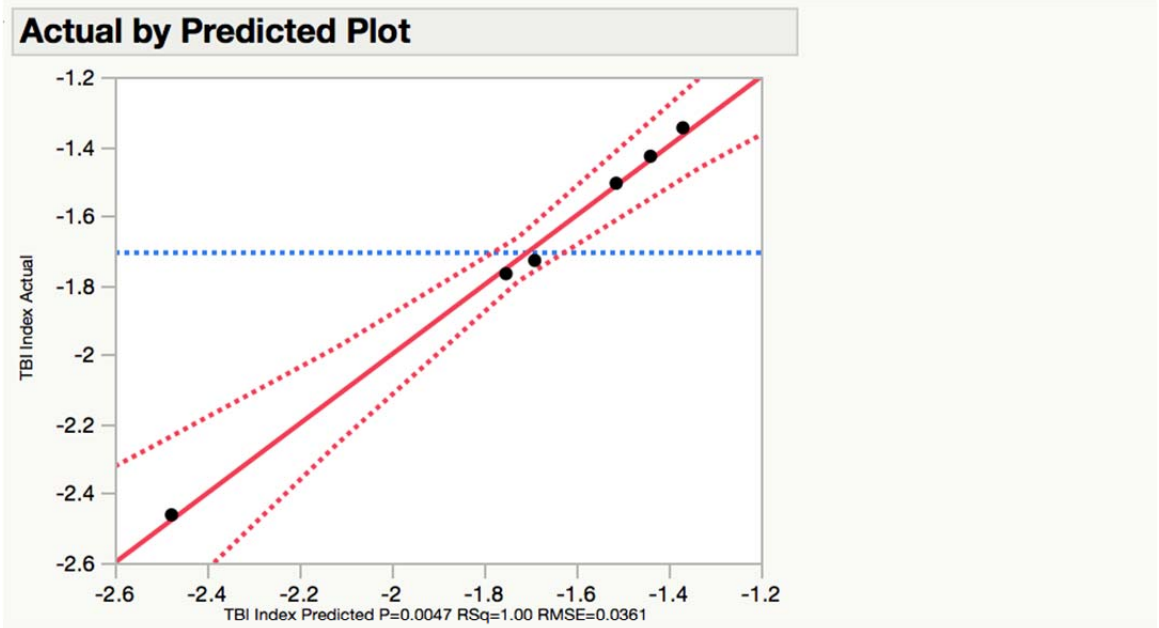
Veteran ID Number	Actual TBI Index
201	-1.429
202	-1.729
188	-1.507
41	1.157
203	-2.462
204	0.249
205	-1.347
64	-1.767

B. EXPLORATORY ANALYSIS

It is likely that a combination of TBI factors affect oculometric function. Therefore, a multiple regression was conducted with the additional predictors of the number of TBI incidences, elapsed time since the most recent TBI injury, and the interaction between these two variables to predict the TBI impairment index using JMP version 10 (SAS Institute, Inc., Cary, North Carolina, 2015). The two outliers previously mentioned are excluded from the model. A significant regression equation was found ($F(3,2) = 209.9$, $p = .005$), with an R-square value of .996:

Predicted TBI impairment index = -0.74 – 0.23 (Number of TBIs) – 0.071 (Time since most recent TBI) + (Number of TBIs – 2.5) -0.042 (Time since most recent TBI—6.83), where time is measured in years.

For example, a veteran who had 5 TBIs and a TBI that occurred 3 years ago would have a predicted TBI index of -1.68. The number of TBIs, time since most recent TBI, and the interaction of the number and time since TBIs in years were all significant predictors of TBI impairment index values. The actual by predicted formula plot and summary statistics (Figure 8) demonstrates the accuracy of the predictions for the TBI impairment index values using the model.



Summary of Fit

RSquare	0.996834
RSquare Adj	0.992086
Root Mean Square Error	0.036052
Mean of Response	-1.70685
Observations (or Sum Wgts)	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.81855395	0.272851	209.9253
Error	2	0.00259951	0.001300	Prob > F
C. Total	5	0.82115346		0.0047*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.743286	0.059	-12.60	0.0062*
Number of TBIs	-0.225778	0.017486	-12.91	0.0059*
Time since most recent TBI (yrs)	-0.071258	0.003255	-21.89	0.0021*
(Number of TBIs-2.5)*(Time since most recent TBI (yrs)-6.83333)	-0.04215	0.003372	-12.50	0.0063*

Figure 8. Actual TBI Index by Predicted TBI Index Plot and Summary Statistics

Actual TBI impairment index and TBI impairment index as predicted by the regression model for each patient is shown in Table 4. Each participant's actual TBI impairment index falls within the predicted 95% confidence interval, demonstrating the accuracy of the model.

Table 4. Predicted Formula TBI Index

Veteran ID Number	Actual TBI Index	Predicted TBI Index	Lower 95% mean CI	Upper 95% mean CI
201	-1.429	-1.44	-1.56	-1.31
202	-1.729	-1.69	-1.77	-1.61
188	-1.507	-1.51	-1.67	-1.36
41	1.157	-3.64	-4.03	-3.24
203	-2.462	-2.48	-2.62	-2.33
204	0.249	-3.10	-3.36	-2.84
205	-1.347	-1.37	-1.47	-1.27
64	-1.767	-1.75	-1.89	-1.62

1. Outlier Case Studies

This section takes an in-depth look at the two outliers identified in the veteran TBI sample. Both outliers reported multiple TBIs above the average of the sample (M = 3.25, SD = 1.83; see Table 5) and based on the results of the multiple regression model described above, these outliers should demonstrate TBI index values that indicate a head injury. For example, participant 41 who had 7 TBIs, with 10 years elapsed since the most recent TBI, has a predicted TBI impairment index of -3.64. Similarly, participant 204, with 4 TBIs and 14 years since the most recent TBI, has a predicted TBI impairment index of -3.10. The actual TBI impairment indices of these outliers exhibit little to no signs of problems with oculomotor functioning associated with chronic TBI. Additionally, the outliers scored better than the average TBI impairment index of the sample (M = -1.1, SD = 1.19). Therefore, several factors are listed in Table 5 as additional areas of interest and are considered as possible influential factors for their TBI indexes.

Table 5. Additional Factors of Outliers

ID#	TBI index	Number of TBIs	Time since most recent TBI (yrs)	Cause of most recent TBI	OIF/OEF deployments	Years since separation frm. military	Years of education	Highest level of education completed	Vision problems (glasses)
41	1.1573	7	10	Explosion	2	2	17	Masters degree	No
204	0.2489	4	14	Hit violently	0	4	15	Some Undergrad.	No

Participant 41 has the highest functioning score, indicating no oculometric impairments. This participant also completed the highest education level out of the group (Master's degree) and reported no difficulty with academic courses in high school. A rocket propelled grenade (RPG) explosion caused this participant's most recent TBI. He also reported that he deployed in recent years for OEF and OIF, with improved protective equipment. The other outlier participant, ID number 204, completed three years of undergraduate education. His military-related TBIs stemmed from motorcycle incidents that occurred over 25 years ago; his most recent TBI is not military related. Both participants separated from the military more recently in comparison to the group average (M = 7, SD = 4.9), indicating long-term access to health care provided by the military. Furthermore, while both participants reported having excellent vision, participant 204 also reported that his eyes are able to trace the movement of a target well due to visual training that he received in his previous military occupation as a sniper. Figure 9 captures this participant's pursuit speed responsiveness relative to target speed as measured by COBRA and displayed by the neuroFit ONE device. Similarly, Figure 10 demonstrates that participant 204's performance regarding speed responsiveness is superior, relative to the normalized distribution of the non-TBI control sample.

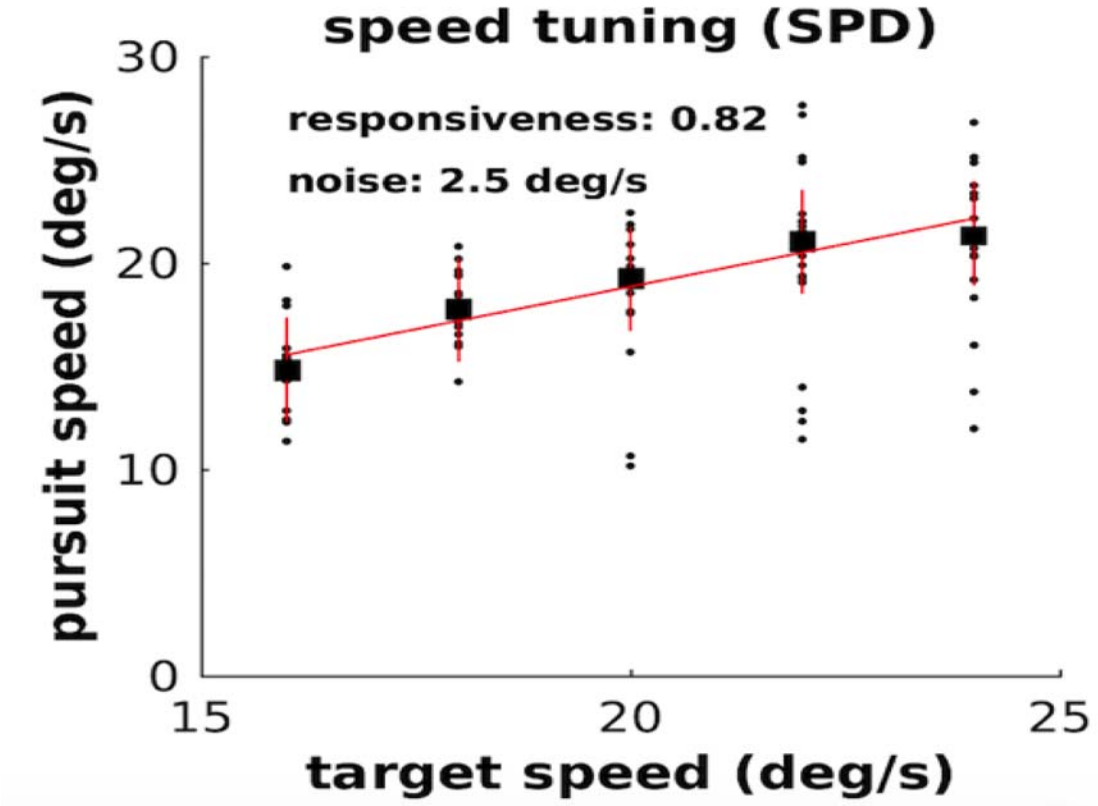


Figure 9. Participant 204: Pursuit Speed Responsiveness by Target Speed as Displayed by the NeuroFit ONE Device

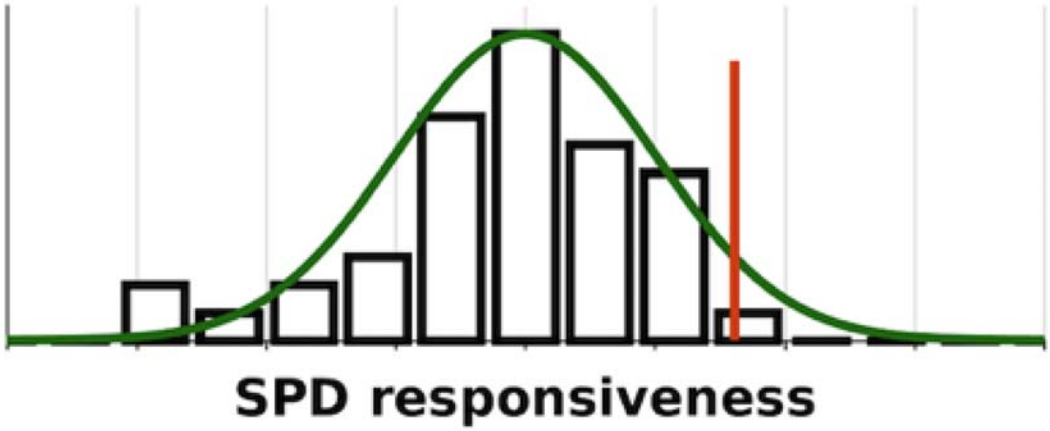


Figure 10. Participant 204 (red line): Speed Responsiveness Performance in Comparison to the Normalized Distribution of the Control Sample as Displayed by the NeuroFit ONE Device

2. Correlations

The demographic surveys collected information about daily experiences with regard to sleep, caffeine use, and alcohol use, which may impact the TBI impairment index With these risks, it is assumed that it is important to explore these possible relationships with the veteran sample.

The results to Spearman's rank order correlations that were used to evaluate whether the identified risk factors are associated with resulting TBI impairment indices are shown in Table 6. The results were not significant enough to determine relationships between each risk factor and TBI index. However, the results did demonstrate possible correlations as predicted, specifically with the relationship between sleep the night before and TBI, $r_s(6) = .56$, p = .145.

Table 6. Correlations between TBI Impairment Indices and Potential TBI Variables

Possible TBI Variables:	Spearman r	p-value
Typical number of hours sleept each night	0.344	0.405
Total hours slept last night	0.565	0.145
Typical number of cups of coffee per week	0	1
Total cups of coffee drank today	-0.18	0.67
Typical number of alcoholic drinks per week	-0.417	0.304

C. USABILITY ASSESSMENT

A usability assessment of the COBRA method and neuroFit ONE device was conducted by the experimenter to accomplish the secondary goal of this study, which is to determine if the integration of the whole system is feasible for military medical settings and personnel. The experimenter's direct involvement with the pilot study and test sessions was central to this assessment. As such, the usability evaluation focused on four components as evaluated by the experimenter's personal immersive experience: training, transportation, resource requirements, and overall task performance. Prior to this study, the experimenter had no previous experience with operating eyetracking systems.

1. Training

As stated in the pilot study section, the COBRA designer provided training, which consisted of an introduction to the system components, a live demonstrations on system setup, initial tests of the camera and subject-response button, calibration procedures, test procedures, and how to locate the file with the summary metrics of each session. Many of the skills required for an operator to conduct a test session with a participant are similar to the skills required for use of basic, commonly used computer programs, which makes instructor-led demonstration an effective method for training a small group of learners. For larger groups, it may be useful to supplement the step-by-step instruction portion of the user manual with relevant graphics and to distribute a copy to each learner. Completing this training with live demonstrations in 45 minutes was adequate; however, an additional training session was requested for the assurance of proper use. Therefore, it is reasonable to consider a 60–90 minute session for operator training, which could include a brief, realistic assessment on the operation and interpretation of COBRA results to evaluate learner knowledge.

2. Transportation

As a whole system, the COBRA and neuroFit ONE device consists of several components including two main monitors, chinrest, an aluminum table base, and a 42-inch tabletop. At least two personnel are required to move these components. Although test sessions can run without a secondary monitor, it was used for this study so it is included in the assessment. The neuroFit ONE device is carried in a soft case with a handle and adjustable shoulder strap, which is convenient for transferring the device between offices and neighboring buildings. A soft travel case is adequate for instances where the neuroFit ONE device will not be moved or transported between facilities over long distances. The soft case offers little protection to sensitive equipment such as the uncovered cameras and computer screen. The soft case is not adequate for shipment, which would be common for training and deployment purposes. Therefore, shipment of neuroFit ONE and the additional system components would require protective packaging, such as a pelican case, for it to be safely shipped in a container.

3. Resource Requirements

In addition to a protective case, additional resources required for test sessions with this study included an adjustable stool, and two adjustable chairs with varying widths. Multiple seating options were required to accommodate variations in height and weight. Participants less than approximately 6ft tall were required to use the adjustable stool without a backrest or arm rests because the table is similarly set to the height of a bar table. For this study, an inclusion criterion specifies the need for participants to be able to sit still and unsupported for 20 minutes. A patient who is unable to meet these requirements may not be suited for the COBRA system. An additional table, approximately 2 by 2.5 ft., was used in this study for the secondary monitor and keyboard to avoid crowding the participant. The neuroFit ONE device requires a viewing distance of 57 cm relative to the participant and it is best to center the device and the positioning of the participant. The approximate space required in a room for the whole system including both tables and movement for one chair is 25 ft^2.

COBRA testing was conducted in an open office, which was conveniently occupied by few people and led to minimal interruptions during the test sessions and no interruptions during the COBRA test. For practical use in a clinical environment, it is suggested to conduct COBRA sessions in a private, dimly lit, and climate-controlled room to ensure comfort and limit distractions. Two participants indicated that their eyes felt dry during the test session. They were reminded that they could blink or take breaks to use a rewetting eye drop as needed. It is important to make sure that there are no vents or other sources of increased airflow that would increase eye dryness and possible discomfort.

4. Overall Performance

Lastly, overall task performance was evaluated based on the number of successfully completed test sessions and time and attempts required to complete a test session. As noted in the participant section, ten participants attempted COBRA test sessions and eight sessions were successful. Similar to pilot testing, the eyetracker was not able to continuously track the pupil of the two excluded participants, which resulted

in incomplete and erroneous results. One of the participants possibly had a condition called ptosis, which causes eyelid drooping. This condition would make it difficult for the eyetracker to track the pupil if it is partially covered by the eyelid. Additionally, it is likely the case that these participants had untracked pupils due to the dark color of their eyelashes, as was seen in pilot testing. Unfortunately, this limitation could exclude a considerable portion of service members. Future modifications should address this issue.

On average, an individual participant completed calibration in 1–2 attempts and the COBRA test portion with one attempt in approximately 15 minutes. The two participants who were unable to complete this portion of the session took approximately 30 minutes and made at least two attempts with the COBRA test. Of the eight successful test sessions, one session took approximately 30 minutes and required more than two attempts to pass calibration.

V. DISCUSSION

Conducting this study in collaboration with NPS, VAPAHCS, DVBIC, and neuroFit Inc. was essential to the execution and successful completion of this study. Access to veteran patients with TBI diagnoses supported the validity of the findings from this study. Evidence from the comparison analysis and determined classification rate demonstrated in the results section supports the use of COBRA as a screening method for TBI and even as a management tool for TBI recovery. Access to and training for the neuroFit ONE device provided the opportunity to contribute to efforts being made by the military to evaluate the use of oculomotor tracking as a detection method for TBI in service members. Results from the usability assessment demonstrate that neuroFit ONE offers a common user interface that current military medical personnel would be able to understand without any additions to their required skill and knowledge set. Based on the assessment of training and resource requirements, the COBRA method and neuroFit ONE device can be integrated with current military medical capabilities.

A. STUDY IMPLICATIONS

It is indicated in previous COBRA research that participants who do not have strong residual impairment from TBIs will have normal COBRA TBI impairment indices (Liston & Stone, 2014). This reduction in impairment can be the result of proper treatment and recovery that occurs over time. Therefore, it is reasonable to believe that the two outliers in this study did not receive a TBI classification because they had had adequate treatment and time to recover from their injuries. As discussed in the outlier case study section, both of the outlier participants reported an above-average elapsed time since their last TBI event. They also reported having excellent visual acuity, which further demonstrates that this assessment could be accurate in that it did not falsely indicate visual degradation indicative of TBI. This occurrence also demonstrates the applicability of use of the COBRA method to monitor recovery over time with individual participants.

Also related to visual acuity is the consideration of improved visual performance. One of the outlier participants suggested that his results could indicate little to no visual problems because his previous occupation of sniper involved training to improve target accuracy. Sports vision training is often used to improve visual performance. Bressan (2003) demonstrated that there is benefit to sports vision skills training and dynamics can help athletes to maximize the use of their vision for sport performance. Visual training is applied in military settings; the U.S. Air Force Academy established a sports vision program in 1994 and continues to conduct research on vision and reaction tests with student athletes through their human performance lab (Zupan & Wile, 2015). In the case of the outlier who had been a sniper, the superior visual performance required for his position was demonstrated in his TBI impairment index. Although this only occurred with one participant, this result is an indication of the possible need to normalize TBI indices to populations such as snipers, airmen, and athletes as well.

Another factor to consider as an explanation for the outlier group is cognitive reserve (Stern, 2002). Cognitive reserve refers to reserve or resistance to brain damage. According to Stern, studies show that life experiences such as education, occupation, and leisure activities later in life, can increase reserve (2012). Although studies related to cognitive reserve generally apply to older adults with neurodegenerative diseases or Alzheimer's, it is conjectured that it could apply to results seen with the two participants in this study. As noted in the results section, there were two participants who demonstrated significant improvement following injury as compared to other participants. The participant who disclosed the most TBIs (n = 7) also had the highest TBI severity index, indicating that he had no injuries. This participant indicated completion of graduate-level education. The second participant with a high TBI severity index has a bachelor's degree.

It is also reasonable to consider the possibility that participant 41 incurred less extensive injuries during his deployments to OIF and OEF because he wore equipment that is more advanced in providing protection in comparison to equipment available in prior conflicts. By the early 2000s, improvements made to the design of helmets increased protection from shock or impact, in addition to ballistic threats than earlier

helmet designs offered (Moss, King, & Blackman, 2009). Three other participants in this study reported that they deployed to OEF and were near an explosion, but no TBIs resulted from these events. Innovations in individual protective equipment and protection are contributing factors in injury prevention and may also be a factor in recovery.

B. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The main limitation of this study is the small sample size, due to several factors. In looking at the occurrence of no-shows at a tertiary care VA medical center, Wyatt, Shriki, and Bhargava (2016) discovered that PTSD was the most common diagnosis in no-show patients; the second was major depressive disorder. PTSD is a common comorbidity of TBI in service members. For this study, there were several missed appointments and shared expressions of disinterest with participating in the study. Understanding additional factors of TBI patients is important to understanding their needs and facilitating involvement in studies such as these. Additionally, participants were not offered compensation for participating in this study and it is possible that this may have influenced the decision not to participate. Although this is to be considered, all participants were willing to participate and did not express any hard feelings about the lack of compensation. Also related to this issue is the fact that the experimenter had a limited time frame to conduct recruitment and data collection.

To address the sample size limitation, it is suggested that long-term studies would be appropriate in the future to increase the sample size and consequently, the power and diversity of the data collected. A multi-year longitudinal study would greatly improve the ability to draw conclusions from the data and allow researchers and clinicians to track the progression of recovery over time using COBRA metrics. A longitudinal study also allows for COBRA metrics to be compared to other assessment methods, or used in conjunction with other reliable means of TBI assessment in veterans.

Another factor, which is also mentioned in the previous COBRA studies, is the application of the COBRA method in emergency clinics. Previous COBRA studies took place in a laboratory (Liston & Stone, 2014). While this study was conducted in a clinical setting (VAPAHCS), the testing room was located in a private and quiet area within the

WRIISC. Thus, it is uncertain how results would transfer to an emergency room setting at a civilian or military hospital. In order to determine the usefulness, reliability, and validity of the COBRA method in an emergency clinic setting, it would be necessary to conduct research under those conditions.

Another similar consideration is to determine the placement of neuroFit ONE in military treatment facilities based on its resource requirements and relevant application. For instance, the DOD military health system (MHS), which manages the mission of health service support activities in theater, outlines distributed capabilities that are provided to military personnel in Joint Publication 4-02 Health Service Support (2012). The distribution of medical resources and capabilities to facilities is determined by the role of care offered at medical treatment facilities. The roles start at Role 1, which is considered unit-level care and as the role levels increase, so does the level of health care such that Role 4 is defined as medical care found in military hospitals located in the U.S. and other safe locations (Joint Chiefs of Staff, 2012). Based on the environment that the neuroFit ONE device was tested in with this study, it is presumed that neuroFit ONE can at least be integrated into Role 2 medical treatment facilities, which provide advanced trauma management and emergency medical treatment (Joint Chiefs of Staff, 2012). Role 2 facilities have the capability to operate specialized medical equipment to include a limited x-ray and have optometry services (Joint Chiefs of Staff, 2012); therefore, it seems ideal that the neuroFit ONE device can be operated at this level as well. Further testing is suggested to determine the application of neuroFit ONE in Role 1 aid stations and similar medical treatment facilities. NeuroFit ONE has limited self-protection and requires a designated quiet space and these requirements should be tested in a field environment to determine whether it is an appropriate fit for Role 1 care.

C. CONCLUSION

TBI screening and identification is an ongoing issue in the military and VA. Establishing a valid and reliable method to screen for TBI would greatly benefit treatment provided to service members. An oculometric screening method could potentially provide early identification and has the potential to capture undisclosed TBI,

which will ensure necessary treatment is provided immediately rather than contributing to prolonged treatment issues. The comparison results from this study demonstrate the sensitivity of the COBRA method with regard to identifying visual problems indicative of TBI. The sensitivity of this assessment method is important because it indicates the need for more thorough, follow-on evaluations. The experience and results of the usability assessment indicate that functions relating to training, operating, and transporting the entire system is within the capabilities of military medical personnel. Based on this study, it is recommended that the COBRA method and neuroFit ONE device be considered for further research. Further investigation on the use of COBRA and neuroFit ONE as a TBI screening method with service members in military and VA medical facilities also is recommended, as well as implementation at Role 1 medical treatment facilities.

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APPENDIX A. TELEPHONE RECRUITMENT SCRIPT

Appendix A
TBI Screening Script

****This form will be read to participants over the phone before they come for testing*

"Hi **<Veteran Name>**, my name is **<Name>** and I am calling from the VA Palo Alto Health Care System. Your physician/health care provider told us you were interested in hearing about a study for screening Traumatic Brain Injury in Veterans.

"Sound like something you would be interested in talking about? Do you have about 30 minutes to talk right now?"

-If not interested: "OK, well thank you so much for your time and your service. If you change your mind or have any questions, don't hesitate to call. I can be reached at <NUMBER>.

***-If no time now*:** "When would be a better time?" **<Schedule and end call>**

-If yes: "Great!" **<Continue with the following>**

I want to make sure you know that this is a screening call only, and that this screening and the research study itself are voluntary; you are under no obligation to participate. If you are eligible to participate, you will be asked to travel to the VA Palo Alto Health Care System (VAPA), which we'll talk about in a bit. But given the time commitment from you and the expense on our end, your honesty during this screening process is greatly appreciated. Also, please stop me at any time if you have any questions, and again my name is <NAME>.

"So let me tell you a little bit about this study. We are assessing the use of an eyetracking method to screen for Traumatic Brain Injury, which I'll refer to as TBI, in Veterans. In this study, we hope to validate an eye-tracking method to screen for TBI in veterans. Eyetracking is non-invasive method for recording a person's eye movements, such as where they are looking, and for how long. This method could prove to be a viable option to immediately screen service members for TBI in a deployed environment and consequently, improve the treatment time and approach for these problems. Research indicates that TBI affects the performance of eye movements and that this can be demonstrated with several non-invasive eye-performance tasks. A participant would simply have to look at moving images on a computer monitor to be screened for TBI.

The study will take about 1 hour of on-site screening, which includes filling out surveys and doing simple computerized tasks while your eye movements are recorded.

"Now that you've heard about the study and the time commitment involved, I want to check in with you. Do you have any questions? Are you still interested in participating?"

***-If no, say*:** "Ok, I understand. Thank you so much for your time. If you change your mind, don't hesitate to give us a call!" **<End call>**

***-If yes, say*:** "That's great. So just to confirm: Thinking about your life and schedule, are you realistically able to commit to coming to the VA for 1 hour for this study? Because the study only takes 1 hour, we can try to schedule it on a day when you may already be coming to the VA.

***-If no, say*:** "Ok, I do understand. Thank you so much for your time. If your schedule changes, don't hesitate to give us a call!" **<End call>**

-***If yes, say***: "Wonderful. Now we need to go over some required information."
<Continue with the following>

"The following is information that I am required to tell you by the VA. It is lengthy and may seem redundant, but please listen carefully as it is meant to ensure your safety as a potential participant in research. The important thing to remember is that your participation is voluntary and that every safeguard will be taken to ensure the safety of your privacy and data. When you are screened, you will be asked a list of questions. You may choose not to answer these questions. You also may choose to stop participating at any time. Information about you that you give during the screening procedure will be kept as confidential as possible as required by law. If you refuse to answer the questions or stop answering them at any time, there will be no penalty, and you will not lose any VA benefits to which you otherwise would be entitled.

"The risk to taking part in this screening process is very small. The screening interview is not designed to ask you for sensitive personal information, but it is possible that some people may feel uncomfortable answering questions with a person they do not know. If you qualify to take part in the study and are interested in taking part in it or in future research studies, then I will record your name and information; this will be kept confidential, but there is a small risk that people outside of the VA Palo Alto could learn this information. It is possible that the Food and Drug Administration, and other federal and state authorities, may inspect this record.
If you are not interested in the study, then I will destroy the personal information you give me.

"The benefit to you of taking part in this screening interview is that you will find out whether you can take part in the study. You will not be paid for answering questions in this interview since it is only to see whether you qualify to take part in the study. One question that we will not ask you at this time is whether you routinely use any recreational drugs that alter your mental functioning or if you have had trouble in the past due to use of these drugs. If you would answer yes to this, please do not consent to this screening procedure and withdraw from the study and we will consider you as not having been enrolled with no additional information recorded.

Risks and Explanation of Screening Questions:
We are very concerned about your safety and for this reason, we will ask you questions designed to assess whether you can safely and comfortably participate in this study. To protect your confidentiality, we cannot talk to your physician unless we have your permission. If you have back pain or any other condition that would prevent you from sitting still in a chair for about 20 minutes we may also ask you not to participate in this study. We will only use the screening information obtained in this interview to determine whether you are able to participate in our study and will otherwise keep all records confidential. Please realize that if you choose to participate, **you may discontinue any of the procedures in this study at anytime.** If you pass our screening and choose to participate, We will also discuss the risks of the project with you in detail before study begins.

[Optional statements if potential participants ask why they are being asked health information.]
We interview people about their health and demographics. There are several reasons for these questions. In some cases, we need to select people according to age, handedness, or education.

We also need to avoid including people with any problems that may involve brain dysfunction such as learning disabilities, stroke or related risk factors, or severe mental illness. This information will be used only to decide whether you are appropriate for out studies and will be kept confidential.]

If you do not want to answer these questions, you do not have to participate in the screening interview.

"I am going to provide you some contact information if you have any questions, concerns, or complaints about this interview or about your rights as a research participant. If you want to write it down, I can wait until you're ready.

-For general study questions, Dr. Maheen Adamson at 650-493-5000, ext 62179
- For your rights as a research participant, Stanford Institutional Review Board (IRB) at 650-723-5244 or toll-free at 1-866-680-2906"

"Ok, that was a lot. Do you have any questions? Are you willing to participate in the screening interview?

-If no, say: Ok, thank you so much for your time. If you change your mind, do not hesitate to give us a call!" **<End call>**

Future Studies
It is possible, though we don't have current plans, that we might ask you to participate again at a later date. Your participation in this study is wholly voluntary. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time.

-If yes, say: Great! Are you able to talk now?

-If NOT able to talk now, say: Ok, let's find a date and time that works best for you. Before I arrange a date and time to be screened, I want to mention a few of the reasons why someone would be excluded from our study. Some of those reasons are:

- If you have a diagnosis of any of the following: psychosis, schizophrenia, bipolar, major depression (MDD), alcohol or drug addiction, suicide ideation, severe TBI, dementia, and MCI.
- If you have suffered a stroke or brain damage resulting in severe cognitive problems.
- If you are taking drugs that affect cognitive function.
- If you have facial injuries that would make using a chinrest uncomfortable.
- If you have conditions that would make the left eye untrackable including eyelid occlusion, paresis, and/or cataracts in the left eye.
- If it would be difficult for you to limit your alcohol, or not use illegal drugs during the length of the study.

After hearing this list, do you think you're still eligible to be in our study?

-If no, say: "Unfortunately, the criteria for the study are based on a set

of rules which we cannot change. It's not a personal judgment, but we have to adhere to the rules of the study. I really appreciate you taking the time to speak with me today. If you have any further questions or concerns about the study please feel free to call"**<End call> (ASK ABOUT FUTURE STUDIES)**

***-If yes, say*: "Great! Let's arrange a time for you to be screened!" <Arrange date and time to be screened. Continue with following script.>**

"Is this number your preferred contact number? And can you please provide me your full name?

"Remember, they'll be asking you some questions during the call. One question they will ask is about any prescribed medications you are on and their directed use. Please make sure you have this information available for the call.

-If yes, say: "Fantastic! Let's get started…" <Proceed with screening>

Health Screen (Use back of form for long responses)

Personal Data

1. Full Name_____
2. Date Interviewed_____
3. Gender M ☐ F ☐

4. Phone_____
5. Age_____
6. Date of Birth_____
7. Referral Source_____
8. Right or left handed_____

Education/Background

1. Number of years of education/degrees: _____
2. Unusual trouble with specific subjects in school: (i.e.: reading, spelling, math) _____
3. Past/present primary job: _____
4. What was first language/any other languages: _____
5. Of what ethnic/racial group or groups do you consider yourself a member? Please indicate any that apply:
   Race: Hispanic Asian African American Native American White No report
   More than 1 _____

Systematic Health

1. Last time saw physician_____
2. Hospitalizations of any sort_____
_____

Health

1. Have you experienced a TBI in the last two months? If YES, EXCLUDE from study	☐ YES	☐ NO
1. Have you experienced a head injury that resulted in loss of consciousness? If YES: how long were you unconscious? _____ (If greater than 24 hours, EXCLUDE from study)	☐ YES	☐ NO
2. Have you ever experienced a head injury that resulted in post-traumatic amnesia? If YES: how long did this last? _____ (If greater than 7 days, EXCLUDE from study)	☐ YES	☐ NO
3. Have you ever experienced a penetrating head wound/open head injury? (If YES, EXCLUDE from study)	☐ YES	☐ NO
4. Have you ever worked as a machinist, metal worker, or any profession or hobby grinding metal?	☐ YES	☐ NO
5. Have you ever had an injury to your eye involving a metallic object?	☐ YES	☐ NO
5a. If yes, Was this object successfully removed? If no, EXCLUDE from study	☐ YES	☐ NO
6. Weight in pounds_____		

_____

Indicate whether you have or have had any of the following conditions

1. Heart or Respiratory Disease_____
2. High Blood Pressure_____
3. Anemia_____
4. Diabetes_____
5. Symptoms. Have you ever felt: Dizziness, fainting spells, loss of memory, numbness or weakness in body, problems understanding what you've read, paying attention to what people have said, frequent or severe headaches_____
6. Sleeping problems (i.e.: apnea) _____
7. Brain Cancer_____
8. Hx of serious or recurrent infections in the brain (i.e.: meningitis, encephalitis)_____
9. How much alcohol use/week? Type of alcohol._____
10. Head injury (length of posttraumatic amnesia)_____
11. History of increased intracranial pressure (e.g. due to infection or trauma)_____
12. Seizures/fainting spells/migraines_____
13. Family history of seizures_____
14. Evaluated for neurological illness such as stroke, lacunar infarct or aneurysms_____
15. Use caffeine or tobacco_____
16. Diagnosis of any of the following: psychosis, schizophrenia, bipolar, major depression (MDD), alcohol or drug addiction, suicide ideation, severe TBI, dementia, and MCI

17. Have suffered from a stroke or brain damage resulting in severe cognitive problems.
18. Taking drugs that affect cognitive function
19. Facial injuries that would make using a chinrest uncomfortable.
20. A condition that would make the left eye untrackable including eyelid occlusion, paresis, and/or cataracts in the left eye

Eye Health

1. How is your vision_____
2. Wear glasses or contacts and what is the prescription _____
3. Last time saw an eye doctor: _____
4. Ever have problems with eyes: (i.e. cataracts, glaucoma)_____
5. Are you colorblind _____

Hearing

1. Last time hearing was tested: _____
2. Have any hearing difficulty: _____
3. Wear hearing aids:_____

Other

1. Is there anything else you might want to add that would be important for us to know about you? (i.e.: any handicap that limits your daily activities):

_____

3. Do you have any intracardiac lines_____
4. Do you have an implanted medication pump_____
5. Do you wear a prosthesis_____

If non-white or Hispanic Circle the following (needed for NIH reporting):

Ethnic Category
Hispanic or Latino
Not Hispanic or Latino
Unknown (Individuals not reporting ethnicity)

Racial Categories
American Indian/Alaska Native
Asian
Native Hawaiian or Other Pacific Islander
Black or African American
White
More than one race
Unknown or not reported

If Hispanic or Latino: Racial Categories
American Indian or Alaska Native
Asian
Native Hawaiian or Other Pacific Islander
Black or African American
White
More Than One Race
Unknown or not reported

Handedness Questionnaire (if unclear about handedness)

	LEFT	RIGHT
What is your dominant hand?	_____	_____
Dominant hand of mother	_____	_____
Dominant hand of father	_____	_____

	LEFT	RIGHT
Maternal grandmother:	_____	_____
Maternal grandfather:	_____	_____
Paternal grandmother:	_____	_____
Paternal grandfather:	_____	_____

How many of your brothers and sisters are **LEFT handed**? _____ **RIGHT handed**? _____

How many of your children are **LEFT handed**? _____ **RIGHT handed**? _____

For the following activities, please indicate your hand preference by marking the most appropriate space. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. The phrases "Never right" and "Never left" mean you would only use that hand if forced to. Please answer all the questions.

	Only Left, Never Right	Left Preferred	No Preference	Right Preferred	Only Right, Never Left
Writing					
Drawing					
Throwing					
Scissors					
Toothbrush					
Knife (without fork)					
Spoon					
Broom (upper hand)					
Striking a match					
Opening a box (lid)					
Foot used for kicking					
Preferred eye when using only one (e.g., looking in a camera or telescope lens)					

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APPENDIX B. DEMOGRAPHICS FORM

Demographics
Subject ID_____

1. What is your age?_____
2. What is your gender? _____
3. What is your race?.....☐American Indian or Alaska Native ☐Asian
   ☐Black or African American
   ☐Native Hawaiian or other Pacific Islander ☐White ☐Unknown
   ☐Other
4. What is your ethnicity?.....☐Hispanic or Latino ☐Non Hispanic or Non Latino ☐Unknown
5. What is the highest level of education that you have completed? ☐Less than high school diploma/equivalency ☐High school graduate or GED ☐Some college ☐College degree ☐Graduate school ☐Graduate degree ☐Technical/trade school ☐Unknown/other
6. Are you receiving disability benefits?.. ☐No ☐Yes
   - Have you applied for disability benefits? ☐No ☐Yes
7. Are you right or left hand dominant? ☐Don't know ☐Left ☐Right ☐Both / Ambidextrous
8. Are you currently (check all that apply)
   ☐a.Not employed and not looking for work ☐b.Self-employed ☐c.Homemaker
   ☐d.Not employed and looking for work ☐e.Student ☐f.Retired
   ☐g.Unable to work due to health reasons ☐h.Employed part-time ☐i.Employed full-time
9. a) Prior to deployment, what was your marital status? ☐Married ☐Divorced ☐Never married ☐Widowed ☐Separated ☐Living as married

   b) Currently, what is your marital status? ☐Married ☐Divorced ☐Never married ☐Widowed ☐Separated ☐Living as married
10. a) Do you have any children that you parent? ☐No ☐Yes

    b) If yes, what are their ages and sex? age_____male/female age_____ male/female age_____ male/female age_____ male/female age_____ male/female age_____ male/female age_____ male/female age_____ male/female
11. Do you have elderly parents or other adults for whom you have caretaking responsibility? ☐No ☐Yes
12. What is your household's current monthly income? $_____per month
13. In which conflict(s) have you served? ☐a.WWII ☐b.Korea ☐c.Vietnam ☐d.Lebanon ☐e.Panama ☐f.Grenada ☐g.Persian Gulf War ☐h.Kosovo ☐i.Bosnia ☐j.Croatia ☐k.Somalia ☐l.Operation Enduring Freedom (OEF) ☐m.Operation Iraqi Freedom (OIF) ☐n.Other (please specify)_____
14. Date and rank upon most recent separation?
    a. Date ____/____/_____

    b. Rank_____
15. What is/was your Military Occupational Specialty (MOS)?
    _____

16. Caffeine Questions:
    a. How many cups of coffee have you had today? _____
    b. How many energy drinks have you had today? _____
    c. How many other caffeine-containing drinks have you had today? _____
    d. How much caffeine do you typically consume in a week? _____
17. Sleep Questions:
    a. How many hours of sleep did you get last night? _____
    b. How was your sleep quality last night? ☐ Great ☐ Good ☐ Average ☐ Bad ☐ Terrible
    c. How many hours do you typically sleep each night? _____
    d. What is your typical sleep quality like? ☐ Great ☐ Good ☐ Average ☐ Bad ☐ Terrible

APPENDIX C. OSU TBI IDENTIFICATION METHOD

Name: _____ Current Age: _____ Interviewer Initials: _____ Date: _____

Ohio State University TBI Identification Method — Interview Form

Step 1

Ask questions 1-5 below. Record the cause of each reported injury and any details provided spontaneously in the chart at the bottom of this page. You do not need to ask further about loss of consciousness or other injury details during this step.

I am going to ask you about injuries to your head or neck that you may have had anytime in your life.

1. In your lifetime, have you ever been hospitalized or treated in an emergency room following an injury to your head or neck? Think about any childhood injuries you remember or were told about.
   ☐ No ☐ Yes—Record cause in chart
2. In your lifetime, have you ever injured your head or neck in a car accident or from crashing some other moving vehicle like a bicycle, motorcycle or ATV?
   ☐ No ☐ Yes—Record cause in chart
3. In your lifetime, have you ever injured your head or neck in a fall or from being hit by something (for example, falling from a bike or horse, rollerblading, falling on ice, being hit by a rock)? Have you ever injured your head or neck playing sports or on the playground?
   ☐ No ☐ Yes—Record cause in chart
4. In your lifetime, have you ever injured your head or neck in a fight, from being hit by someone, or from being shaken violently? Have you ever been shot in the head?
   ☐ No ☐ Yes—Record cause in chart
5. In your lifetime, have you ever been nearby when an explosion or a blast occurred? If you served in the military, think about any combat- or training-related incidents.
   ☐ No ☐ Yes—Record cause in chart

Interviewer instruction:
If the answers to any of the above questions are "yes," go to Step 2. If the answers to all of the above questions are "no," then proceed to Step 3.

Step 2

Interviewer instruction: If the answer is "yes" to any of the questions in Step 1 ask the following additional questions about each reported injury and add details to the chart below.

Were you knocked out or did you lose consciousness (LOC)?

If yes, how long?

If no, were you dazed or did you have a gap in your memory from the injury?

How old were you?

Step 3

Interviewer instruction: Ask the following questions to help identify a history that may include multiple mild TBIs and complete the chart below.

Have you ever had a period of time in which you experienced multiple, repeated impacts to your head (e.g. history of abuse, contact sports, military duty)?

If yes, what was the typical or usual effect—were you knocked out (Loss of Consciousness - LOC)?

If no, were you dazed or did you have a gap in your memory from the injury?

What was the most severe effect from one of the times you had an impact to the head?

How old were you when these repeated injuries began? Ended?

Step 1	Step 2						
	Loss of consciousness (LOC)/knocked out				Dazed/Mem Gap		Age
Cause	No LOC	< 30 min	30 min-24 hrs	> 24 hrs	Yes	No	

If more injuries with LOC: How many?_____ Longest knocked out?_____ How many ≥ 30 mins.?_____ Youngest age?_____

Step 3								
	Typical Effect		Most Severe Effect				Age	
Cause of repeated injury	Dazed/ memory gap, no LOC	LOC	Dazed/ memory gap, no LOC	LOC < 30 min	LOC 30 min - 24 hrs.	LOC > 24 hrs.	Began	Ended

Adapted with permission from the Ohio State University TBI Identification Method (Corrigan, J.D., Bogner, J.A. (2007). Initial reliability and validity of the OSU TBI Identification Method. J Head Trauma Rehabil, 22(6):318-329.

(Continuation from reverse side, if needed)

Name: _____ **Current Age:** _____ **Interviewer Initials:** _____ **Date:** _____

Step 1	Step 2						
	Loss of consciousness (LOC)/knocked out				Dazed/Mem Gap		Age
Cause	No LOC	< 30 min	30 min-24 hrs	> 24 hrs	Yes	No	

If more injuries with LOC: How many?_____ Longest knocked out?_____ How many ≥ 30 mins.?_____ Youngest age? _____

Step 3	Typical Effect		Most Severe Effect				Age	
Cause of repeated injury	Dazed/ memory gap, no LOC	LOC	Dazed/ memory gap, no LOC	LOC < 30 min	LOC 30 min - 24 hrs.	LOC > 24 hrs.	Began	Ended

Interpreting Findings

A person may be more likely to have ongoing problems if they have any of the following:

- **WORST**
  One moderate or severe TBI
- **FIRST**
  TBI with loss of consciousness before age 15
- **MULTIPLE**
  2 or more TBIs close together, including a period of time when they experienced multiple blows to the head
- **RECENT**
  A mild TBI in the last weeks or a more severe TBI in the last months
- **OTHER SOURCES**
  Any TBI combined with another way that their brain function has been impaired

For more information about TBI or the OSU TBI Identification Method visit:

- Ohio Valley Center at OSU
  www.ohiovalley.org/informationeducation
- BrainLine.org
  www.brainline.org

(Updated July 2013)

LIST OF REFERENCES

Agius, R. (2010). What is occupational health? Retrieved from http://www.agius.com/hew/resource/ohsilo.htm

Anderson, G. (2012). Psychological health and traumatic brain injury. *Military Medicine, International Journal of AMSUS*, *177*(8), 1–86.

Bagalman, E. (2013). Traumatic brain injury among veterans. Congress (CRS Report No. R40941). Retrieved from Congressional Research Service website: http://www.fas.org/sgp/crs/misc/R40941.pdf

Barker, F., Ciuffreda, K., Jacobs, J., Kardon, R., Scheiman, M., Schuchard, R., & Walsh, D. (2013). Traumatic brain injury detection using oculomotor and eye movement tracking: A technical working group critical review. *Group OTW. Version 1.3,* Fort Detrick, MD: Combat Casualty Care Research Program. 2013.

Boehm-Davis, D., Durso, F., & Lee, J. (2015). *APA handbook of human systems integration*. Washington, DC: The American Psychological Association.

Brain Injury Association of America. (2012). Brain injury facts: Brain injury statistics. Retrieved from http://www.biausa.org/glossary.htm

Bressan, E. S. (2003). Effects of visual skills training, vision coaching and sports vision dynamics on the performance of a sport skill. *African Journal of Physical, Health Education, Recreation and Dance 99*(1), 20–31.

CDC. (2016). Injury prevention & control: Traumatic brain injury & concussion. Retrieved from https://www.cdc.gov/traumaticbraininjury/severe.html

Defense and Veterans Brain Injury Center. (DVBIC). (2016). DOD worldwide numbers for TBI. Retrieved from http://dvbic.dcoe.mil/DOD-worldwidenumbers-tbi

Defense and Veterans Brain Injury Center (DVBIC). (2017a). Strategies for symptom management. Retrieved from http://dvbic.dcoe.mil/article/strategies-symptom-management

Defense and Veterans Brain Injury Center (DVBIC). (2017b). TBI basics. Retrieved from http://dvbic.dcoe.mil/article/tbi-basics

Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury (DCoE) & Defense and Veterans Brain Injury Center (DVBIC). (2010). Mild traumatic brain injury pocket guide (CONUS). Retrieved from http://www.dcoe.mil/Conten/Navigation/Documents/Mild%20Traumatic%20Brain%20Injury%20Pocket%20Guide%20.pdf

Defense Health Board. (2016). A scientific review of post-concussive computerized neurocognitive assessments. Retrieved from https://health.mil/Reference-Center/Reports/2016/02/10/Post-Concussive-Computerized-Neurocognitive-Assessments

Donnelly, K., Donnelly, J., Dunnam, M., & Alt, M. (2011). Reliability, sensitivity, and specificity of the VA traumatic brain injury screening tool. *The Journal of Head Trauma Rehabilitation, 26*(6), 439–53.

Farmer, C., Krull, H., Concannon, T., Simmons, M., Pillemer, F., Ruder, T. … Hepner, K. 2016). Understanding treatment of mild traumatic brain injury in the military health system. Retrieved from https://www.rand.org/pubs/research_reports/RR844.html

Gean, A. D. (2014). *Brain injury*. Philadelphia, PA: Wolters Kluwer Health.

Glass, I., Groswasser, Z., & Grosswasser-Reider, I. (1995). Impersistent execution of saccadic eye movements after traumatic brain injury. *Brain Injury, 9*, 769–775.

Guise, E., LeBlanc, J., Feyz, M., Lamoureux, J., & Greffou, S. (2017). Prediction of behavioural and cognitive deficits in patients with traumatic brain injury at an acute rehabilitation setting. *Brain Injury*, 1–8. doi: 10.1080/02699052.2017.1297485

Haddad, S., & Arabi, Y. (2012). Critical care management of severe traumatic brain injury in adults. *Scandanavian Journal of Trauma, Resuscitation and Emergency Medicine, 20*, 1–12.

Jaffee, M., Helmick, K., Girard, R., Meyer, K., Dinegar, K., & George, K. (2009). Acute clinical care and care coordination within department of defense. *Journal of Rehabilitation Research & Development, 46*(6), 655–666.

JMP®, Version 12. SAS Institute Inc., Cary, NC, 2015.

Joint Chiefs of Staff. (2012). *Health Service Support* (JP 4-02). Washington, DC.

King, N., Crawford, S., Wenden, F., Moss, N., Wade, D., & Caldwell, F. (1997). Measurement of post-traumatic amnesia: how reliable is it? *Journal of Neurology, Neurosurgery, and Psychiatry, 62* (1), 38–42. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC486693/

Kraus, M., Little, D., Donnell, A., Reilly, J., Simmonian, N., & Sweeney, J. (2007). Oculomotor function in chronic traumatic brain injury. *Cognitive Behavior Neurology, 20*, 170–8.

Liston, D., & Stone, L. (2014). Oculometric assessment of dynamic visual processing. *Journal of Vision*, *14*(14), 1–17.

Liston, D., Wong, L., & Stone, L. (2017). Oculometric assessment of sensorimotor impairment associated with TBI. *Optometry and Vision Science*, *94*(1), 51–59.

Marchman, L., Jakabek, D., Hennessy, M., Quirk, F., & Guazzo, E. (2013). Post-traumatic amnesia. *Journal of Clinical Neuroscience 20*(11), 1475–1481.

Masel, B., & DeWitt, D.(2010).Traumatic brain injury: A Disease process, not an event. *Journal of Neurotrauma*, *27*, 1529–1540.

MATLAB® Version 9.2. The MathWorks Inc., Natick, MA, 2017.

Mayo Clinic. (2014). Diseases and conditions: Traumatic brain injury. Retrieved from http://www.mayoclinic.org/diseases-conditions/traumatic-brain-injury/basics/definition/con-20029302?p=1

McKee, A. & Robinson, M. (2014). Military-related traumatic brain injury and neurodegeneration. *The Journal of the Alzheimer's Association, 10*(3), 242–253.

McMillan, T., Jongen, E., & Greenwood, R. (1996). Assessment of post-traumatic amnesia after severe closed head injury: Retrospective or prospective? *Journal of Neurology, Neurosurgery, and Psychiatry, 60*(1), 422–427. Retrieved from http://jnnp.bmj.com/content/jnnp/60/4/422.full.pdf

Microsoft. (2010). Microsoft Excel [computer software]. Redmond, Washington: Microsoft.

Moschner, C., Crawford, T., Heide, W., Trillenberg, P., Kompf, D., & Kennard, C. (1999). Deficits of smooth pursuit initiation in patients with degenerative cerebellar lesions. *Brain: A Journal of Neurology, 122*(11), 2147–2158.

Moss, W., King, M., and Blackman, E. (2009). Skull flexure from blastwaves: A mechanism for brain injury with implications for helmet design," *Physical Review Letters 103*, 1–4.

Mysliwiec, V., McGraw, L., Pierce, R., Smith, P., Trapp, B., & Roth, B. 2013. Sleep disorders and associated medical comorbidities in active duty military personnel. *Sleep, 36*(2), 167–74.

neuroFit Inc. (2016). Neurofit ONE setup manual: The eyes are the windows into the brain. (NPS.manual.161012). Mountain View, CA: Dorion Liston.

Newsome, W. T., Wurtz, R. H., Dursteler, M. R., & Mikami, A. (1985). Deficits in visual motion processing following ibotenic acid lesions of the middle temporal visual area of the macaque monkey. *Journal of Neuroscience, 5*(3), 825–840.

Rashbass, C. (1961). The relationship between saccadic and smooth tracking eye movements. *Journal of Physiology, 159*, 326–338.

Regasa, L., Thomas, D., Gill, R., Marion, D., & Ivins, B. (2016). Military deployment may increase the risk of traumatic brain injury following deployment. *Journal of Head Trauma Rehabilitation, 31*(1), 28–35.

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society, 8*, 448–460.

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. *Lancet Neurology, 11*(11), 1006–1012. doi: 10.1016/S1474-4422(12)70191-6

Teasdale, G., & Jennett, B. (1974). Assessment of coma impaired consciousness: A practical scale. *The Lancet, 304* (7872), 81–84. Retrieved from http://thelancet.com/journals/lancet/article/PIIS0140-6736(74)91639-0/abstract

Thier, P., Bachor, A., Faiss, J., Dichgans, J., & Koenig, E. (1991). Selective impairment of smooth-pursuit eye movements due to an ischemic lesion of the basal pons. *Annals of Neurology, 29*(4), 443–448.

Vanderploeg, R., Belanger, H., Duchnick, J., & Curtiss, G. (2007). Awareness problems following moderate to severe traumatic brain injury: Prevalence, assessment methods, and injury correlates. *Journal of Rehabilitation Research & Development, 44*(7), 937–950.

Vital, M. Traumatic brain injury: Hope through research. *National Institute of Health Publication, 2*(158). Retrieved from http://www.ninds.nih.gov/disorders/tbi/tbi_htr.pdf

Wyatt, A., Shriki, J., & Bhargava, P. (2016). Dealing with no shows: A quality improvement initiative at a tertiary care Veterans Affairs medical center. *Journal of the American College of Radiology, 13*(6), 702–704.

Zupan, M., & Wile, A. (2015). Eyes on the Prize. *Training and Conditioning 21*. Retrieved from http://training-conditioning.com/2011/03/21/eyes_on_the_prize/index.php

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