After the Boom, the Complexity of Blast Induced TBI

A Monograph

by

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14. ABSTRACT
Traumatic Brain Injury (TBI) has become a major health concern in the US Army. Since October 2001, over 2.6 million service members have deployed in support of combat operations, where TBI, primarily caused by blast, has been underreported and underdiagnosed. The Department of Defense (DoD) reports that nearly 384,000 service members serving in the Global War on Terror have suffered a TBI, classifying eighty two percent as mild TBI (mTBI). Labeled an “invisible wound,” mTBI has proven difficult to both prevent and diagnose. In addition, blast injuries further complicate mTBI diagnosis, adding to the problem’s complexity. In this light, protecting soldiers from blast-induced TBI (bTBI) has attracted attention from the public, senior DoD officials, and the government. The DoD has funded studies to help medical professionals diagnose bTBI and help identify its associated effects in order to treat those injured and return them to service. As the Army races to test and field new equipment to better protect soldiers, diagnosing mTBI, especially those induced by blast, remains a problem for health professionals and the Army at large. Thus, further research is needed that will spark new strategies to help alleviate blast-induced brain injuries and their ramifications in soldier’s lives.

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Abstract

After the Boom, the Complexity of Blast Induced TBI, by LTC Gregory J. Hirschey, US Army, 57 pages

Traumatic Brain Injury (TBI) has become a major health concern in the US Army. Since October 2001, over 2.6 million service members have deployed in support of combat operations, where TBI, primarily caused by blast, has been underreported and underdiagnosed. The Department of Defense (DoD) reports that nearly 384,000 service members serving in the Global War on Terror have suffered a TBI, classifying eighty two percent as mild TBI (mTBI). Labeled an "invisible wound," mTBI has proven difficult to both prevent and diagnose. In addition, blast injuries further complicate mTBI diagnosis, adding to the problem's complexity. In this light, protecting soldiers from blast-induced TBI (bTBI) has attracted attention from the public, senior DoD officials, and the government. The DoD has funded studies to help medical professionals diagnose bTBI and help identify its associated effects in order to treat those injured and return them to service. As the Army races to test and field new equipment to better protect soldiers, diagnosing mTBI, especially those induced by blast, remains a problem for health professionals and the Army at large. Thus, further research is needed that will spark new strategies to help alleviate blast-induced brain injuries and their ramifications in soldier's lives.

Contents

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To my kids: Hayden, Jacob, Zachary, and Maddison, continue to strive for excellence in everything you do! From the classroom to the court, field, or pool, or on the job, I wish you the very best.

Acronyms

ACH	Army Combat Helmet
ANAM	Automated Neuropsychological Assessment Metric
bTBI	blast induced Traumatic Brain Injury
BTF	Brain Trauma Foundation
BTI	Brain Trauma Indicator
CTE	Chronic Traumatic Encephalopathy
DHA	Defense Health Agency
DTI	Digital Tensor Imaging
DVA	Department of Veterans Affairs
DVBIC	Defense and Veterans Brain Injury Center
DoD	Department of Defense
ECH	Enhanced Combat Helmet
EOD	Explosive Ordnance Disposal
FDA	Food and Drug Administration
GWOT	Global War on Terrorism
IED	Improvised Explosive Device
ICD	Internal Classification of Diseases
IOTV	Improved Outer Tactical Vest
LOC	Loss of Consciousness
LRMC	Landstuhl Regional Medical Center
MACE	Military Acute Concussion Evaluation
MIT	Massachusetts Institute of Technology
MOS	Military Occupational Specialty
MRAP	Mine-Resistant Ambush Protected
MRI	Magnetitic Resonance Imaging
mTBI	mild Traumatic Brain Injury
NCAT	Neurocognitive Assessment Tool
P&R	Personnel and Readiness

PIE	Proximity Immediately Expectancy
PDHA	Post Deployment Health Assessment
PDHRA	Post Deployment Health Reassessment
PTSD	Post-Traumatic Stress Disorder
SOF	Special Operations Forces
TBI	Traumatic Brain Injury
TED	TBI Endpoints Development
USD	Under Secretary of Defense
USUHS	Uniformed Services University of the Health Sciences
UXO	Unexploded Ordnance

Introduction

For hundreds of thousands of soldiers who have served in the US Army since the beginning of the Global War on Terror (GWOT), the likelihood of suffering a Traumatic Brain Injury (TBI) during active duty has changed from a statistical possibility to a personal, often life-changing reality. Since October 2001, over two million service members have deployed in support of combat operations in Iraq, Afghanistan, and Syria; of those, studies show that up to twenty-three percent—or more than 380,000—have suffered a TBI of some degree or category.[1] As mounting health issues have accompanied service members returning home, concern from soldier's loved ones, the medical community, and US governmental agencies has risen as well. In response, independent study groups, task forces, and a Presidential Commission in 2012 were formed to study the effects of TBI and make recommendations.

This monograph focuses on mild Traumatic Brain Injury (mTBI), specifically TBI induced by blast (bTBI) and categorized as mild. The medical community uses the term "mTBI" when the injury includes a number of established, albeit inconsistent criteria, including a loss of consciousness lasting less than thirty minutes (or not at all) and relying heavily on a patient's self-reported symptoms; thus, when occurring in combat or during military operations, bTBIs may go undetected or undiagnosed. Often, soldiers do not realize they have even suffered an injury, with the onset of symptoms occurring well after a blast event. In other words, bTBIs are complex injuries that health care providers may not readily diagnose or treat. While imaging scans have proven ineffective for detecting a bTBI, emergent technologies show promise. In addition, medical researchers do not fully understand the exact mechanism of blast wave transport to the

[1] "DoD Worldwide Numbers for TBI," DVBIC, last modified June 9, 2016, accessed October 2, 2018, http://dvbic.dcoe.mil/dod-worldwide-numbers-tbi.

brain but have formed several prevailing theories. They do cite that bTBI symptoms are similar to those of Post-Traumatic Stress Disorder, and the two may be inter-related.

Research shows that bTBI injuries stand unique because blast waves affect the brain differently than a typical injury from blunt force. More specifically, the mechanism for injury to the brain is different than in typical concussion-type events, and research indicates that bTBI causes injury in different areas of the brain as well.

This monograph will discuss the challenges across a broad spectrum of issues that accompany mTBI and will argue that bTBI, while hard to prevent, may be even more difficult to diagnose. Blast-induced TBI is hard to prevent, proves difficult to diagnose, and necessitates further dedicated research in order to implement steps to reduce the occurrence and effects of this battlefield injury.A look into the background of TBI can help advance the course of discussion by first defining TBI specifically and then reviewing its history.

Background: TBI Defined

In 2008, policy makers and health experts developed a standard TBI definition for all services, Department of Defense (DoD), and other governmental health agencies. TBI is defined as "traumatically induced structural injury and/or physiological disruption of brain function as a result of an external force that is indicated by new onset or worsening of at least one of the following clinical signs, immediately following the event: any period of loss of or decreased level of consciousness; any loss of memory for events immediately before or after the injury; any alteration in mental state at the time of the injury (confusion, disorientation, slowed thinking, etc.); neurological deficits (weakness, loss of balance, change in vision, praxis, paresis/plegia, sensory loss, aphasia, etc.) that may or may not be transient; or intracranial lesion.

For clarification, the following definitions accompany the varying degrees of a TBI diagnosis:

(m) Concussion/Mild TBI is characterized by a confused or disoriented state that lasts less than 24 hours; loss of consciousness for up to 30 minutes; or memory loss lasting less than 24 hours. It excludes penetrating TBI. A CT scan is not indicated for most patients with mild TBI, and if obtained, it is normal.[2]

(M) Moderate TBI is characterized by a confused or disoriented state that lasts more than 24 hours; loss of consciousness for more than 30 minutes but less than 24 hours; memory loss lasting greater than 24 hours but less than seven days; or it meets criteria for Mild TBI but with an abnormal CT scan present. It excludes penetrating TBI, and a structural brain imaging study may be normal or abnormal.[3]

(S) Severe TBI is characterized by a confused or disoriented state that lasts more than 24 hours; loss of consciousness for more than 24 hours; or memory loss for more than seven days. It excludes penetrating TBI, and a structural brain imaging study may be normal but usually is abnormal.[4]

(P) Penetrating TBI, or open head injury, is characterized by a head injury in which the scalp, skull, and dura mater (the outer layer of the meninges) are penetrated. Penetrating injuries can be caused by high-velocity projectiles or objects of lower velocity, such as knives or bone fragments from a skull fracture that are driven into the brain.[5]

A wide variety of mechanisms can cause TBI, including injury to the head via slipping, tripping, or falling, or head injury from blunt force blows to the head during training or combat.

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[2] "Surveillance Case Definitions," Military Health System, accessed October 16, 2018, http://www.health.mil/Military-Health-Topics/Health-Readiness/Armed-Forces-Health-Surveillance-Branch/Epidemiology-and-Analysis/Surveillance-Case-Definitions.

[3] Ibid.

[4] Ibid.

[5] "Surveillance Case Definitions."

Injury mechanisms can also occur through the exposure of blast events. TBIs assessed as mild, or mTBIs caused by a blast event, are referred to as bTBI. The Army does not specifically separate or categorize bTBIs and refers to them generally on the scale of severity for TBI.

Background: History of TBI

As technology and cultures have advanced, the nature of warfare has changed as well. Yet, one constant has remained: injuries to the human body. Throughout history, humans in combat have suffered a wide variety of wounds. Prior to the issue of the steel helmet in World War I, British soldiers fighting in the trenches were susceptible to head injuries or trauma from shrapnel, blasts, or blunt trauma. Without proper head protection, soldiers were vulnerable to head injury from constant mortar and artillery explosions. Common head wounds and brain injuries provided the opportunity for British medical personnel to research brain trauma, especially as large numbers of soldiers treated at aid stations displayed many diverse symptoms. They reported amnesia, poor concentration, headache, tinnitus, sensitivity to light, hypersensitivity to noise, dizziness, and tremors.[6] Medical personnel struggled with diagnoses as they witnessed symptoms similar to those of soldiers who had sustained cerebral injuries.

In late 1914, A British psychiatrist consulting the British Expeditionary Force, Charles S. Myers, coined the term “shell shock,” associating its symptoms with “exploding ordnance” without visual external injury.[7] He noted that the injured soldiers exhibited both neurological and psychological symptoms such as hysteria, anxiety, paralysis, limping and muscle contractions, nightmares and insomnia, depression, dizziness, and loss of appetite.[8] However, the diagnosis of

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[6] Edgar Jones, Nicola T. Fear, and Simon Wessely, “Shell Shock and Mild Traumatic Brain Injury: A Historical Review,” *American Journal of Psychiatry* 164, no. 11 (November 2007): 1641–1645. 1641.

[7] Ibid., 1642.

[8] Rebecca J. Anderson, “Shell Shock: An Old Injury with New Weapons,” *Molecular Interventions* 8, no. 5 (October 1, 2008): 204.2.

shell shock proved controversial as some soldiers showed the same symptoms of shell shock without blast exposure. The mystery surrounding these symptoms led medical professionals to consider shell shock a psychiatric illness.[9]

The British Adjutant General's records show that only ten percent of soldiers diagnosed with "shell shock" suffered a concussion.[10] British medical professionals adopted the terms "functional nervous disorder," "traumatic war neurosis," and "neurasthenia" in favor of shell shock.[11] However, the British army and general public failed to recognize those terms, continuing to prefer the use of "shell shock" until World War II.[12]

By the time the US entered World War I in early 1917, the diagnosis of shell shock had become so prevalent that US Army Major Thomas Salmon was ordered to study shell shock and give recommendations to US Army policy makers.[13] As a result of his input, the Army created a psychiatric base hospital to serve as a triage for injured soldiers with shell shock symptoms or signs, but the number of cases continued to rise. Lieutenant Colonel John Rein, consultant in neuropsychiatry to the American Expeditionary Force, reported that fifty to sixty percent of soldiers admitted to the base hospital with shell shock reported to have suffered a concussion.[14] By late 1917, medical professionals noted that not all shell shock cases involved head injury, bolstering medical authorities' attempts to restrict the diagnosis.[15] In 1919, thirty eight percent of hospitalized veterans were classified as either mental or nervous cases.[16] Due to a lack of consensus among medical personnel, they categorized shell shock as either a physical or

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[9] Ibid., 9.

[10] Ibid., 2.

[11] Ibid.

[12] Ibid.

[13] Jones, Fear, and Wessely, "Shell Shock and Mild Traumatic Brain Injury," 1642.

[14] Ibid., 1641.

[15] Ibid., 1642.

[16] Anderson, "Shell Shock," 2.

emotional injury and lamented the difficulty of distinguishing a mild head injury from a highly stressful event.[17]

As World War II began, US medical personnel lacked experience with shell shock and drew upon incidences from their civilian practice.[18] From the war's outset, military psychiatrists relied on drug therapy to treat service members suffering from shell-shock associated symptoms.[19] In essence, medical approaches to treating shell shock resembled those of World War I: soldiers were treated near the front lines by trained psychiatrists, received rest and hot meals, and returned to combat within three days.[20] In the Korean War, medical professionals followed a more simplified approach, using the acronym PIE: treat shell shock casualties near the front lines (Proximity); treat at the soonest opportunity (Immediately); and give treatment in an atmosphere that encourages their return to combat (Expectancy). In the Vietnam War, the treatment philosophy proved similar, with the exception that medical personnel treated shell shock away from front lines.[21]

Shell shock became the signature wound of wars prior to the Global War on Terror (GWOT). Yet, as the war on terrorism prevailed, a new signature wound surfaced: Traumatic Brain Injury (TBI), which garnered attention from the highest levels of the Department of Defense, including Congress. Over the past seventeen years, over two million service members

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[17] Jones, Fear, and Wessely, "Shell Shock and Mild Traumatic Brain Injury," 1644.

[18] Ibid., 3.

[19] Ibid.,10.

[20] Anderson, "Shell Shock," 10.

[21] Ibid., 10.

have deployed in support of the GWOT, with over 380,000 diagnosed with at least one TBI; 80 percent of those diagnosed have been considered mild TBI (mTBI).[22]

As Americans watched the initial combat operations in Afghanistan and Iraq, few suspected that both conflicts would play out over an extended period fueled by insurgency and enemy resistance. In March 2003, coalition forces began combat operations in Iraq, and by May 2003, President George W. Bush announced the end of major combat operations aboard the aircraft carrier USS *Abraham Lincoln*. For a short time, coalition forces enjoyed the freedom of movement throughout Iraq as service members conducted a variety of stability support operations.

In early 2003, coalition forces faced an emergent weapon limited only by the imagination of the maker: the Improvised Explosive Device (IED). As the enemy's weapon of choice and effectively evolving over time, the IED rapidly became one of the largest threats to servicemen in Iraq. Early in both the Afghanistan and Iraq conflicts, military vehicles where not intended to protect personnel from IEDs; they lacked the proper armor and hull design and easily fell victim to roadside bombs. In response, the Army quickly overcame rudimentary roadside bombs with the fielding of the new family of Mine-Resistant Ambush Protected (MRAP) vehicles. The newly fielded MRAP vehicles proved to increase soldier survivability on the battlefield. However, the incidence of bTBI continued unabated.[23]

As friendly forces continued to hunt Al Qaeda in Iraq and Taliban forces in Afghanistan, blast injuries from IEDs became one of the most prevalent causes of injuries in both theaters. As combat operations continued, the Army identified the need and rapidly fielded a new helmet

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[22] "Colston_12-13-17.Pdf," n.d., US Committee on Armed Services. accessed October 1, 2018, https://www.armed-services.senate.gov/imo/media/doc/Colston_12-13-17.pdf. 2.

[23] Lauren Fish, "Protecting Warfighters from Blast Injury," Center for A New American Security, April 29, 2018, accessed April 15, 2019, https://www.cnas.org/publications/reports/protecting-warfighters-from-blast-injury.

design and body armor: the Army Combat Helmet (ACH) and Improved Outer Tactical Vest (IOTV).

During both conflicts, service members were frequently exposed to IED strikes, but due to expedient medical evacuation to medical trauma centers, survival rates increased. MRAPs and more robust vehicle armor provided additional protection from blasts due to their unique design, and survival rates increased further. Service members on some occasions walked away from vehicles damaged beyond repair. More dismounted troops targeted by IEDs survived due to the increased protection in body armor, helmets, and rapid medical evacuation to field hospitals.

Many case studies have assessed the effects of blast injuries to service members to determine correlation of TBI with cognitive impairment and other side effects.[24] Now, after seventeen years of conflict, the services have deployed personnel on multiple tours of combat. As these personnel returned, however, many who had no visible wounds found themselves suffering with the signature wound, TBI, also labeled the "invisible wound."[25] Combat deployments continue to decline as the environment slowly changes from counter-terrorism operations to large-scale combat, but injured service members with ongoing TBI symptoms still remain within formations.[26]

Literature Review

While the scant published literature addressing TBI in the late 19th and early 20th centuries may seem explicable, an apparent literature gap still persists today. However, the gap is beginning to close. The Defense Health Agency (DHA) founded in 2013 recognizes today's lack of quality writings and published information for blast-induced TBI in the March 2018 *Military*

[24] Terri L. Tanielian and Lisa Jaycox, *Invisible Wounds of War: Psychological and Cognitive Injuries, Their Consequences, and Services to Assist Recovery* (Santa Monica, CA: RAND, 2008).

[25] Ibid., xix.

[26] Ibid., xxii.

Medicine, providing a historical approach.[27] Likewise, in her article "Shell Shock: An Old Injury with New Weapons," Rebecca J. Anderson suggested that medical experts a century ago were slow to correlate brain injury with psychological trauma; in reviewing soldiers' medical cases from World War I, she revisited researchers' first attempts to understand the link between neurological and psychological impairment. Anderson explored the difficult challenge medical experts have faced, from World War I to present day, to properly diagnose and categorize the brain injury and psychological impairment link. Further, she outlined the technological leaps in medicine that have enabled medical experts to begin to understand the correlation between brain injury and psychological functions.[28]

Exploring shell shock's devastating effects and the enigma surrounding its diagnosis, author Caroline Alexander brings a new side to the conversation. In her article "'Shell Shock'—The 100 Year Mystery May Now Be Solved," Alexander shared the findings of a research team that studied autopsies of eight recent veterans; their brains had suffered blast injury lesions that appeared different from those common to football players or boxers. The subjects of the study had endured exposure to blast and had experienced anxiety, headaches, depression, insomnia, memory and concentration problems, chronic pain, and seizures—all symptoms associated with the accepted term "shell shock." The subjects also exhibited symptoms similarly associated with what is now called Post Traumatic Stress Disorder (PTSD).[29] Without taking a far leap, one can conclude that brain injuries were often overlooked or simply misdiagnosed when associated with

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[27] Anna E Tschiffely et al., "Recovery from Mild Traumatic Brain Injury Following Uncomplicated Mounted and Dismounted Blast: A Natural History Approach," *Military Medicine* 183, no. 3–4 (March 1, 2018): e140–e147.

[28] Anderson, "Shell Shock: 204.2-18.

[29] "'Shell Shock'—The 100-Year Mystery May Now Be Solved," National Geographic, accessed October 3, 2018, https://news.nationalgeographic.com/2016/06/blast-shock-tbi-ptsd-ied-shell-shock-world-war-one/.

shell shock early on. In "'Shell Shock' Revisited: An Examination of the Case Records of the National Hospital in London," Stefanie Caroline Linden and Edgar Jones point out that during World War I, the injuries of servicemen treated and diagnosed at Britain's National Hospital were different from those at German hospitals, due in part to cultural differences and medical understanding.[30] One consistent theme resonated, however: shell shock was mostly diagnosed as or associated with neurosis or a psychological disorder, with no mention of injury from blast or concussion. As shell shock became the signature wound of twentieth century combat, the medical arena mostly associated it with battlefield fatigue and, later, with PTSD. Until recently, medical professionals have struggled to diagnose and link simple brain injury with psychological injury or neurological symptoms. In *PTSD: A Short History,* author Allen V. Horwitz, Ph.D., dean of social and behavioral sciences at Rutgers University, discusses the origins of PTSD and its constant change in diagnosis and definitions. He argues that today's cultural understanding and acceptance of mental health illness shape the diagnosis and reporting of PTSD, making it today's signature medical diagnosis.[31] Since the beginning of the GWOT, over two million US servicemen and women have deployed into combat, with several hundred thousand thought to have experienced a TBI during their deployment.

Clearly, since the late 1990s, TBI has become more commonly understood and studied, but prompt and accurate diagnosis still eludes medical professionals. In his article, "Traumatic Brain Injury Treatment, Diagnosis Continues to Elude Military Doctors," David Wood criticizes the military after his 10 years of combat for not having the mechanism to accurately diagnose and treat injured service members. His concern lies in the plausible assumption that many service

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[30] Stefanie Caroline Linden and Edgar Jones, "'Shell Shock' Revisited: An Examination of the Case Records of the National Hospital in London," *Medical History* 58, no. 4 (October 2014): 519–545.

[31] Allan V. Horwitz, *PTSD: A Short History* (Baltimore: Johns Hopkins University Press, 2018), 1.

members wounded early in the Afghanistan or Iraq wars were separated from the service without proper diagnosis and continued to suffer additional symptoms related to TBI.

After the Department of Defense (DoD) received public criticism for not doing enough to identify brain injuries in service members, the Military Health Communications Office responded with a release, "Military Health System: IDs of Brain Injuries During Deployment Increase." In this article, the DoD quickly counters that the Army enacted two policy changes: ALARACT 143/2006 and 160/2007; the former alerted unit commanders to concussions and to the reporting of soldiers injured with concussion; the latter issued a directive for units to conduct TBI training prior to deployment. These two policies led to a three-fold increase in TBIs identified.[32]

Additionally, the Defense Department's 2010 directive type memorandum (DTM 09-033), which mandated a medical evaluation for all service members who were within 50 meters of a blast, saw reporting increases across all services.[33] Gregg Zoroya's news story, "Army Officials: Brain Injuries Overdiagnosed," reports that leading medical health researchers Army Colonel (R) Charles Hogue and Army Colonel (R) Carl Castro recommended changes to the post deployment health assessment (PDHA) in their *New England Journal of Medicine* article. These researchers argue that brain injuries can present or exhibit in unique ways, include various levels of severity, and are distinct medical conditions. They theorize that the PDHA relies on flawed science and overemphasizes TBI, increasing the likelihood that other symptoms will be overlooked and go untreated, such as PTSD. The article not only drew the attention of the Army's Surgeon General, who considered changing the screening process, but garnered criticism from government and private researchers who disagreed with the findings and recommendations.

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[32] "Military Health System: IDs of Brain Injuries during Deployment Increase," Fortcampbellcourier., accessed October 5, 2018, http://fortcampbellcourier.com/lifestyles/article_4149c6a0-3387-11e8-90f2-3b6021b1f398.html.

[33] Ibid.

Critics were concerned this policy change could leave injured service members unprotected and without proper medical treatment.[34]

Even though the DoD enacted policy changes to increase proper TBI identification, T. Christian Miller and Daniel Zwerdling, in “Military Still Failing to Diagnose, Treat Brain Injuries,” found that military doctors and screenings still fail to properly identify concussions and miss up to forty percent of injuries. They reported that medical experts criticize concussion and TBI exams, describing them “as reliable as a coin flip.” When proper diagnosis does occur, no one documents the information in the permanent record, they attest. Additionally, they found gaps in the medical administrative system that proved unreliable in an austere environment.[35]

Though it seems the process for the TBI identification stands disputed, Kathleen Curthoy’s *Military Times* article suggests a new solution; “This New Blood Test Can Detect Traumatic Brain Injury in Troops” lauds a new technology that the military will field to the force in the near future.[36] A simple blood test may aid in the proper identification of brain injury, which could lead to early diagnosis and rapid treatment options.

Methodology

To consider the question of how the Army can protect soldiers from blast injuries as well as how medical professionals can better diagnose TBI caused by blast (bTBI), the applied methodology includes a broad evaluation; it first looks at historical markers and important milestones, including policy improvements as well as TBI screening methods; plus, it provides an

[34] “Army Officials: Brain Injuries Overdiagnosed,” *ABC News*, last modified April 15, 2009, accessed October 5, 2018, https://abcnews.go.com/Politics/story?id=7346747&page=1.

[35] “Military Still Failing to Diagnose, Treat Brain Injuries,” *NPR*, accessed October 5, 2018, https://www.npr.org/2010/06/08/127402993/military-still-failing-to-diagnose-treat-brain-injuries.

[36] “This New Blood Test Can Detect Traumatic Brain Injury in Troops,” Military Times, accessed October 10, 2018, https://www.militarytimes.com/news/your-military/2018/02/22/this-new-blood-test-can-detect-traumatic-brain-injury-in-troops/.

analysis of pertinent issues, from blast physics and prevailing neurological impairments to increased disease risk, bTBI prognosis and recovery, treatment challenges, and more. This comprehensive overview adds depth to analysis and future recommendations.

Department of Defense (DoD) Milestones

Particularly for the DoD, TBI among US military personnel has become a critically important health concern. Accordingly, both the DoD and the US Army have met several milestones in the past decade to further diagnosis and treatment protocols.

Incremental improvements since 2005

As improvements in DoD policy and medical support for TBI continue to build, advancements in protecting US soldiers from the long-term effects of bTBI can begin to escalate. A brief overview of steps that may improve the diagnosis and treatment of bTBI includes the following:

- 2005: The VA developed the Polytrauma System of Care, an integrated network of rehab programs that help those with combat- and civilian-related TBI to find the right location and treatment plan options.
- 2005: Defense and Veterans Brain Injury Center (DVBIC) was established.
- 2006: The DoD Directive 6025.21E was issued.
- 2006: ALARACT 143/2006 was issued.
- 2007: ALARACT 160/2007 was issued.
- 2008: Congress enacted the Traumatic Brain Injury Act, building on the original 1996 legislation.
- 2010: Two directive-type memorandums were issued, DTM 09-033 and DTM 10-22.
- 2012: President Obama issued an executive order to establish the National Research Action Plan, to identify TBI as an illness needing better understanding of underlying mechanisms to "make progress in future prevention, diagnosis, and treatment efforts."
- 2012: Research linked repeated TBI to CTE and correlation to PTSD.
- 2013: The DoD established the Center for Neuroscience and Regenerative Medicine Brain Tissue Repository.

2015: The DoD and Department of Veteran's Affairs were directed to study the effects of combat service and suicide and other mental health issues.[37]
2015: A study found veterans exposed to blast appear to experience faster brain aging.[38]
2015: A study found the service members exposed to a blast may still have brain damage without showing any signs or symptoms of TBI.[39]
2018: The DoD issued Mandate for Comprehensive Strategy and Action Plan for Warfighter Brain Health.[40]

TBI Screening

Identifying mTBI may prove especially difficult for health professionals due to the lack of physical injury such as a penetrating head wound. Consequently, the DoD and the US Department of Veterans Affairs (DVA) have established a standardized protocol that serves as the guide for all service health professionals to assess and evaluate service members for a concussion. Screening occurs after an event and includes an assessment that helps professionals decide the extent of injury. Clinicians determine if there was a loss of consciousness (LOC), memory loss or cognitive impairment, or post-traumatic amnesia associated with or after the event.[41]

To further advance the reliability of this evaluation, the DoD in 2008 issued a mandate to establish a neurocognitive baseline for each service member. Prior to deployment, all service members were directed to complete an online evaluation called the Automated Neuropsychological Assessment Metric (ANAM), which supports the Defense and Veterans

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[37] "Congress Orders Defense Dept. to Study Combat's Effects on Veteran Suicide Rates,"*The New York Times*, accessed October 3, 2018, https://www.nytimes.com/2015/12/19/us/congress-orders-defense-dept-to-study-combats-effects-on-veteran-suicide-rates.html.

[38] "Traumatic Brain Injury (TBI)," VA Office of Research and Development, accessed November 13, 2018, https://www.research.va.gov/topics/tbi.cfm#research4.

[39] Ibid.

[40] "Comprehensive Strategy and Action Plan for Warfighter Brain Health,", accessed April 15, 2019, https://health.mil/News/Articles/2019/03/01/DoD-recognizes-Brain-Injury-Awareness-month-promotes-warfighter-brain-health?types=Policies.

[41] "Concussion Screening," DVBIC, last modified November 5, 2013, accessed November 15, 2018, http://dvbic.dcoe.mil/article/concussion-screening.

Brain Injury Center (DVBIC) for data collection, management, and oversight of the Neurocognitive Assessment Tool program (NCAT). This program's goal is to ensure implementation of the evaluation system across all services, helping to facilitate the assessment of service members after they have sustained a concussion; this will also assist with the building and implementation of the second version of the NCAT ANAM, a system update that will collect data regardless of the service member's location when seeking medical attention. The system's future goals include incorporating of the NCAT 2 into service member's permanent medical file and giving health professionals access to records worldwide.[42]

Another screening and assessment tool for use in a deployed environment, the Military Acute Concussion Evaluation (MACE) does not help identify concussions or TBI but assists medical professionals with the neurocognitive evaluation process. Administered post injury by a trained medic, corpsman, or health professional,[43] the MACE proves most effective when given as soon as possible—the sooner the better. In this light, the DoD has designated a unique medical facility in Germany, Landstuhl Regional Medical Center (LRMC), to conduct concussion assessment for service members evacuated from the combat theater, unless medically unfeasible. LRMC's goal for MACE screening lies in identifying service members with a TBI history (combat or non-combat related) or determining the presence or absence of concussion symptoms.[43]

The third type of screening, the Post Deployment Health Assessment (PDHA), is administered upon redeployment; it consists of a questionnaire that determines if a service member has experienced a head injury and concussion symptoms, past or present. To follow-up

[42] "Concussion Screening."

[43] Ibid.

[43] Ibid.

this assessment, service members receive the Post Deployment Health Reassessment (PDHRA) to ensure they are not concussion symptomatic, with further follow-up warranted.[44]

Blast Physics

To best evaluate the implications of bTBI and its prevalence during deployment, gaining a basic understanding of the physics of blast occurrences as well as resulting injuries may prove essential. Medical professionals from the DVBIC, David F. Moore, MD, Ph.D., and Michael S. Jaffee, MD, define a blast as "an explosion in the atmosphere, characterized by a release of energy in such a short period of time and within such a small volume [that it results] in the creation of a non-linear shock and pressure wave of finite amplitude, spreading from the source of the explosion."[45] More specifically, when an explosion occurs, a blast wave forms from chemical reactions from the explosives themselves. The produced energy released from the explosion creates a blast wave that rapidly travels away from the point of origin. A near instantaneous rise in air pressure occurs within the surrounding air, which rapidly reaches peak overpressure. As the blast wave travels through the air, the pressure wave dissipates in inverse proportion to the distance of the point of origin. The second phase of the detonation occurs when the detonation products over-expand, creating a partial vacuum. Turbulent air flow following the blast wave forces debris and material to travel at high rates of speed away from the blast source. The waveform (called the Friedlander wave) describes pressure changes relative to the site of detonation.[46]

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[44] "Concussion Screening."

[45] David F. Moore and Michael S. Jaffee, "Military Traumatic Brain Injury and Blast," *NeuroRehabilitation* 26, no. 3 (March 2010): 179–181.179.

[46] Arul Ramasamy et al., "The Effects of Explosion on the Musculoskeletal System," *Trauma* 15 (May 29, 2013). 3.

Notably, the injuries resulting from these blast events prove significantly different than those of normal collision or impact. A blast event can cause multiple injuries through shock waves traveling faster than the speed of sound. During a blast, the primary blast wave causes damage to soft tissue and organs by overpressure. In the next phase, debris such as shrapnel, gravel, rock, building materials, or parts of the explosive itself travel through air, striking targets and surrounding objects. In the tertiary phase of injury, the victim is hurled through the air, striking other objects. The last phase of injury occurs when the thermal energy releases from the detonation, causing burn.[47] Complicating the physics behind a blast or detonation, not all explosives detonate simultaneously, and multiple shock waves result. Nearby surfaces can cause blast waves to reflect, causing initial pressure waves to collide with reflecting waves and thus creating larger waves.[48]

For those caught in a complex, multi-phase blast event such as this, the often painful and traumatic physical effects are dependent on several variables. First, the type and quantity of explosives used affect the detonation velocity and size of blast wave. In addition, the relationship of the victim or target from the point of detonation, including distance, elevation, and the surrounding areas, plays a role. Finally, the materials in the near vicinity can deflect or absorb blast waves, making them less destructive or even more so, making the effects of each blast unique and often inimitable.

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[47] Ramona R. Hicks et al., "Neurological Effects of Blast Injury," *The Journal of Trauma* 68, no. 5 (May 2010): 1257–1263.2.

[48] Ibid., 2.

Neurological Impairments

In April 2008, four agencies came together to co-sponsor a workshop to explore the mutual understanding of TBI: the DVIBC; the Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury; the DVA; and the Interagency Committee on Disability Research.[49] Neuroscientists, clinicians, and engineers attending the conference discussed the physics of blast as well as the acute clinical observations and treatments for blast exposure. Exploring the neurological effects of bTBI on the low end of the spectrum, the workshop described bTBI as similar to "shell shock," with a wide variety of symptoms that include retrograde amnesia, headache, confusion, amnesia, difficulty concentrating, mood disturbance, alterations in sleep patterns, and anxiety. As a workshop speaker, Army Lieutenant Colonel David Benedek of the Uniformed Services University of the Health Sciences described delayed symptoms from the onset of injury that fluctuate in severity and are triggered by later life events, often months to years after the injury.

In December 2014, the National Institute of Health published "Military-Related Traumatic Brain Injury and Neurodegeneration" by Ann C. McKee and Meghan E. Robinson, stating the co-authors' primary contention based on the suggestion of growing evidence: that individuals develop persistent and cognitive changes in behavior even after mild neuro trauma. During a TBI, they explain, rapid acceleration-deceleration causes the brain to flex, stretching cells and blood vessels and altering membrane permeability. Although the injury affects all cells,

[49] Hicks et al., "Neurological Effects of Blast Injury."

the axons are at most risk due to their long length and high membrane-to-cytoplasm ratio.[50] Pathological studies of concussion show multifocal traumatic axonal injury that compares or correlates with the TBI's severity; these studies postulate that the axonal injury plays a key role in the neurological and cognitive impairment observed after an injury.[51] More specifically, the shearing of the axons leads to a disruption in connectivity to different regions in the brain. Added evidence has linked fine-fiber unmyelinated axons disproportionately vulnerable to traumatic injury, which may contribute to the morbidity associated with mTBI. Concurrent to the breakdown of the axon and myelin sheath, the axon terminals also undergo neurodegenerative change and deafferentation.[52] However, since most personnel with mTBI fully recover, the authors suggest that the brain can recover from low-level injury. However, multiple TBI and increased severity in some individuals might trigger a progressive neurodegenerative cascade.

Mechanism for Blast Transport

While most people envision horrific visible wounds associated with an IED event, shrapnel and debris can miss the intended target. Soldiers targeted by IEDs may experience exposure to blast and escape without any sign of physical injury, walking away unscathed but dazed and confused. As of 2018, the DVBIC reports that 384,000 service members have been diagnosed with TBI since October 2001. Of those, the clear majority of reported TBI, roughly more than 80 percent, are classified as mTBI.[53] A gap in data exists, however, to sufficiently

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[50] Ann C. McKee and Meghan E. Robinson, "Military-Related Traumatic Brain Injury and Neurodegeneration," *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* 10, no. 30 (June 2014): S242–S253.

[51] Maria M. D'souza et al., "Traumatic Brain Injury and the Post-Concussion Syndrome: A Diffusion Tensor Tractography Study," *Indian Journal of Radiology & Imaging* 25, no. 4 (November 2015): 404–414.404.

[52] McKee and Robinson, "Military-Related Traumatic Brain Injury and Neurodegeneration," 5.

[53] "DoD Worldwide Numbers for TBI."

categorize TBI with those injuries associated with blast. The unique and complex nature of blast injuries make them stand apart from conventional injuries.[54] In particular, primary blast waves alone can cause physiological damage to the brain's soft tissue, which can lead to cognitive impairment.[55]

Three Possible Pathways to the Brain

It remains unknown exactly how blast pressure reaches the brain, but one theory focuses on primary blast waves entering through orbital areas, openings in the body such as the mouth, ears, and nostrils.[56] Another theory contends that blast pressure reaches the entire body and is transmitted through soft tissue throughout the chest and thoracic cavity, then surges to the brain through the vascular system. Once the blast wave arrives inside the skull, it travels the speed of sound to reach the brain.[57] Theories also suggest that high pressure waves transmitted through the vascular system cause additional damage to structures close to cerebral vessels, axonal fibers, and other cells.[58]

These findings coincide with those of scientists at Lawrence Livermore National Laboratory, who point to their discovery that nonlethal blasts can cause the brain to flex enough to generate potentially damaging loads without direct impact to the head.[59] Their methodology includes computer simulations to prove that a blast wave directly impacting the head causes the

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[54] Anna E Tschiffely et al., "Recovery from Mild Traumatic Brain Injury Following Uncomplicated Mounted and Dismounted Blast: A Natural History Approach," *Military Medicine* 183, no. 3–4 (March 1, 2018): 140–147.

[55] Ibid., e141.

[56] "'Shell Shock'—The 100-Year Mystery May Now Be Solved," 6.

[57] Ibid., 6.

[58] G.A.Elder and A. Cristian, "Blast-Related Mild Traumatic Brain Injury."

[59] "Blast Waves May Cause Human Brain Injury Even Without Direct Head Impacts," *ScienceDaily*, accessed October 15, 2018, https://www.sciencedaily.com/releases/2009/08/090826152713.htm.1.

skull flexure, “producing mechanical loads in brain tissue comparable to an injury producing impact, even at non-lethal blast pressures as low as one bar above atmospheric pressure.”[60] Using nonlethal blast pressure, their study produced simulations that caused the head to flex fifty microns (the width of a human hair), large enough to cause potential damaging loads on the brain. The team produced results that showed blast waves affect the brain in different ways than brain injuries caused by direct impact.

Theories of how Blast-induced Brain Damage Occurs

While researchers have reached a current consensus that the brain is vulnerable to blast injury, they concede that they do not completely understand the blast energy’s pathway to the brain. To clarify, the primary blast wave can travel to the brain in multiple ways, with three mechanisms in which transduction can occur: the first is through direct transcranial propagation; the next is through the vascular system to reach the brain; and the last is through the cerebrospinal fluid in the spinal cord to the foramen magnum.[61] Based on studies using rats, Dr. Ibola Cernak of Johns Hopkins University’s Applied Physics Laboratory hypothesized that blast waves transfer kinetic energy through the vasculature and trigger oscillating waves leading to the brain.[62]

Since the pathway for blast injury to the brain still remains undetermined, different theories exist that all suggest brain injury can occur without any direct impact to the head. In fact, several theories prevail that pressure in the brain caused by blast waves may cause bTBI. One such theory looks at the explosive effect on hollow spaces in the brain; this theory suggests that blast overpressure causes air bubbles in the brain to pop, leaving small holes in the brain, whereas

[60] “Blast Waves May Cause Human Brain Injury Even Without Direct Head Impacts,” 1.

[61] Hicks et al., “Neurological Effects of Blast Injury,” 2.

[62] Ibid., 2.

a blunt force concussion causes stretching and tears within the brain.[63] Another theory asserts that pressure causing injury to the brain is called "barotrauma," which occurs when a pressure wave rapidly transmits across media of different brain densities. Steep changes in pressure caused by the blast waves create bubble formations between the cerebral spinal fluid and the brain; this can cause damage to brain tissue, capillaries, and axons.[64] As the primary transmission lines in the nervous system, axons also comprise the nerves when bundled. However, the axons tear when brain tissue of less density overly expands into higher density regions and when ventricles expand much more than the brain tissue around them.[65] Yet, while neuro specialists can paint this detail of blast transport's physical effects, the timely diagnosis of bTBI often still remains elusive when no head injury is visually apparent.

Causes include the Recoilless Rifle

One example of a simple tactical task that exposes soldiers to injury risk without any direct cranial impact is through the use of a recoilless rifle. DoD studies have shown that repeated firing of shoulder-fired weapons is associated with cognitive impairment, reduced visual spatial memory, and less executive function. Studies show that cognitive function is not restored until 72 to 96 hours after the heavy weapons firing.[66] A 2015 Army survey compared those in breacher operations to those in non-breacher roles for concussion and post-concussion symptoms. Breachers, who are commonly exposed to low-level blasts, reported symptoms that interfered with their daily living activity. The study concluded that a medical concern did exist for the

[63] Fish and Scharre, "Protecting Warfighters from Blast Injury," 10.

[64] Ibid., 10.

[65] Fish and Scharre, "Protecting Warfighters from Blast Injury" 10.

[66] Ibid., 15.

correlation of low level blasts from shoulder-fired weapons and breaching operations with symptoms associated with bTBI.[67]

Distinctive bTBI Characteristics

Even with the prevalence of multiple blast transport pathways, theories of brain injury effects, and numerous causes identified, the characteristics of bTBI stand unique in several respects. Daniel Perl, a neuropathologist at Uniformed Services University of the Health Sciences, led a research effort that found distinct lesions in the brains of deceased service members previously exposed to blast;[68] these lesions formed scarring in the brain called "astroglial scarring." The service members varied in age from 26 to 45, had been exposed to explosive blast events in either Iraq or Afghanistan, and lived from four days to nine years from the time they experienced injury. Prior to death, the service members had reported a range of symptoms that included headache, anxiety, depression, insomnia, memory and concentration problems, seizures and chronic pain.[69] The team discovered scarring in the brain inconsistent with damage seen in any other type of brain injury.[70] According to Perl, "Our findings revealed that those with blast exposure showed a distinct and previously unseen pattern of scarring, which involved the portion of the brain tissue immediately beneath the superficial lining of the cerebral cortex—the junction between the gray and white matter—and the vital structures adjacent to the cavities within the brain that are filled with cerebral spinal fluid."[71]

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[67] Fish and Scharre, "Protecting Warfighters from Blast Injury" 14.

[68] "'Shell Shock'—The 100-Year Mystery May Now Be Solved."

[69] Ibid., 7.

[70] Ibid., 3.

[71] "Invisible Wounds of War Now Able to Be Seen," *Neuroscience News*, June 10, 2016, accessed November 12, 2018, https://neurosciencenews.com/blast-tbi-neurology-4435/.

Perl hypothesized that the injured area of the brain correlated with previously reported behavioral symptoms. Reviewing post-mortem autopsies of brains in eight service members, researchers saw that one of the brains showed signs of chronic traumatic encephalopathy (CTE), a neurodegenerative disease caused by repeated mild injuries to the brain; another brain showed signs of early stage CTE. The cause of death of the eight service members were listed as suicide or drug overdose (four), blast injury (three), and undetermined cause (one).[72]

As stated, mild blast concussion with head injuries associated with a blast have been a difficult to diagnose due to the absence of any physical damage and the microscopic level at which injuries occur; in addition, the unreliability of even the latest diagnostic tools adds further complexity. Currently, magnetitic resonance imaging (MRI) and computed tomography (CT) scans have proven unreliable for physicians to identity mTBI, let alone identify injuries from a blast event, bTBI.[73] An MRI can detect structural abnormalities in the brain as small as one to two millimeters. Less definitive than MRIs, CT scans perform poorly in bTBI diagnosis, with low assessment as a preferred method. Another diagnostic tool, neuropathology at the time of death, can effectively detect injury abnormality as small as .5 micron in diameter and can identify proteins and lipids associated with structural abnormalities.[74] Yet, currently, no neuroimaging studies have provided a consistent indication for the presence of lesions in patients who are still alive, and they can only be detected in autopsy after death.[75] Research using different scan

[72] "'Shell Shock'—The 100-Year Mystery May Now Be Solved."

[73] Sharon Baughman Shively et al., "Characterisation of Interface Astroglial Scarring in the Human Brain after Blast Exposure: A Post-Mortem Case Series," *The Lancet. Neurology* 15, no. 9 (2016): 944–953.

[74] Daniel Perl, "Viewing the Invisible Wound: The Effects of Blast Traumatic Brain Injury (Tbi) On the Human Brain," *Military Medicine* 182 (January/February 2017).

[75] Ibid.

techniques such as MRI, CT scan, and digital tensor imaging (DTI) have yielded inconclusive results in identifying and distinguishing the different types of mTBI.[76]

Medical professionals struggle to identify mTBI because the brain injuries occur at the micro-level (cellular or molecular) while modern scan technologies identify injuries at the macro-level. However, researchers at the University of Virginia may have developed a new TBI-identification technique. Using an approach similar to a "trojan horse," the research team drew on their knowledge that neutrophils respond to damaged or inflamed areas in an injured brain via cerebral spinal fluid injections. Researchers attached radioactive tracers to the neutrophils and used positron emission tomography to track the neutrophils to the site of injury.[77] This research has produced promising results applicable to future improvements in TBI identification and diagnosis.

bTBI and Disease Risk

Perhaps not surprisingly, researchers have linked the risk for debilitating disease to TBI. For example, in May 2014, Ann C. McKee and Meghan E. Robinson reported that mTBI is difficult to diagnose, with increased evidence that a single mTBI event can produce long-term white and gray matter atrophy, precipitate or accelerate age-related neurodegeneration, and increase the likelihood of Alzheimer's, Parkinson's, and motor neuron disease.[78] Furthermore, researchers claim that multiple mTBIs can lead to the development of tauopathy and chronic

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[76] Kimberly R. Byrnes et al., "FDG-PET Imaging in Mild Traumatic Brain Injury: A Critical Review," *Frontiers in Neuroenergetics* 5 (January 9, 2014), accessed November 12, 2018, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3885820/.

[77] "Could a 'Trojan Horse' Better Identify Traumatic Brain Injury?," University of Virginia School of Medicine, accessed October 15, 2018, https://med.virginia.edu/radiology-research/new-mri-coming/.

[78] McKee and Robinson, "Military-Related Traumatic Brain Injury and Neurodegeneration," 9.

traumatic encephalopathy.[79] Tauopathy is a neurodegenerative disorder caused by the buildup and deposit of the protein “tau” in the brain;[80] tau is the major protein constituent that induces neuron death.[81] Chronic traumatic encephalopathy produces atrophy to the brain’s frontal and temporal lobes and presents similar pathological features as both post-concussive syndrome and PTSD, indicating that the three disorders may be inter-related.[82] McKee and colleagues examined the post-mortem brains of four service members exposed to blast from one to several years prior to death and found evidence of neurodegeneration and CTE.[83]

CTE is characterized by changes in mood and behavior, progressive decline in memory, and cognitive impairment that eventually leads to dementia over time.[84] This progressive, degenerative brain disease is found in individuals with a history of repeated brain trauma that includes concussions and blows to the head that produce concussive-like symptoms. The repeated brain trauma triggers progressive degenerations of the brain tissue, including the buildup of tau, an abnormal protein. The changes can take place immediately or months and years after a concussive event. The common symptoms of brain degeneration known as CTE include memory loss, confusion, impaired judgement, impulse control problems, aggression, depression, suicide ideations, Parkinsonism, and eventually, progressive dementia.[85] In May 2015, Thor Stein, a staff neuropathologist at the Boston and Bedford VA Medical Centers, reported the findings of a

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[79] McKee and Robinson, “Military-Related Traumatic Brain Injury and Neurodegeneration,” 9.

[80] Miranda E. Orr, A. Campbell Sullivan, and Bess Frost, “A Brief Overview of Tauopathy: Causes, Consequences, and Therapeutic Strategies,” *Trends in Pharmacological Sciences* 38, no. 7 (July 2017): 637–648.

[81] Ibid.

[82] McKee and Robinson, “Military-Related Traumatic Brain Injury and Neurodegeneration,” 9.

[83] Ibid.

[84] Ibid., 10.

[85] “Repetitive Brain Injuries May Accelerate Aging, Dementia Risk,” *ScienceDaily*, accessed November 7, 2018, https://www.sciencedaily.com/releases/2015/05/150512185032.htm.1.

research effort that examined a large group of deceased athletes and military veterans with diagnosed pathological CTE. Researchers found that athletes and military veterans were four times more likely to develop beta-amyloid deposits in their brain. Additionally, the occurrence of buildup happened ten to fifteen years earlier than in the normal aging group.[86] The researchers compared the athletes and vets with beta-amyloid to those subjects without it. They discovered that individuals with beta-amyloid deposits had more advanced disease and decline in their thinking ability. Also, individuals with beta-amyloid were more likely to have Parkinson's-like pathology and symptoms.[87] Thus, correlation of repetitive head injuries may lead to the acceleration of the aging process by increasing the buildup of beta-amyloid in the brain and thus increasing the likelihood of dementia.[88] "This study suggests that treatment of some forms of CTE likely will require targeting beta-amyloid, suggesting that in some cases treatments being developed for Alzheimer's disease will also be helpful in CTE," Stein concluded.

bTBI injuries correlate with incidents of PTSD

While research recognizes the correlation between bTBI and PTSD, it also acknowledges that their overlapping cognitive and behavioral functions can make diagnosis very difficult.[89] Essentially, service members who have suffered bTBI are more likely to experience psychiatric disorders than those who have not.[90] In fact, bTBI can result in a myriad of symptoms similar to PTSD. More specifically, bTBI increases the likelihood of anxiety disorder as seen in PTSD,

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86 "Repetitive Brain Injuries May Accelerate Aging, Dementia Risk," *ScienceDaily*.

87 Ibid.

88 Thor D. Stein et al., "Beta-Amyloid Deposition in Chronic Traumatic Encephalopathy," *Acta neuropathologica* 130, no. 1 (July 2015): 21–34.

89 David L. Trudeau et al., "Findings of Mild Traumatic Brain Injury in Combat Veterans With PTSD and a History of Blast Concussion,"*The Journal of Neuropsychiatry and Clinical Neurosciences* 10, no. 3 (September): 308-13, accessed April 15, 2019, http://dx.doi.org/10.1176/jnp.10.3.308.

90 "Super Soldiers," Center for a New American Security, accessed November 13, 2018, https://www.cnas.org/super-soldiers.

most likely due to the damage to the part of the brain responsible for controlling emotions and fear, the amygdala.[91] In some studies, bTBI doubled the incidence of PTSD in injured members.[92] Symptoms of post-concussive syndrome, CTE, and PTSD include neuropsychiatric symptoms indicative of frontal lobe dysfunction, memory loss, difficulty in multi-tasking, impaired judgement, impulsivity, degraded executive function, emotional instability, and difficulty with complex decision making. Other shared symptoms include changes in personality, social behavior, and sleep patterns.[93] In a post-deployment survey of over 2,500 infantry soldiers deployed to Iraq, forty-four percent of soldiers with a bTBI exhibited symptoms or PTSD.[94] As stated, PTSD and CTE share close associations, and symptoms are difficult to separate, especially in CTE's early stages.[95] To illustrate, 80 percent of veterans who suffered from a blast injury while deployed to Operation Iraqi Freedom and Operation Enduring Freedom had a neuropathologically verified CTE and PTSD diagnosis.[96]

Combat MOSs Show Disproportional Rates of mTBI

In August 2016, researchers conducted a study to identify DoD occupations affected by injuries to the head and other neurosensory areas—the first study of its kind to correlate military occupational specialty and mTBI.[97] The team conducted surveys of several DoD data bases and found occupations with the highest rate of injured personnel (i.e., head, brain, visual, and

[91] "Super Soldiers," 10.

[92] Ibid., 7.

[93] McKee and Robinson, "Military-Related Traumatic Brain Injury and Neurodegeneration."11.

[94] Ibid., 11.

[95] Ibid., 11.

[96] Ibid., 11.

[97] Ben D. Lawson et al., "Military Occupations Most Affected by Head/Sensory Injuries and the Potential Job Impact of Those Injuries," *Military Medicine* 181, no. 8 (August 2016): 887–894.

vestibular). Using these injury categories, the team identified the top 10 most affected occupations and selected three Army Military Operational Specialties (MOSs) for further detailed analysis.[98] These three included Infantry (11B), Cavalry Scout (19), and Field Artilleryman (13B). After reviewing the injury classifications, the team selected International Classification of Diseases-9 (ICD-9) codes as most relevant for the study; these codes exhibited a high correlation of injuries associated with concussive events due to blast or blunt force, high explosion, or overpressure.[99] The study involved ambulatory patients due to the low severity of injury, relevance to mTBI, and high likelihood to return to duty. Researchers also selected enlisted service members of any rank, age, race, marital status, and sex who were injured during the years 2001 to 2010; this period had the highest reported incidents of IEDs, peaking in 2007 in Iraq, along with the highest number of troops deployed.

Of particular interest, the results of the study concluded that Army Combat MOSs of Infantry, Cavalry Scout, and Field Artilleryman are disproportionately affected by a TBI and/or sensory injury.[100] All three MOSs share common tasks in training and combat that imply that critical job tasks and injuries are not MOS specific.

Blood Test Helps Identify TBI

As a DoD initiative at more than twenty universities and hospitals, the TBI Endpoints Development (TED) is designed to establish a collaborative, multi-disciplinary approach to advance patient care and treatment; moreover, it seeks to develop biomarkers approved by the

[98] Ben D. Lawson et al., “Military Occupations Most Affected by Head/Sensory Injuries and the Potential Job Impact of Those Injuries,” 887.

[99] Ibid., 88.

[100] Lawson et al., “Military Occupations Most Affected by Head/Sensory Injuries and the Potential Job Impact of Those Injuries,”892.

Food and Drug Administration (FDA) for use in TBI identification. One TED initiative involved the use of a test kit to identify head trauma—a new tool that Banyan Biomarkers, a company founded by scientists from the University of Florida, has developed. The FDA has approved the implementation of Banyan Biomarkers' brain trauma indicator (BTI), and the Army will use it in FY 19 for limited testing.[101]

The BTI test kit detects proteins in the blood that are present due to brain injury. More specifically, when an injury occurs to the head, the brain produces two specific proteins: ubiquitin carboxy-terminal hydrolase-L1; and glial fibrillary acidic protein. The brain produces these two proteins rapidly after injury, and they will remain elevated in the blood for 12 hours after the incident.[102] As it determines serious injury such as brain bleeding or blood clots, the BTI will provide health professionals a rapid assessment for additional brain scans. While the test kit currently provides results in three to four hours, improvements are under way to yield faster responses for deployed use. One of the test's drawbacks lies in its inability to identify either bTBI or mTBI due to the lack of protein production during a concussion.[103]

Notably, the DoD has directed initiatives to improve TBI identification and treatments for injured service members. Namely, on October 1, 2018, the DoD directed the Under Secretary of Defense (USD) for Personnel and Readiness (P&R) to develop a comprehensive strategy to promote warfighter brain health and counter TBI. Effective immediately under this directive, the armed services will implement procedures that identify events for inclusion in the study of blast exposure for all service members during training and combat; this includes all service members

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[101] Military Health System Communications Office, "Military Health System: Test for Detecting Brain Injury Cleared by FDA," *The Fort Campbell Courier*, accessed October 9, 2018, http://fortcampbellcourier.com/lifestyles/article_43f1ce8c-2e02-11e8-8038-67d3b716a188.html.1.

[102] Ibid.

[103] Ibid.

using recoilless rifles and high over-pressure weapons systems. The study will accomplish the following:

1. Monitor, record, and analyze data of any service member exposed to blast in training or combat.

2. Assess the feasibility for historical documentation to a service member's record in a blast exposure log, in the event medical issues arise, to ensure the service member receives medical care for service-connected injuries.

3. Review weapon safety protocols to account for research related to cognitive impairment associated with blast.[104]

The study and directive will address issues related to TBI as well as leverage initiatives and capabilities across the DoD, interagency, and private sector. Within one year of the date of the implementation of this policy, the Secretary of Defense will submit a report or action plan for the study to the US House Committee on Armed Services and in four years will submit a repost of the study's results.

Prognosis and Recovery

The major concern of prognosis and recovery from TBI poses several challenges. First, the majority of scientific investigations of recovery after brain injury focus on focal brain injury, mostly stroke.[105] In addition, gaps in knowledge severely complicate surveillance methodologies and processes to identify previous injuries related to TBI. To add further complexity, individuals with behavioral abnormalities such as depression, personality disorder, or substance abuse exhibit symptoms also seen in post-concussion syndrome. Another challenge for health care providers lies in the lack of working definitions for "full recovery" vs "persistent disability," which can

[104] "Comprehensive Strategy and Action Plan for Warfighter Brain Health."

[105] Thomas Frieden, *Report to Congress On Traumatic Brain Injury in the United States: Understanding the Public Health Problem Among Current and Former Military Personnel*, ed. Vikas Kapil (Washington DC: Department of Defense, 2013), 130, .132.

occur in individuals affected by TBI.[106] TBI recovery also shows as highly variable and dependent on many factors—the most important being the injury's severity and extent. Milder injuries, 80 to 90 percent, have better outcomes than those more severe and usually see recovery in one to three months.[107] Estimates show that 10 to 50 percent of individuals with mild injury experience long-term health issues such as persistent headache, memory or concentration, or mood changes.[108] Just 20 percent of individuals with more severe injury make a recovery assessed as "good" in two or more years.[109] Clinical trials testing treatments in adults with severe TBI correlated age with recovery outcomes; older people proved strongly predictive of worse outcomes.

Treatment for TBI

In a 2005 collaboration with the DVBIC and the Uniformed Services University of the Health Sciences (USUHS), the Brain Trauma Foundation (BTF) published the *Guidelines for the Field Management of Combat-Related Head Trauma*.[110] The guidelines took into account civilian treatment options and accounted for austere environmental conditions; gave health professions a decision tree; and provided assistance for triage and treatment options.[111] TBI treatment options can vary and are dependent on injury severity. Medics or emergency rooms often see service members suffering an mTBI, providing assessment and release. Prior to discharge, patients are

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106 Thomas Frieden, *Report to Congress On Traumatic Brain Injury in the United States: Understanding the Public Health Problem Among Current and Former Military Personnel, 33.*

107 Ibid.

108 Ibid.

109 Ibid.

110 "Report to Congress on Traumatic Brain Injury," 20.

111 Ibid.

given instructions that include a follow-up if a list if symptoms persist or worsen.[112] Service members suffering a moderate to severe injury are more apt to receive treatment in a specialized unit such as intensive care or neurosurgical unit. Treatment options depend on several factors such as type and extent of injury—including injuries to other body regions and the patient recovery progress. Patient rehabilitation remains the focus for those in recovery's sub-acute stage while for those in acute care, the goal is to stabilize and prevent injuries.[113]

TBI and Long-Term Health or Disability Outcomes

The list of health issues for individuals injured with a TBI is long and better understood today than in military conflicts prior to the GWOT. The list of dysfunctions includes cognitive impairment, with memory retention deficits or memory loss; difficulty in performing complex tasks and using good judgment;[114] and neuropsychiatric disorders, depression, anxiety, PTSD, suicidal ideation, and substance abuse, providing challenges to return to work and reintegrate with the community.[115] TBI can also cause movement and sensory disorders that disrupt balance, vision, perception, and hearing;[116] it can also lead to sleep disturbances, headaches, pain, and fatigue.[117] In addition, longitudinal MRI-based studies have shown brain atrophy in the months to years after a TBI. Evidence suggests that individuals who suffer a moderate or severe TBI are two to four times at risk for dementia while the risk for those with a mild TBI remains unsubstantiated.[118] Also, evidence has shown a positive correlation that repetitive TBIs can lead

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[112] Ibid.

[113] Ibid.

[114] "Report to Congress on Traumatic Brain Injury," 35.

[115] Ibid.

[116] Ibid.

[117] Ibid.

[118] Ibid., 36.

to CTE; as explained, CTE is caused by a build-up of the protein tau in nerve cells. Some studies show that tau build-up has the ability to spread from one nerve cell to another, leading to widespread damage over time.[119] As stated, CTE symptoms are similar to those of PTSD and include poor concentration and memory, suicidal ideation, depression, and irritability.

Challenges and Issues

Identifying injured service members or veterans with service-related TBI provides health care professionals with ongoing challenges. In an effort to advance its diagnosis capabilities, reduce morbidity, and improve prognoses, the health care community often looks to public health surveillance initiatives to gather and disseminate information. Public health surveillance is “the ongoing, systematic collection, analysis, interpretation, and dissemination of data on a health-related event such as TBI, for use in reducing morbidity and mortality and to improve health.”[120] A labor-intensive process, surveillance such a this requires adequate resources and infrastructure for success and sustainability.[121] Early in the War on Terror, health surveillance systems provided limited TBI information, and health care professionals were unable to diagnosis some injury cases, leaving them unclassified. In 2015, the military clarified the TBI case definition, and upon review of prior cases, determined that some of the unclassified cases were likely mTBI.[122] Also, as the injured service member must provide some metrics that classify TBI severity, he or she may be unable to recall, remember, or calculate the conditions correctly, such as duration of

[119] "Report to Congress on Traumatic Brain Injury," 37.

[120] Ibid., 38.

[121] Ibid.

[122] “Worldwide-Totals-2018Q1_jun-21-2018_v1.0_2018-07-26_0.Pdf,” DVBIC, accessed October 2, 2018, http://dvbic.dcoe.mil/files/tbi-numbers/worldwide-totals-2018Q1_jun-21-2018_v1.0_2018-07-26_0.pdf.o

unconsciousness, loss of memory, or altered mental state.[123] For reporting purposes, individuals who suffer multiple TBIs are credited with one TBI; and the most severe type of TBI is reported.[124] Also, service members seeking care within civilian services pose a data collection challenge as military and civilian health care data bases are not inter-connected. Within the data collection, potential for duplication exists for reporting the number of persons with mTBI. Conversely, individuals who suffer a mild injury may choose not to seek medical attention.

As discussed, due to delayed symptom onset, many blast victims go undiagnosed and unreported. In other words, persons suffering an mTBI may not be correctly diagnosed because the signs and symptoms were not present at the time of evaluation.[125] Additionally, accurate measures of accumulated blast exposures add further challenges for data collection. In 2009, a military TBI study found that military doctors often did not account for injuries that did not result in bleeding or include a penetrating injury.[126] Other concerns include malingering as well as civilian health care professionals' inability to access military medical records to document the injury.[127]'

Another challenge not often discussed lies in Army culture itself; this culture produces a "Warrior Ethos" that adds complexity for soldiers to seek medical attention for an injury that exhibits no physical signs of injury. As this ethos discourages showing a sign of weakness or lack of toughness, some soldiers may fear ridicule from teammates or from within the unit. It may

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[123] Fish and Scharre, "Protecting Warfighters from Blast Injury," 6.

[124] "DoD Worldwide Numbers for TBI."

[125] "Report to Congress on Traumatic Brain Injury in the United States: Understanding the Public Health Problem among Current and Former Military Personnel," 52.

[126] Fish and Scharre, "Protecting Warfighters from Blast Injury," 6–12.

[127] "Report to Congress on Traumatic Brain Injury in the United States: Understanding the Public Health Problem among Current and Former Military Personnel,"52.

prove reasonable to believe that mTBI instances go unreported due to the stigma or fear associated with the appearance of "taking a knee" or seeking medical help during deployment, where every soldier counts.

During the heat of battle, chaos easily creates opportunities for injury, either mTBI or bTBI; soldiers may not recognize or understand that they have been injured when the onset of symptoms is delayed. In some cases, soldiers engaging in firefights do not recall or remember the event, having lost hours of memory after blast exposure.[128] Soldiers without clear recollection or memory of these types of events are unable to link the delayed symptoms to the corresponding blast. This adds difficulty for the injured soldier to explain the symptoms' cause and accurately report the nature of the injury to medical personnel.[129]

Perhaps not surprisingly, family members and friends are sometimes the first to recognize changes in behavior.[130] Since some bTBIs are subtle, some injured soldiers fail to report their injury or seek medical attention even though they suspect medical issues. Due to the stigma of seeking treatment for psychological-related symptoms as the result of bTBI, some service members do not want the association of PTSD in their medical records. Additionally, some patients lack the initiative to seek medical attention due to their cognitive and emotional deficits caused by the mTBI.

Soldier Protection from Blast

As the DoD has recognized the incidence of TBI occurring in training and combat operations, it has taken steps to address the need for innovative equipment and protective gear; while these innovations have proven helpful, they also may be limited in addressing key issues in

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[128] Fish and Scharre, "Protecting Warfighters from Blast Injury," 6–13.

[129] Ibid., 5–17.

[130] Anderson, "Shell Shock," 11.

reducing the incidence of blast-induced TBI. For example, the DoD has developed and the Army has fielded blast monitoring devices that measure overpressure to the service member wearing the device. This is the first step to help measure and record a soldier's environmental exposure to blast overpressure, acceleration, and temperature.[131] These devices, called "blast monitors" or known as blast gauges, are attached to the top of the helmet and can measure and record up to 500 concussive events. Blast monitors have continuous battery power for seven months of operation and can measure the following: acceleration up to 4000g in three directions; ambient temperature; and peak pressure up to 17 atmospheres.[132] The blast monitor also contains sensors capable of distinguishing blast from blunt force trauma events. Downloading data from the sensors to a personal computer via a USB port, personnel can track impact location, magnitude, duration, blast pressure, angular and linear accelerations, and time of the event or events.

Blast monitors helps unit leaders and personnel advance their knowledge base for improved decision-making in numerous areas. First, Army personnel can use blast monitors as screening devices to identify soldiers exposed to blast who may need to seek medical attention. Second, the device provides an objective tool to help validate changes in environmental conditions associated with a blast and helps prevent over- and under-reporting.[133] Next, blast gauges can help unit leaders identify and validate tactics and techniques during heavy weapons firing in training and combat to decrease the soldier's risk to blast effects. Finally, the monitors can help medical personnel assess the probability of an injury due to the amount of overpressure recorded. Data collected from these monitors help medical personnel to better understand the relationship between blast events and injury to the brain.

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[131] Fish and Scharre, "Protecting Warfighters from Blast Injury," 6.

[132] Duncan Wallace, "Combat Helmets and Blast Traumatic Brain Injury," *Journal of Military and Veterans' Health* 20 (January 2012).

[133] Fish and Scharre, "Protecting Warfighters from Blast Injury," 6.

Combat Helmet Improvements

The combat helmet is designed to protect the soldier's head, primarily from shrapnel, gunshots, and blunt force trauma that a variety of mechanisms can cause. As technology has advanced, the combat helmet has seen several evolutions of redesign to better protect soldiers in training and combat. Helmets originally made from steel were replaced by lightweight materials made from Kevlar. The Army developed and, in 2011, issued its new design, the Enhanced Combat Helmet (ECH) made of ultra-high density, lightweight polyethylene. The helmet is thicker but lighter than the helmet issued previously.

Currently however, no helmet exists that protects soldiers from blast. Studies reveal that the previous Kevlar and ACH had shortfalls in protecting soldiers from TBI. After 2005, researchers began to collect data on US service members injured with a TBI and discovered 77 percent were wearing their helmets at the time of injury.[134] In a 2009 study conducted at Lawrence Livermore Laboratory, researchers argued that Kevlar helmets without padding experienced "underwash"[135]—an adverse effect that occurs when a blast wave focused under the helmet produces pressures that exceed those outside the helmet. Thus, the soldier experiences an increased mechanical load, causing the skull to flex and resulting in injury similar to that from blunt force.[136] A 2010 Massachusetts Institute of Technology (MIT) study used computational modeling and found helmets with padding effectively reduced harm to the wearer.[137] The ACH padding mitigated the blast wave and decreased pressure or changed the location of pressure on the brain, benefitting the soldier. While the study indicated that the head still experienced

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[134] Wallace and Rayner, "Combat Helmets and Blast Traumatic Brain Injury," 3.

[135] "Super Soldiers," 10.

[136] Ibid.

[137] Ibid.

pressure, it was significantly less than with no helmet. In the most important finding of the study, computer simulations showed that the addition of a face shield to the helmet resulted in an 80 percent reduction in blast pressure.

Development of Robotic Teammates

Future innovations that continue to address the soldier's need for increased bTBI protection may include the much-anticipated battlefield robots once only dreamed about in comic book lure. Indeed, robotic teammates may accompany soldiers in future combat, giving their human counterparts an added protective barrier and shielding them from blast waves. The robotic partner could automatically position itself to intercept the blast wave by creating a vacuum in space that would reduce overpressure. Researchers have hypothesized a futuristic concept in which protective shields with "low-pressure, low-density air" could absorb or collapse a blast wave to protect the intended target.[138] While this concept holds potential to change or even revolutionize the soldier's battlefield experience, reduce the incidence of bTBIs, and even bolster effectiveness in military operations, its use in the field may still be many years away. In any case, challenges still persist and call for continued developments and improvements for soldiers confronting blast waves and TBIs on the battlefield.

Analysis and Recommendations

As new innovations offer hope for US soldiers' increased safety from bTBI's physical and psychological ramifications, a review of progress made in diagnosing and treating service members with bTB, as well as steps taken to reduce its incidence, can help advance understanding of this inquiry.

[138] "Super Soldiers," 15.

Analysis

First, an analysis of brain injuries from World War I through the Vietnam War highlights the medical professional's struggle to identify and treat the signature wound "shell shock." During this time, medical professionals widely misunderstood shell shock as they debated whether the injury was physical or psychological. The fact that the US government spent over one billion dollars for psychiatric care in treating injured veterans from World War I to World War II adds to the premise that the extent of soldiers coping with brain injuries or psychological deficits loomed wide in scope.[139]

Since 2000, nearly 384,000 service members have suffered a TBI; a majority of these, roughly 82 percent, have been classified as mTBI. However, these numbers may actually be much higher as a blast injury without any physical signs of injury proves difficult to diagnose. Estimates of the number of TBIs vary greatly due to data-gathering methods. Many studies have included the following shortfalls: a lack of clinical diagnosis accompanying the screening questionnaires; screening samples that omitted data from all those deployed; and misdiagnosis of TBI due to PTSD's overlapping symptoms. In addition, prior to 2009, Army doctors did not report TBI that did not include bleeding or physical injury to the head; this has potentially led to a gross underreporting of TBI cases.

In 2006, the DoD mandated soldiers to complete the PDHA immediately upon redeployment and the PDHRA three to six months upon redeployment. However, both the mandated PDHA and PDHRA have shown to be less than effective. Two longitudinal studies

[139] Anderson, "Shell Shock," 11.

reviewed the PDHA and PDHRA as completed by the 88,235 soldiers returning from Iraq.[140] The study found that soldiers answered the PDHA questions differently than they did those on the PDHRA. This variance included a greater proportion of active duty soldiers reporting health issues on the PDHRA that they left unmentioned on the PDHA. After conducting a second study, the research team found comparable results. The researchers suggested potential problems associated with the post deployment mental health screening as well as military personnel's underestimation of mental health concerns. The preliminary results suggest that soldiers may be untruthful on mandated surveys for several reasons. As stated, soldiers may choose not to disclose an injury due to service culture, which may discourage them from seeking medical care. As the PDHA and PDHRA are part of the Defense Surveillance System and become part of soldiers' permanent health record, they may fear their responses may be used against them for promotions or job opportunities. Some soldiers fear the stigma of a mental health diagnosis and may fail to report out of worry that it could impact their career. The study also showed that less than half of the respondents with a mental health diagnosis sought follow-up care with medical personnel. The author of the study stated, "The low percentage of referrals noted in response to personnel with PDHRA-identified mental health risks raises doubts about the DoD's ability to assess risk factors and address health concerns that could emerge over time following deployment. Not only may unidentified and/or unresolved health issues become worse in time and have serious consequences for the health status of the veteran and his family but may also negatively impact subsequent military and civilian health service delivery systems."

[140] Laurel Hourani et al., "Comparative Analysis of Mandated Versus Voluntary Administrations of Post-Deployment Health Assessments Among Marines," *Military Medicine* 177, no. 6 (June 2012): 643–648.

Current health care definitions lack specific language linking blast events to TBI.[141] However, research shows strong evidence that a bTBI remains unique and that damage to the brain caused by blast injures the brain differently than a normal concussion or blunt force. The health care definition should include language that categorizes bTBI separately from mTBI. This would also aid in health surveillance, helping the soldier receiving the proper treatment and aiding researchers in future studies and data collection.

Army personnel that include Infantry, Cavalry Scout, and Field Artillery were found proportionally at risk for mTBI due to sharing common core tasks not MOS specific. This proved true for a myriad of reasons: Explosive Ordnance Disposal (EOD) (89E/D) specialists routinely conduct high risk operations that involve possible exposure to blast; they render-safe and dispose of unexploded ordnance (UXO), conduct Counter-IED operations, and support maneuver elements during offensive operations. Consequently, these EOD personnel are at high risk for experiencing a bTBI.

The EOD career field is very small, runs in a high OPTEMPO environment, and consists of two- to three-man teams to carry out its missions. EOD specialists routinely deploy to combat operations in support of conventional and Special Operational Forces (SOF). When supporting SOF, EOD soldiers perform high-risk missions that often result with a detonation in near proximity. Additionally, EOD specialists deploy in support of humanitarian demining throughout Asia, Europe, and Africa; they support local law enforcement off DoD installations to render-safe and dispose of UXO and IEDs; and they are highly trained to mitigate blast exposure but may be at elevated risk due to mission and time constraints. Depending on the scenario, EOD specialists

[141] "Report to Congress on Traumatic Brain Injury in the United States: Understanding the Public Health Problem among Current and Former Military Personnel."

may use remote means through robotics to conduct their mission but remain at risk for bTBI. Currently, no research has been conducted to assess EOD personnel for risk to blast exposure.

In a final analysis, the specifications for the current Army combat helmet does not include any requirement to protect soldiers from blast.[142] Currently, some off-the shelf helmets such as the MTEK, worn by select law enforcement agencies and special operations units, include facial protection. Yet, the trade-off for a helmet design that offers a face shield or mandible protection may come at the cost of limited visibility or increased weight. Adding any weight to the existing helmet might increase spinal or neck injuries, however. Another consideration to note is that a helmet design other than the current Army issue may have incompatibility issues with night-vision device mounting or the current communications harness.

Recommendations

After reviewing findings presented in current research and literature, as well as through evaluating the premises outlined in this study's methodology, the practical analysis provides the catalyst for the following recommendations:

1) Expand the language in the health case definition to further categorize bTBI and associate the injury with that of blast exposure.

2) Incorporate EOD personnel in studies to determine the neurological impact and implications of blast exposure from conducting routine operations.

3) Develop a requirement for a combat helmet that protects against blast.

4) Continue research that differentiates bTBI from mTBI caused by blunt force.

5) Continue research to further study the positive correlation between bTBI and PTSD.

[142] Wallace and Rayner, "Combat Helmets and Blast Traumatic Brain Injury."

6) Study the validity of PDHA and PDHRA to better develop policy for bTBI identification.

Conclusion

TBI has captured the attention of the public, policy makers, and senior officials at the DoD and within the government at large; as such, it remains a serious health concern for all involved. While technological advancements in medicine have helped medical professionals understand the nature of the injury, the precise mechanism for blast effects on the brain is still not fully understood. Initial research shows that blast to the brain causes brain injury differently than do conventional concussions by blunt force. Soldiers exposed to a blast without any physical injury may not realize they have been injured, and as symptoms appear later, problems for health care and TBI identification are compounded. Currently, no medical technology exists to identify a mTBI caused by a blast. Advancements in the use of DTI have shown promise for detecting brain injury but remain ineffective for detecting mild blast-induced injuries. Soldiers experiencing bTBI show high correlation with signs and symptoms of PTSD, further complicating diagnosis. A strong debate surrounds whether PTSD is the result of a physical injury, psychological injury, or both; medical research indicates that PTSD is the result of both physical and psychological trauma. Research has shown that soldiers who experience multiple exposures to a blast are at risk for developing early onset for dementia and Alzheimer's disease.

The Army has implemented policy to help identify TBI in soldiers returning from deployment through the use of surveys; yet, these assessments may be unreliable for a variety of reasons. During the heat of combat, soldiers react to many stimuli that increase adrenaline; in other words, soldiers exposed to a mild blast may not recall the event due to the chaos occurring in combat. Further, soldiers knocked unconscious by a blast event may not recall the full event details and inaccurately report the duration of loss of consciousness (LOC), perhaps not recalling a LOC at all. In addition, soldiers may inaccurately report survey information due to fearing a loss of promotion, job, or assignment opportunities, or even separation from service entirely. Some soldiers may even report injury inaccurately out of an ulterior motive and seek compensation or disability payments to which they are not entitled. In any event, TBI is categorized as a behavioral health issue and carries a negative stigma. The shame or consequences of reporting a TBI forthrightly may contribute to soldiers' lack of transparency in survey and reporting tendencies. In other words, soldiers may fail to report an injury to avoid the stigma or label of having a mental or behavioral condition.

Clearly, while the nature of warfare continues to change, its violence will certainly ensue, with injuries to soldiers continuing as well. The Army has acknowledged the threat of blast exposure to soldiers in training and combat and has mandated policy to help unit leaders implement safety measures in the firing of recoilless rifles and conducting breaching operations. Notably, these policies will be only as effective as the unit leaders who enforce them. Protecting soldiers from blast in combat and training will remain a challenge, but advancement in technology has improved soldier survivability and detection to blast exposure. These advancements have come at a cost and have still not resolved the detection of mTBI associated with a blast. In the future, it is easy to imagine an environment where soldiers wear blast monitors interconnected to unit mission command systems, to give real-time updates for blast occurrence in the environment. The future battlefield may include soldiers protected by materials specifically designed to protect them from blast.

TBI remains a very complex problem and calls for further research to gain understanding of the mechanisms of blast injury to the brain, to more effectively detect bTBI, and to develop Army policy across the spectrum to help soldiers return to duty and live quality lives.

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