A Review of U.S. Military Traumatic Brain Injury Studies

Trends, Gaps, and Opportunities

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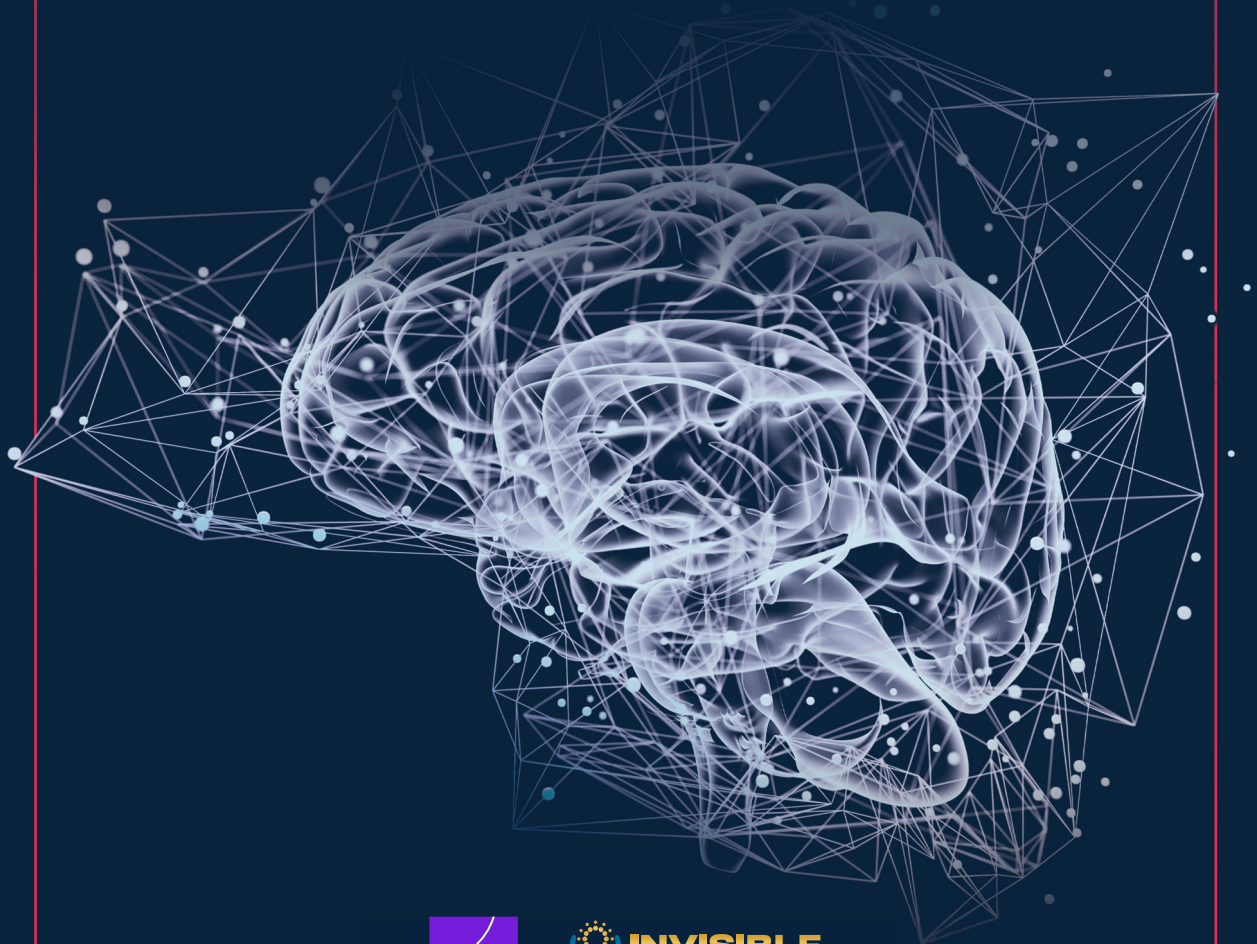

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About This Report

Military service–related traumatic brain injury (TBI) is a signature wound of war, affecting more than 500,000 service members since 2000. Despite its prevalence and the significant investments in research, efforts remain fragmented, which hinders collaboration and the translation of findings into practice. In response, the Invisible Wounds Foundation commissioned the RAND Epstein Family Veterans Policy Research Institute to conduct this scoping review to analyze the TBI research landscape, clarify progress, identify gaps, and highlight opportunities for innovation and collaboration, ultimately supporting informed decision-making and advancing recovery for those affected by TBI. The Invisible Wounds Foundation was established in 2022 to safeguard the brain health of special operations forces.

This report reviews TBI studies from 2015 to 2025, with a focus on the special operations forces community. It maps research progress, identifies overlaps and gaps, and highlights areas of concentrated investment. The synthesis aims to guide stakeholders in directing efforts and resources to maximize impact in TBI research.

The work was conducted by RAND researchers working within RAND Health Care and the RAND Epstein Family Veterans Policy Research Institute.

RAND Epstein Family Veterans Policy Research Institute

This work was conducted within the RAND Epstein Family Veterans Policy Research Institute, which is dedicated to conducting innovative, evidence-based research and analysis to improve the lives of those who have served in the U.S. military. Building on decades of interdisciplinary expertise at RAND, the institute prioritizes creative, equitable, and inclusive solutions and interventions that meet the needs of diverse veteran populations while engaging and empowering those who support them. For more information, visit veterans.rand.org or email veteranspolicy@rand.org.

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Summary

Military service–related traumatic brain injury (TBI) is a signature wound of war, affecting more than 500,000 service members since 2000, with special operations forces (SOF) at particularly high risk because of frequent blast exposures and repetitive neurological stresses. Many TBIs go undiagnosed or are mild, yet they often co-occur with such conditions as posttraumatic stress disorder (PTSD) and depression and lead to significant long-term health impacts. Despite substantial federal and private investment, TBI research remains fragmented and siloed, highlighting the need for a comprehensive assessment of research efforts and funding in this critical area.

To address this, the Invisible Wounds Foundation asked RAND to conduct a scoping review of TBI research. Specifically, we mapped the progress of TBI research from January 2015 to June 2025 and identified overlaps and gaps in specific areas. We also highlighted the areas that received the most-focused investment. The results of the study can inform opportunities to better align research efforts and investments, ultimately addressing gaps in TBI knowledge and care for service members.

How the Study Was Conducted

We conducted a comprehensive search of peer-reviewed and gray literature on military service–related TBI from January 2015 to June 2025 across multiple databases, focusing on research involving human subjects and limiting in vivo and modeling approaches. Using literature review software, we screened and abstracted key data from 480 eligible articles, including type of TBI, comorbidities, study design, and funding information. We also mapped TBI research investments by extracting and analyzing funding data from major public and private sources. Award amounts were adjusted for inflation, and all inclusion criteria were applied iteratively to maintain consistency throughout the review process.

Key Findings

Type and Volume of Research on Military Service–Related TBI

There is limited research focused on TBI among SOF, although this population faces a higher risk of blast exposure and TBI. Of the papers reviewed, 83 percent focused on military populations, and most did not specify the branch of service or include details on SOF. Army and Marine Corps members were the most frequently studied populations; only seven papers focused solely on SOF, and 14 included SOF in mixed samples.

Most TBI research studies are observational and focused on diagnostic methods; far fewer papers focus on interventions or the root causes of blast injuries. Many studies com-

bined approaches, such as imaging and biomarker analysis, and a smaller number of papers discussed modeling, product development, and expert recommendations. Our emphasis on human research may have excluded some relevant blast physics or in vitro studies. The small number of scale validation studies highlights the ongoing challenges in diagnosing TBI with existing tools.

Nonhuman research mainly uses murine models, with few studies involving larger animals or digital simulations. Most papers reported the source and severity of blasts, often including multiple types of TBI; however, cases of subconcussive injury were rare (31 papers). This low count may be due to the study's limited search terms and to underdiagnosis, suggesting an area for further study.

Most TBI studies examine TBI in the presence of other conditions. Sixty-eight percent of the articles reviewed reported findings on TBI with at least one comorbidity. Many studies examined multiple co-occurring issues, with PTSD being the most common, often appearing with neurological, psychological, behavioral, or sleep disorders. This subanalysis specifically focused on neurological conditions, the second most frequent comorbidity assessed in the literature.

Studies on short- and long-term outcomes of TBI focus on different issues. Studies that assessed the short- to medium-term period following TBI described general neurological symptoms, such as pain, inflammation, balance issues, and sensory changes, rather than any specific diagnoses. Longer-term studies examined neurodegenerative conditions, such as Alzheimer's disease, Parkinson's disease, and chronic traumatic encephalopathy (CTE), whereas others explored early biomarkers without clear clinical outcomes.

Most studies focus on one stage of TBI care, and few focus on prevention and rehabilitation. The analysis showed that 12 percent of the studies (58 papers) addressed prevention, mainly related to blast injuries; 46 percent (224 papers) focused on diagnosis, often using imaging and biomarkers; and 15 percent (77 papers) examined treatment, management, or mitigation strategies, including both animal and human studies. In contrast, only 9 percent (46 papers) addressed rehabilitation and long-term care.

Funding Sources and Amounts for Military Service–Related TBI Research

Since 2015, federal and private sources have invested more than $2.1 billion in TBI research. Most of this funding has come through grants, which make up 75 percent of all awards and more than 85 percent of total dollars spent, supporting a wide variety of research across the continuum of care.

The U.S. Department of War (DOW) and the U.S. Department of Health and Human Services (HHS) are leading research funders.[1] These federal agencies contributed $930 mil-

[1] DOW is designated the Department of Defense under Public Law 81-216, National Security Act Amendments of 1949.

lion and more than $1 billion, respectively, from January 2015 to June 2025. DOW funding primarily supports battlefield care, medical research for service members, and rehabilitation, whereas HHS funds basic science, diagnostics, prevention, and patient care, mainly through the National Institutes of Health. DOW's investment is less strongly tied to publication output than HHS's is. Additional research support comes from the U.S. Department of Veterans Affairs and the National Science Foundation for specialized research and treatment initiatives.

Grant funding peaked in 2022, reflecting a significant increase in investment and interest in TBI research. More specifically, federal grant funding peaked in 2022, at more than double the 2015 level. Since then, the number and scale of awards have fluctuated annually, highlighting evolving research priorities and growing interest in addressing gaps in TBI knowledge and care.

Philanthropic contributions have steadily increased to nearly $80 million cumulatively, supporting various initiatives within TBI research. These philanthropic funds have helped advance genetic studies, innovative treatments, caregiver support, and programs for specific groups, such as SOF, often at the community level.

Opportunities for Aligning Research Efforts and Funding

Substantial progress has been made in TBI research over the past ten years, especially in advanced imaging, biomarker discovery, and comorbidities, such as PTSD, depression, and sleep disorders. These advances have deepened our knowledge of TBI's mechanisms and its complex overlap with broader neurological and psychological health issues.

Yet in mapping TBI research with funding sources, we found that military service–related TBI research is siloed between agencies and specialties, which ultimately limits information-sharing, the translation of findings into practice, and the ability to address challenges that cut across different fields and areas of concern. Despite significant investment in TBI research, several critical gaps persist:

- **Understudied populations:** Little research since 2015 has focused on identifying and treating TBI among SOF, airmen, sailors, and members of the National Guard or reserve, even though these groups face high risks.
- **Injury types:** Studies and funding mainly address blast-related and mild TBI. Subconcussive and penetrating TBI has been less studied, highlighting an opportunity for targeted investment. Few studies examine the links between injury characteristics (e.g., blast pressure, soldier positioning, blast source) and clinical outcomes.
- **Comorbidities:** Although there has been growth in research on co-occurring PTSD, sleep disorders, and neurological conditions linked to TBI, such areas as substance misuse and sensory impairments (auditory and ocular conditions) receive little attention.

- **Rehabilitation and recovery:** There is little research on rehabilitation and long-term care for TBI and its comorbidities, leaving service members and veterans with few long-term, evidence-based recovery pathways.
- **Research focus:** Most studies are observational or imaging based. There is a need for more longitudinal, qualitative, and translational research to capture real-life experiences and long-term outcomes and for more etiological studies on injury mechanisms.

By highlighting both research achievements and persistent gaps, this study provides a road map for policymakers, funders, and researchers to align priorities to close knowledge gaps. A more coordinated research agenda is essential to advance prevention, diagnosis, treatment, and long-term recovery and ensure comprehensive care and support for all service members and veterans living with TBI.

Contents

Figures and Tables

Figures

Tables

CHAPTER 1

Introduction

Military service–related traumatic brain injury (TBI) is a signature wound of war, with more than 500,000 service members diagnosed since 2000.[1] TBI is particularly prevalent among special operations forces (SOF) personnel, who experience higher rates of blast exposure and repetitive neurological stress in both combat and training compared with other service members.[2] Unfortunately, although TBI is both common and potentially devastating, it often goes unnoticed,[3] especially when mild or occurring alongside other comorbidities, such as posttraumatic stress disorder (PTSD) and depression.[4] This combination of conditions especially can pose lasting health challenges for service members and veterans.

The persistent burden of these injuries suggests that there is a need to step back to comprehensively review the research and investment landscape in this critical area. Indeed, an initial scan of the TBI research ecosystem indicates fragmentation. Several productive efforts have been made over the past 25 years to evaluate the state of the science of blast injury research. Work by RAND, the National Academies, and others has found that despite substantial federal and private investments, efforts are often disconnected, with various groups working in

[1] Military Health System, "DOD TBI Worldwide Numbers," webpage, last updated August 25, 2025.

[2] Cory McEvoy, Adam Crabtree, John Case, Gary E. Means, Peter Muench, Ronald G. Thomas, Rebecca A. Ivory, Jason Mihalik, and James S. Meabon, "Cumulative Blast Impulse Is Predictive for Changes in Chronic Neurobehavioral Symptoms Following Low Level Blast Exposure During Military Training," *Military Medicine*, Vol. 189, Nos. 9–10, September–October 2024.

[3] Sandra M. Escolas, Margie Luton, Hamid Ferdosi, Bianca D. Chavez, and Scot D. Engel, "Traumatic Brain Injuries: Unreported and Untreated in an Army Population," *Military Medicine*, Vol. 185, Supp. 1, January–February 2020; David X. Cifu, Jay P. Granier, Jamie Grimes, Tammy Crowder, Ajit B. Pai, and Henry L. Lew, "The History and Evolution of Traumatic Brain Injury Rehabilitation in Military Service Members and Veterans in the United States," in Jomana Amara and Ann M. Hendricks, eds., *Military Health Care: From Pre-Deployment to Post-Separation*, Routledge, 2013.

[4] Joshua E. Wilk, Richard K. Herrell, Gary H. Wynn, Lyndon A. Riviere, and Charles W. Hoge, "Mild Traumatic Brain Injury (Concussion), Posttraumatic Stress Disorder, and Depression in U.S. Soldiers Involved in Combat Deployments: Association with Postdeployment Symptoms," *Psychosomatic Medicine*, Vol. 74, No. 3, April 2012.

silos.[5] As a result, divisions between clinical fields are reinforced, making collaboration less likely and reducing the chances that research efforts will translate into practice.

To address these challenges, the Invisible Wounds Foundation, an organization dedicated to supporting meaningful service-related TBI research, commissioned our team to conduct a scoping review of TBI studies from the past decade, with a particular emphasis on the SOF community. Our review mapped the progress of TBI research from January 2015 to June 2025, identified areas of overlap and gaps, and highlighted where investment has been most concentrated. To help the foundation and other stakeholders target their efforts and investments for the greatest impact in TBI research, this broad research synthesis clarifies where advances have occurred, where funding has been directed most, and where efforts have been duplicated.

Objectives and Key Questions

This report describes the type and focus of TBI research conducted over the past ten years (January 2015 to June 2025). The following key questions guided our analysis:

1. What are the research trends and gaps in TBI-related topics, particularly service-related neurological injuries induced by blast exposure?
2. What are the trends and priorities in public and private investments in TBI research?
3. What are the strategic opportunities for aligning research and investment to address gaps in TBI knowledge and care?

Organization of This Report

The remainder of this report proceeds as follows. Chapter 2 presents our methodology, detailing the procedures for the literature review and analysis of public and private invest-

[5] Carrie M. Farmer, Heather Krull, Thomas W. Concannon, Molly M. Simmons, Francesca Pillemer, Teague Ruder, Andrew M. Parker, Maulik P. Purohit, Liisa Hiatt, Benjamin Saul Batorsky, and Kimberly A. Hepner, *Understanding Treatment of Mild Traumatic Brain Injury in the Military Health System*, RAND Corporation, RR-844-OSD, 2016; Lauren Fish and Paul Scharre, "Protecting Warfighters from Blast Injury," Center for a New American Security, April 29, 2018; Samantha McBirney, "Repeated Exposure to Low-Level Military Occupational Blasts: An Overview of the Research, Critical Gaps, and Recommendations," testimony presented before the U.S. Senate Armed Services Committee, Military Personnel Subcommittee, RAND Corporation, CT-A3250-1, February 28, 2024; National Academies of Sciences, Engineering, and Medicine, "Accelerating Progress in Traumatic Brain Injury Research and Care," webpage, undated; Molly M. Simmons, Charles C. Engel, Emily Hoch, Patrick Orr, Brent Anderson, and Gulrez Shah Azhar, *Neurological Effects of Repeated Exposure to Military Occupational Levels of Blast: A Review of Scientific Literature*, RAND Corporation, RR-2350-A, 2020; Éder M. Sousa, Samantha McBirney, Emily Hoch, and Tepring Piquado, *Toward a Unified Multiscale Computational Model of the Human Body's Immediate Responses to Blast-Related Trauma: A Review of the Scientific Literature*, RAND Corporation, RR-A500-1, 2021; Terri Tanielian and Lisa H. Jaycox, eds., *Invisible Wounds of War: Psychological and Cognitive Injuries, Their Consequences, and Services to Assist Recovery*, RAND Corporation, MG-720-CCF, 2008.

ment data related to TBI research. Chapter 3 presents findings on research trends and gaps in TBI-related topics, particularly focusing on service-related neurological injuries. Chapter 4 analyzes the investments in TBI research, revealing funding sources and trends. Chapter 5 explores strategic opportunities for aligning research efforts and investments to address existing gaps in TBI knowledge and care. Finally, Chapter 6 offers a discussion and conclusions, synthesizing the findings and identifying possible areas for future research and investment in TBI care.

The report also contains appendixes that provide more detail on our study. Appendix A presents the inclusion and exclusion criteria used in the review and the definitions of the codes we used in the Covidence literature review software platform for data abstraction.[6] In an annex to this report, available at www.rand.org/t/RRA4199-2, Appendix B provides the literature review search strings by database, and Appendix C provides a bibliography of all the papers abstracted in the third level of review.

[6] Covidence, homepage, Veritas Health Innovation, undated.

CHAPTER 2

Methodology and Limitations

We conducted a scoping review of academic and gray literature and public investment data from January 2015 to June 2025. We sought to fulfill three goals: (1) identify trends and gaps in service-related TBI research, (2) examine where government agencies and philanthropic organizations have invested in TBI research, and (3) highlight strategic opportunities for aligning research and investment to address gaps in TBI knowledge. For each area of query, we searched for documents published on service-related TBI along the continuum of care: prevention, diagnosis, treatment, and rehabilitation.

Literature Review Search Strategy

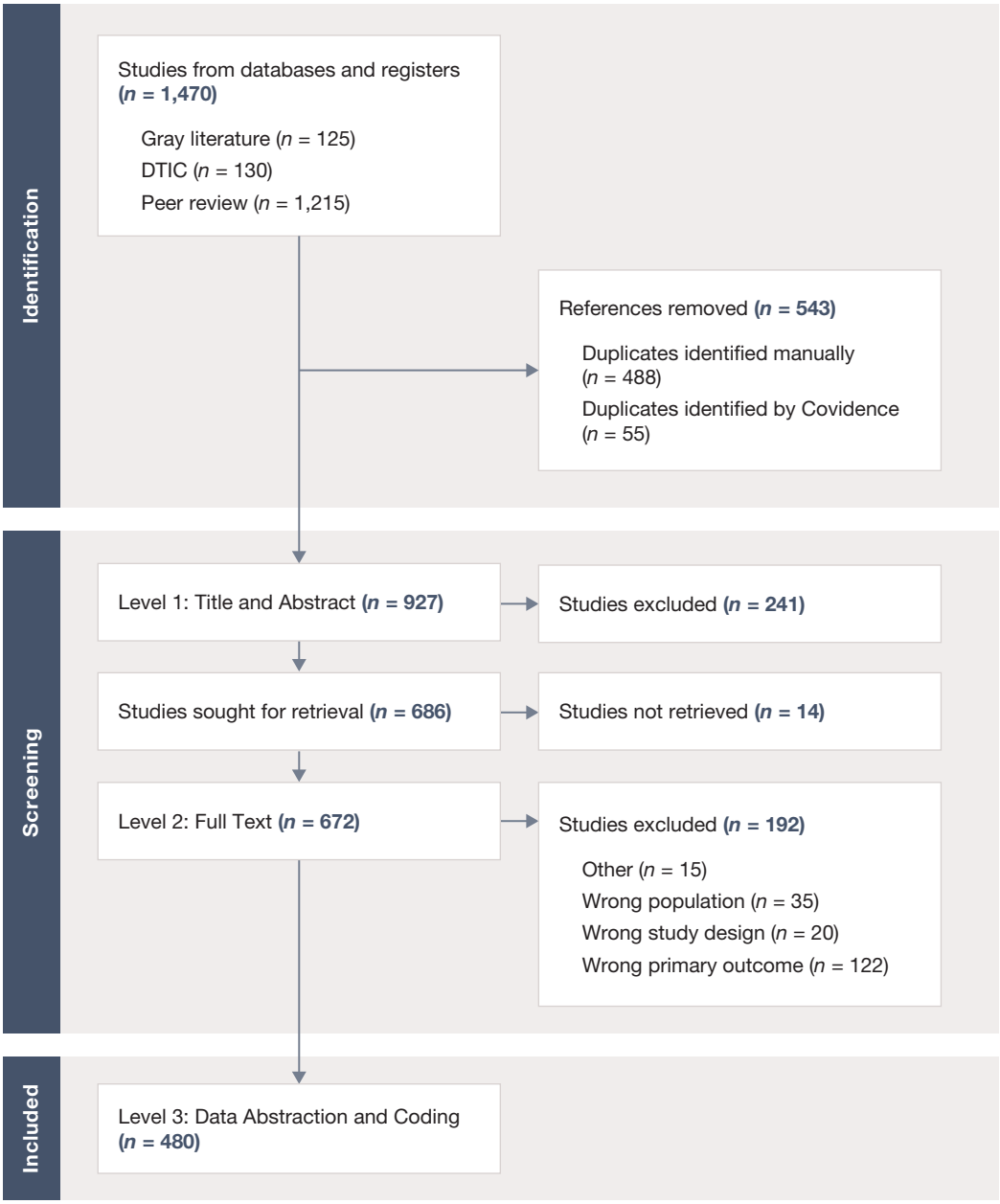
Working in tandem with a research librarian, we performed an interdisciplinary search of English-language, peer-reviewed literature indexed in PubMed (National Library of Medicine and National Institutes of Health [NIH]), Web of Science Core Collection (Clarivate), Military and Government Collection (EBSCOhost), Military Database (ProQuest), OpenAlex, and the Defense Technical Information Center (DTIC). Search terms were categorized around branch of military service, different types of TBI (e.g., blast, penetrating), TBI symptoms, weaponry, and terms commonly associated with the diagnosis of TBI, such as biomarkers and imaging techniques. The full search strings are available in Appendix B in an annex to this report, available at www.rand.org/t/RRA4199-2. An additional search of gray literature focused on reports from research and nonprofit organizations and progress reports to U.S. Department of War (DOW) funders.[1]

To be included, sources needed to directly reference military service–related TBI. The focus was research directly supporting human subjects; thus, in vivo and modeling studies were excluded. However, studies that combined either of these methods with other study designs were included for further review. Furthermore, to maintain a strict focus on TBI, papers in which TBI was not the primary or coprimary outcome were removed. We used Covidence literature review software at each step of the review process. The initial search captured 1,470 articles that met our criteria; after deduplication, we identified 927 unique

[1] The Department of War is designated the Department of Defense under Public Law 81-216, National Security Act Amendments of 1949.

articles eligible for screening, and, ultimately, we identified 480 articles eligible for abstraction. The full search strategy is shown in Figure 2.1.

FIGURE 2.1
Search Strategy



Screening Procedure

After removing duplicate documents, we used an iterative methodology to create inclusion and exclusion criteria (Table A.1 in Appendix A) and ensure a consistent set of review criteria.[2] Throughout the literature screening process, the team met weekly to validate these conditions. For each article, we reviewed the title and abstract to exclude any paper that did not focus on military service–related TBI or that focused solely on in vivo research. The remaining articles then underwent an independent full-text screening to retain only those in which TBI was a primary focus, those with findings that were directed toward military personnel, and those that met our earlier inclusion criteria. The initial screen identified an array of comorbid conditions, including auditory conditions, ocular conditions, and chronic pain. The two most common comorbidities with TBI were PTSD and neurological conditions.

Finally, for all 480 included publications, the full data abstraction extracted data on branch of service, type of TBI, study design, comorbidities, where on the continuum of care the study focused, and the study funder as identified in the funding acknowledgments section of the publication. Any categories that were not included in the paper were left blank. Considering the large body of literature already covering the relationship between TBI and PTSD, we decided to further abstract data on the second most commonly identified condition in our review, neurological conditions. Looking at explicit mentions of diagnoses or neurological symptoms, we logged each of these conditions, such as changes in executive function or memory loss, in addition to any other comorbid conditions. In addition to this, we noted the time frame for data collection and the description of treatments for publications identified as including a neurological condition. A detailed list of abstraction criteria is available in Table A.2 in Appendix A.

Research Investment Data: Identification and Approach

An initial scan of public and private funding for TBI research identified DOW, the U.S. Department of Health and Human Services (HHS), the U.S. Department of Veterans Affairs (VA), Small Business Innovation Research (SBIR), the National Science Foundation (NSF), and private philanthropy as the largest donors. The abstraction of investment data was divided into four components. An application programming interface was used to rapidly extract all data with the term *traumatic brain injury* or *TBI* from USAspending.gov, NIH Data RePORTER, ClinicalTrials.gov, DOW, SBIR, and Candid.[3] Not all research investments were solely for service-related TBI research; investments for research on TBI specifically incurred in youth sports, accidents, or direct service provision and research focused on caregiver support were excluded. The remaining data are discussed and analyzed in greater detail in Chapter 4.

[2] Andrea C. Tricco, Erin Lillie, Wasifa Zarin, Kelly O'Brien, Heather Colquhoun, Monika Kastner, Danielle Levac, Carmen Ng, Jane Pearson Sharpe, Katherine Wilson, et al., "A Scoping Review on the Conduct and Reporting of Scoping Reviews," *BMC Medical Research Methodology*, Vol. 16, February 9, 2016.

[3] Candid formed in 2019 with the merger of GuideStar and Foundation Center.

Analytic Approach

Using a similar method to that of the literature review, we screened all data for inclusion of the relevant keywords in the title or abstract. Misaligned awards, such as those for research on total body irradiation, also designated as TBI, or for tangentially related studies, such as those principally focused on cerebral blood flow but potentially informative for brain injury research broadly defined, were removed from the sample. To form a more complete picture, any relevant clinical trial data and SBIR project solicitations were acquired. Finally, the analysis of private foundation grant data supplemented public investment to highlight priority research areas for advocates and private organizations.

Award amounts were adjusted for inflation and converted to 2025 U.S. dollars using U.S. Bureau of Labor Statistics data released on June 1, 2025.[4] Records were screened to align with the scoping review study period from January 2015 to June 2025.

Limitations

We acknowledge several limitations that may affect the comprehensiveness of our findings. First, although our search methodology was designed to be thorough, it is possible that some relevant papers were not identified. Research discussing subconcussive injuries may not have used the specific keywords we employed, which could result in their exclusion. Second, papers examining TBI as a secondary outcome, foundational scientific research that could support our conclusions, or civilian-sector studies with applicable insights may not have been captured in our review. Third, the ten-year lookback omitted the large body of literature published before 2015, including some seminal papers in the field. In the investment analysis section, our examination was based on publicly available data, which may limit the depth of our insights. For instance, the availability of patent data was insufficient to allow the same rigorous analysis applied to public spending. Our approach to identifying federal research investments relied on publicly reported data from government funding websites, which did not include information about VA intramural research. VA has prioritized research on TBI, such as the Long-Term Impact of Military-Relevant Brain Injury Consortium and the Chronic Effects of Neurotrauma Consortium (LIMBIC-CENC), although spending on these efforts did not appear in our search and thus is not included in our estimates of federal funding. We note that VA budget and advance appropriations requests for fiscal years 2021 to 2025 included $45 million to $55 million each year for TBI and brain health research.

Finally, the potential for human error should be acknowledged. Despite the implementation of validation checks throughout the research process, there remains a possibility that some papers were misclassified or inadvertently omitted. Ongoing refinement of search methodologies and broader inclusion of research sources will contribute to the robustness of future studies.

[4] U.S. Bureau of Labor Statistics, "Consumer Price Index," webpage, undated.

CHAPTER 3

Service-Related TBI Research: Scoping Literature Review Findings

This chapter presents the study characteristics of the 480 papers included in the scoping review. As discussed in Chapter 2, we categorized papers by continuum of care, study design, and whether the study outcome included comorbidities. Table 3.1 offers a quantitative view of the characteristics of the studies we considered. We discuss our findings according to each category in the remainder of the chapter.

Service-Related TBI Research: Scoping Literature Findings in Brief

SOF are an understudied population at increased risk for TBI because of blast exposure. Only seven papers focused exclusively on SOF, and 14 included SOF in mixed samples.

Most TBI research was observational and centered on diagnostic methods, with far fewer studies addressing interventions or the root causes of blast injuries.

Nonhuman research primarily used murine models, with limited studies involving larger animals, nonhuman primates, or digital simulations.

The majority of TBI studies examined TBI alongside other conditions; 68 percent of articles reported findings on TBI with at least one comorbidity, most commonly PTSD.

Research on TBI outcomes varied by time frame. Short- and medium-term studies described general neurological symptoms, whereas longer-term studies focused on neurodegenerative conditions or early biomarkers.

Most studies addressed a single stage of TBI care, with diagnosis, particularly through imaging and biomarkers, being the most common focus (46 percent, 224 papers). Only 9 percent (46 papers) addressed rehabilitation and long-term care.

TABLE 3.1

Quantification of Study Characteristics from the 480 Included Papers

Characteristic	Number of Publications	Percentage of Scoping Review
Military characteristics		
Active duty	120	24.59
U.S. Air Force (USAF)	27	5.53
U.S. Army	49	10.04
Generic military	208	42.62
U.S. Marine Corps	40	8.20
National Guard or reserve	12	2.46
U.S. Navy	31	6.35
SOF	21	4.30
Veteran	188	38.52
Study design		
Three-dimensional (3D) cell model	1	0.20
Animal	94	19.26
Biomarker	107	21.93
Cell culture	9	1.84
Epidemiological	90	18.44
Etiological	20	4.10
Human postmortem	3	0.61
Imaging	111	22.75
Literature review	63	12.91
Observational	140	28.69
Other	45	9.22
Qualitative	15	3.07
Scale validation	12	2.46
Trial or intervention	47	9.63
Type of TBI		
Blast	316	64.75
Close impact	66	13.52
Mild TBI (mTBI)	180	36.89
Multiple TBI types	41	8.40
Not described	26	5.33

Table 3.1—Continued

Characteristic	Number of Publications	Percentage of Scoping Review
Other	11	2.25
Penetrating	16	3.28
Subconcussive	31	6.35
Comorbid conditions		
Auditory	33	6.82
Behavioral	103	21.28
Chronic pain	39	8.06
Dermatological	1	0.21
Musculoskeletal	20	4.13
Neurological	170	35.12
Ocular	31	6.40
Other	64	13.22
PTSD	181	37.40
Psychological	153	31.61
Sleep	75	15.50
Substance misuse	26	5.37
Neurological condition or disorder		
Alzheimer's disease	16	3.31
Amyotrophic lateral sclerosis	2	0.41
Chronic traumatic encephalopathy (CTE)	18	3.72
Cognitive deficits	54	11.16
Communication disorders	1	0.21
Epilepsy	7	1.45
Frontotemporal dementia	5	1.03
Hydrocephalus	2	0.41
Memory loss	55	11.36
Migraines	12	2.48
Other	93	19.21
Parkinson's disease	9	1.86
Persisting symptoms	20	4.13
Vascular injury	17	3.51

Table 3.1—Continued

Characteristic	Number of Publications	Percentage of Scoping Review
Continuum of care		
Diagnosis	224	46.28
Other	9	1.86
Prevention	58	11.98
Rehabilitation and long-term care	46	9.50
Treatment, management, or mitigation	77	15.91

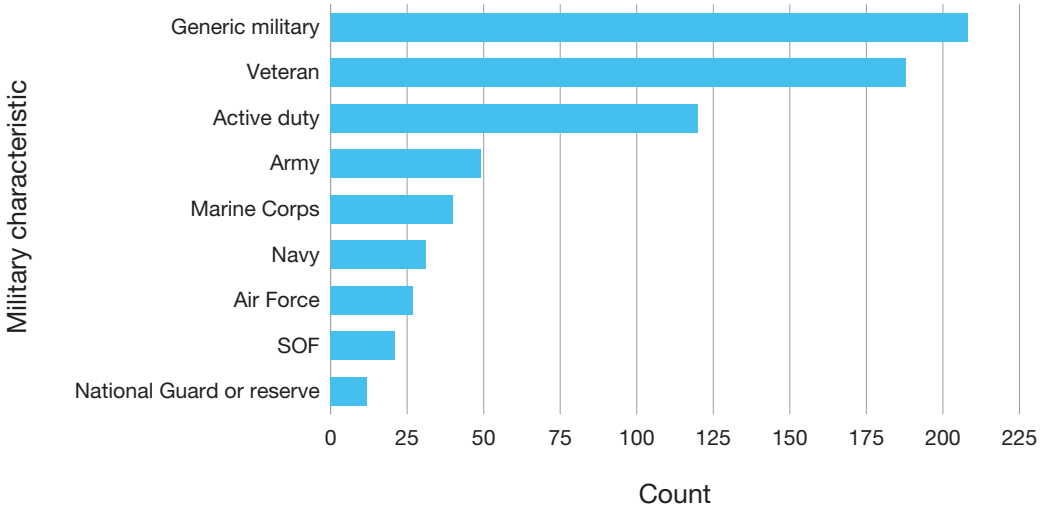
SOURCE: Authors' quantification of study characteristics via Covidence of the 480 publications included in this scoping review.

NOTE: Percentages are based on the proportion of the full body of included literature. Counts are not exclusive to characteristic categories (e.g., a paper can be about the Army and the Navy).

Military Characteristics

In part due to our focus on research that directly affects service members, 83 percent ($n = 403$) of the papers studied military populations. The remainder examined nonhuman subjects but had direct military implications and contributed to understanding the underlying biology of TBIs. Most papers did not disaggregate by branch of service, even if they noted whether the sample included active-duty personnel, National Guard or reserve personnel, or veterans. Additionally, many papers collected data in clinical settings, where members of several different services received care. In those cases, each time a service was described, it was included in the sample. Owing to the increased likelihood of occupational exposures, members of the Army ($n = 49$) and Marine Corps ($n = 40$) were the most frequently studied populations. Few papers focused solely on SOF ($n = 7$). Although 14 additional papers included SOF in their samples, many more may have included SOF without specifically identifying them. We disaggregate these findings in Figure 3.1.

FIGURE 3.1
Military Characteristics Represented Across the Body of Literature



SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review.

Study Designs

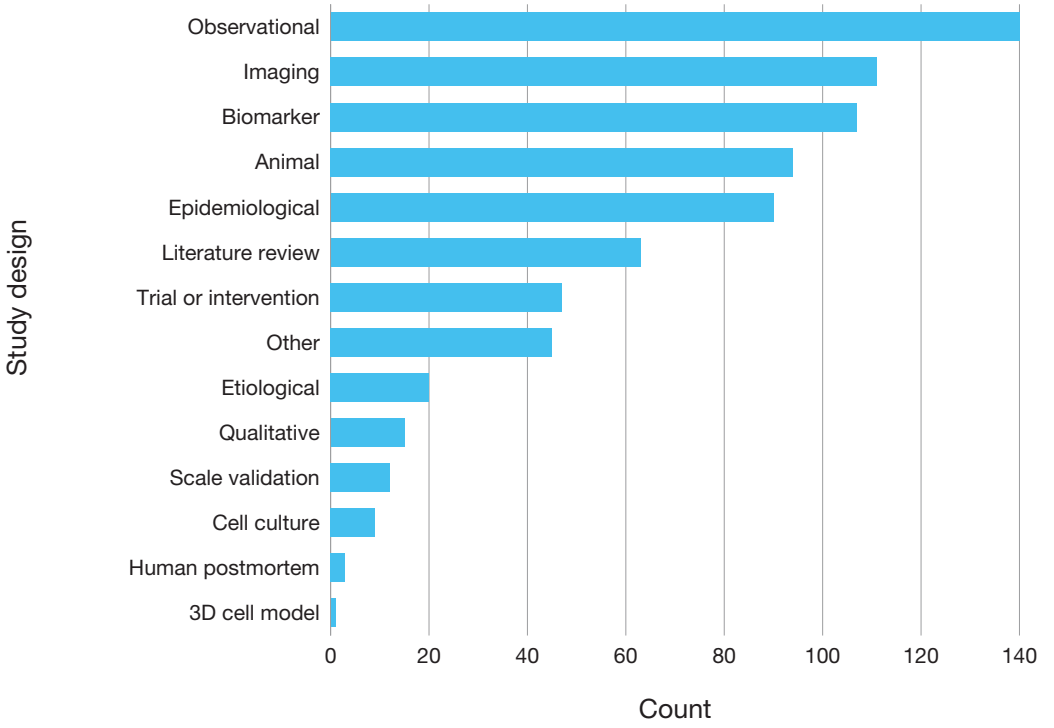
Figure 3.2 displays the great deal of observational research designs (n = 140) in the sample and the limited paper output in intervention research (n = 47) or etiological research (n = 20) looking at treatments or the root causes of blast, respectively. Many of the study designs were used in conjunction with others, such as combinations of imaging studies (n = 111) and biomarker studies (n = 107). Papers defined as *other* included modeling and product development and represented gray literature, such as expert panels, clinical recommendations, or meeting proceedings. Our focus on human research may have excluded blast physics or other in vitro research relevant to this space. The studies that included these techniques were often in conjunction with other study designs. The limited number of scale validation papers (n = 12) points to the difficulty of diagnosing TBI with existing tools.

TBI Type

Figure 3.3 shows the count of publications by TBI type. Many papers included multiple types of TBI, and we counted each separately. Many of the papers we reviewed described the source and severity of blasts (n = 316) experienced by either service members or small animals. This finding was not unexpected, as *blast* was one of the search terms used to identify relevant research. Notably, counts of subconcussive injury (n = 31) were quite low. Future researchers performing literature reviews of this topic may wish to investigate why these injuries were

FIGURE 3.2

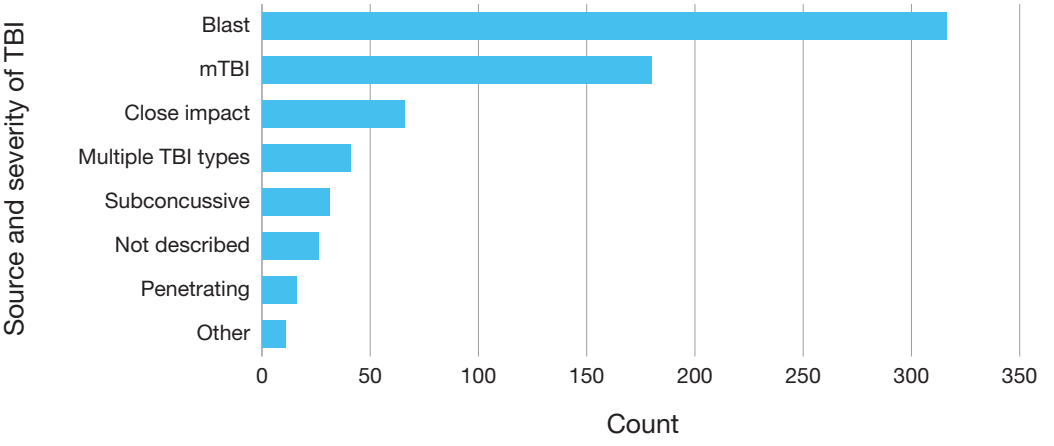
Study Designs in the Identified Literature



SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review.

FIGURE 3.3

Source and Severity of TBI Described in the Review



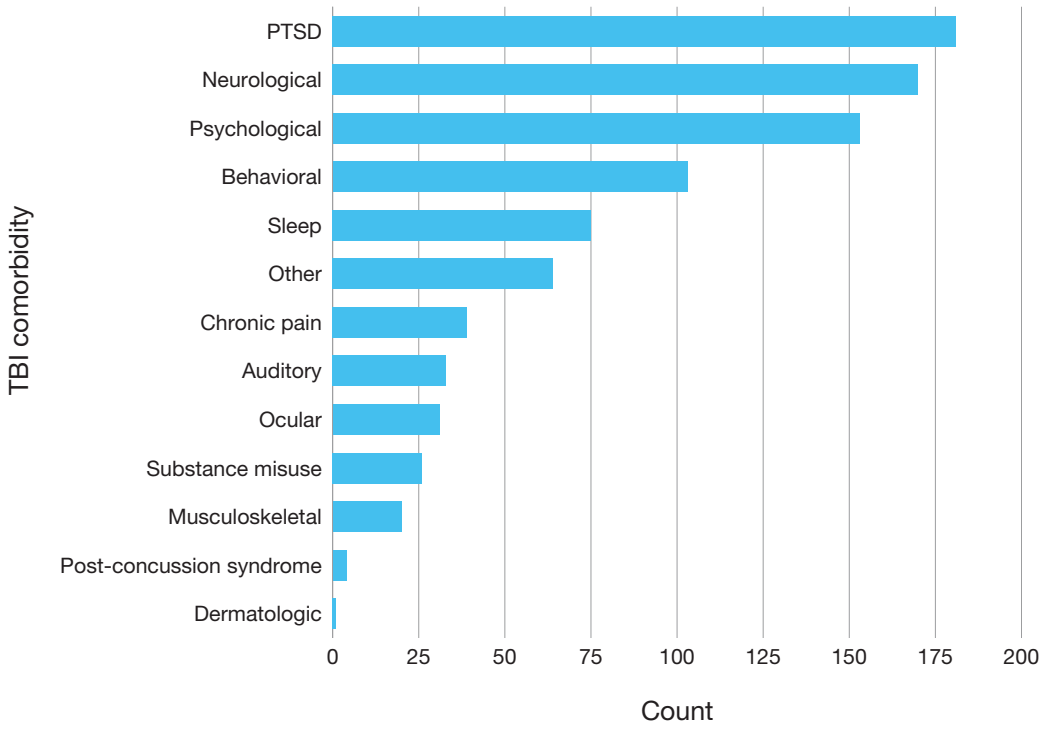
SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review.

overlooked; it may be due to the selection of search terms or to the fact that subconcussive injury continues to be an underdiagnosed condition.

Comorbid Conditions

TBI is frequently diagnosed in conjunction with other conditions or symptoms. Of the 480 articles reviewed, 327 (68 percent) presented findings on TBI in conjunction with one or more co-occurring conditions, shown in Figure 3.4. These conditions were associated with TBI in the short or long term. Among the 327 articles, 121 focused on only one comorbidity, 82 focused on two comorbidities, and 124 focused on three or more comorbidities. Furthermore, isolating the 181 articles that presented research on PTSD as a comorbidity, we found that 136 included at least one comorbidity in addition to PTSD. The comorbid conditions most frequently included with PTSD were neurological (n = 58), psychological (n = 99), behavioral (n = 60), and sleep-related (n = 58) disorders. As was stated earlier, we focused our subanalysis on neurological conditions, the second most frequent comorbidity in our sample (n = 237). For a detailed description of the abstracted conditions, please refer to Table A.2 in Appendix A.

FIGURE 3.4
TBI Comorbidities in the Scoping Review

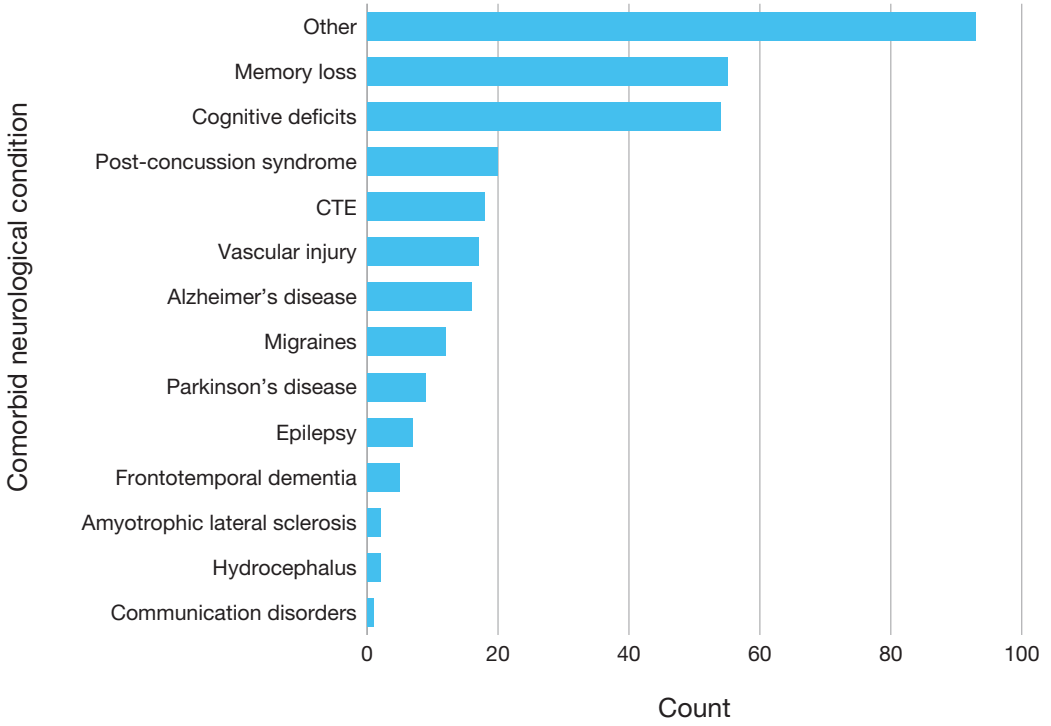


SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review.

Neurological Conditions

Most of the reviewed papers, shown in Figure 3.5, described neurological symptoms instead of named diagnosed conditions and were defined as *other* ($n = 93$). Many of these studies were conducted in the short- to medium-term post-TBI period and reported such complaints as loss of executive function, inflammation, pain, sensory dysfunction, and changes to gait and balance. Neurodegenerative conditions were investigated in the long-term studies, years after the brain injury may have occurred, and included Alzheimer's disease ($n = 16$), Parkinson's disease ($n = 9$), and CTE ($n = 18$). Other studies explored early-stage biomarkers without specific clinical endpoints.

FIGURE 3.5
Number of Publications That Report on Comorbid Neurological Conditions



SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review. Note that *persisting symptoms* was previously known as *post-concussive syndrome*, and this term may have been used in some of the reviewed literature.

Continuum of Care

We categorized studies into a single point in the continuum of care: prevention; diagnosis; treatment, management, or mitigation; or rehabilitation and long-term care. Figure 3.6 compares the volume of papers counted in each category.

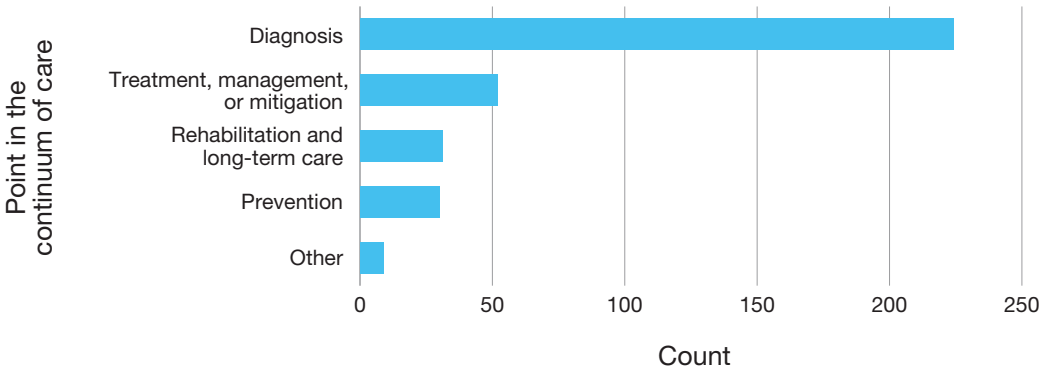
Prevention

Twelve percent of papers (n = 58) focused on an element of preventing TBIs. Of these papers, the majority focused on blast-related injuries, and six developed etiological models to examine the impact of sudden spikes in blast overpressure, improvements to helmet design, and comorbid conditions that can affect the risk of TBI. However, because of our focus on TBI as the primary outcome, we excluded from our analysis papers related to other prevention areas, such as armor designed to mitigate underbody blast or hearing and eye protection, and etiological studies of blast physics. Additionally, we did not include studies that focused on how comorbid conditions, including previous exposure to head injuries, may increase the propensity for TBI during military service.

Diagnosis

Our team identified 224 papers (46 percent) that discussed various methods and strategies for diagnosing TBI. Among these, studies predominantly employed observational designs that incorporated imaging and/or biomarkers. Imaging studies used a variety of techniques (e.g., magnetic resonance imaging [MRI], computed tomography [CT], diffusion tensor imaging [DTI]) to identify the structural changes caused by different types of TBI.

FIGURE 3.6
Categorizing Studies Along the Continuum of Care



SOURCE: Authors' analysis of abstracted data from the publications included in this scoping review.

Biomarker studies were predominantly conducted in animal models. A handful of papers involved military personnel undergoing breacher training; in these studies, blood samples were collected to identify differences in biomarker expression before and after blast exposure. Many papers combined methodologies, integrating biomarkers, imaging, and other techniques to enable accurate detection of mild and subconcussive injuries.

Treatment, Management, or Mitigation

Fifteen percent (n = 77) of articles investigated the treatment, management, and/or mitigation of TBI, either independently or with a comorbid condition. Experimental approaches were favored, divided between papers using animal studies (n = 15) and papers using clinical trials or interventions (n = 23). A deeper dive into articles on neurological conditions identified studies that focused on treatment efforts. Of these studies, 13 focused on the treatment of TBI alone, 13 focused on the treatment of a comorbid condition on its own, and 12 focused on the co-treatment of both TBI and a comorbid condition. Mitigation techniques encompassed nonpharmaceutical interventions and limiting the risk of secondary injury.

Rehabilitation and Long-Term Care

Nine percent of the articles (n = 46) were classified as investigating rehabilitation and/or long-term care; these articles focused on return-to-duty outcomes and the restoration of quality of life. Most study designs were epidemiological and observational, especially among the studies that focused solely on long-term outcomes. The few randomized controlled studies encompassed a broader continuum of care, suggesting a gap in causal evidence published with an explicit focus on rehabilitation and long-term care.

CHAPTER 4

Assessing Investments in TBI Research

Federal and private organizations have made significant investments in TBI research since 2015. In this chapter, we examine trends in these investments. We provide a detailed analysis by funding agency, award type, and period.

Findings

Since 2015, more than $2 billion in federal and private funds have been invested in service-connected TBI research across the continuum of care. Table 4.1 displays the distribution of funds between the largest federal funders of TBI research and private philanthropy. Of all reviewed public and private awards, grants constitute 75 percent of the total awards and more than 85 percent of the total dollars spent. The primary difference between grants and contracts lies in how involved the sponsor is in the research process and the amount of flexibility

Investment in TBI Research: Findings in Brief

Since 2015, federal and private sources have invested more than $2.1 billion in TBI research. Most of this funding has come through grants, which make up 75 percent of all awards and more than 85 percent of total dollars spent.

DOW and HHS have been the largest contributors to TBI research, providing approximately $930 million and more than $1 billion, respectively.

Grant funding peaked in 2022, at more than double the 2015 level. Since then, funding has fluctuated by year.

Philanthropic contributions have steadily increased to nearly $80 million cumulatively, supporting various initiatives within TBI research, including genetic studies, innovative treatments, caregiver support, and programs for specific groups, such as former SOF members.

in the research design and objectives.[1] We did not include any HHS contracts ($n = 52$) because these were deemed to be unaligned with project goals and removed from the analysis.[2]

DOW Funding

Within DOW, the Defense Health Agency (DHA) and the Army have funded the majority of TBI research (Figure 4.1), followed by the Uniformed Services University of the Health Sciences (USUHS), the Navy, the USAF, and DOW. Because of their smaller contributions to the overall research budget, several organizations are not included in the figure. These are the Defense Threat Reduction Agency (approximately $1.4 million), the Defense Advanced Research Projects Agency (approximately $0.750 million), and the Defense Contract Management Agency (approximately $0.460 million).

Almost three-fourths of DOW's TBI-related grant contributions during the study period came from DHA and the Army. Recipients included researchers from within DOW, other government agencies, and academia. DHA supports medical research across the Military Health System, incorporating basic science, clinical investigations, and implementation studies across the services. U.S. Army Medical Research and Development Command (formerly U.S. Army Medical Research and Materiel Command) funds a science and technology program for battlefield care and combat and casualty medicine. USUHS, the Navy, the USAF, and other DOW components contributed the remainder of large grants. Smaller grants were provided by the NSF and the Defense Advanced Research Projects Agency, often for basic science research.

TABLE 4.1
Total Federal and Private Awards in TBI Research, January 2015 to June 2025

	Awards			
Funder	Total	Grants	Contracts	Value ($)
DOW	506	423	83	930,484,713.41
HHS	896	896		1,053,830,973.90
NSF	21	21		9,354,918.23
VA[a]	511	6	505	111,683,469.36
Federal total	1,934			2,105,354,074.90
Private foundations	450			77,507,157.90
Total awards	2,384			2,182,861,232.80

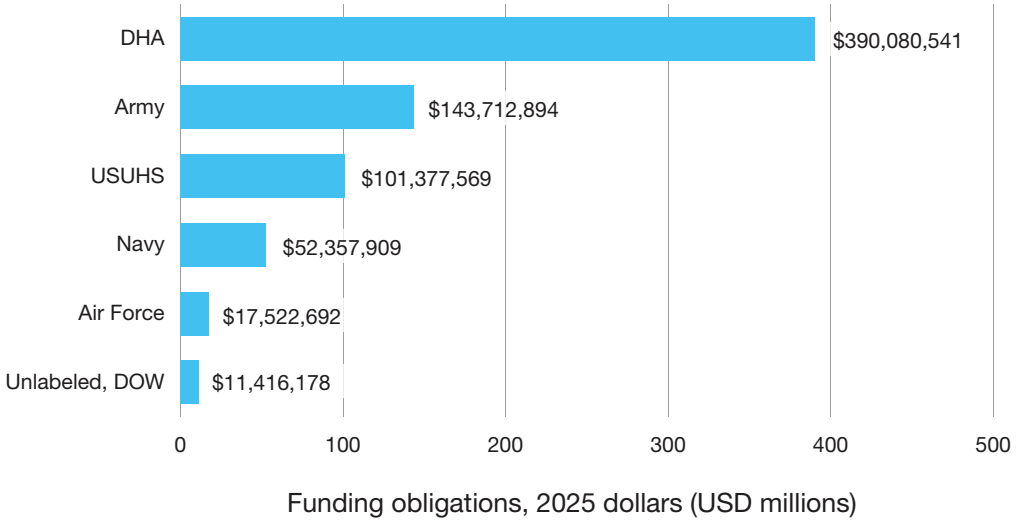
SOURCE: Authors' analysis of USAspending.gov and Candid data, July 15, 2025.

[a] VA includes extramural funding only.

[1] U.S. Small Business Administration, "Contracts vs Grants," webpage, undated-a.

[2] We reviewed the abstract for each HHS contract for relevance to the project's goals. Removed contracts were oriented toward nonresearch aims, such as technical assistance and convenings.

FIGURE 4.1
DOW Subagency Grant Totals Greater Than $10 Million, 2015–2025



SOURCE: Authors' analysis of USAspending.gov data, July 15, 2025.
NOTE: USD = U.S. dollars.

VA Funding

VA extramural funds support TBI treatment, rehabilitation services, and assisted living for former service members. VA intramural funds, which constitute the majority of VA's funding, support VA investigators working at VA facilities in direct service provision, medical research, and clinical trials.[3] Although we were not able to determine the total amount of VA intramural funding spent on TBI research, a more detailed investigation of the publication impact of VA research is discussed in Chapter 5.

HHS Funding

Within HHS, as displayed in Figure 4.2, the NIH leads TBI-related grantmaking. The NIH is the largest funder of medical research in the United States, granting funds to universities, private and nonprofit organizations, and other federal agencies. These funds are almost entirely dedicated to basic science aimed at understanding brain injury, exploring new treatments, and developing new pathways for diagnostics. The Administration for Community Living supports research to increase TBI advocacy services, screening capabilities, and education for patients and caregivers. The Centers for Disease Control and Prevention, primarily through its Injury Center, directs funds to state health departments for TBI prevention. The Health

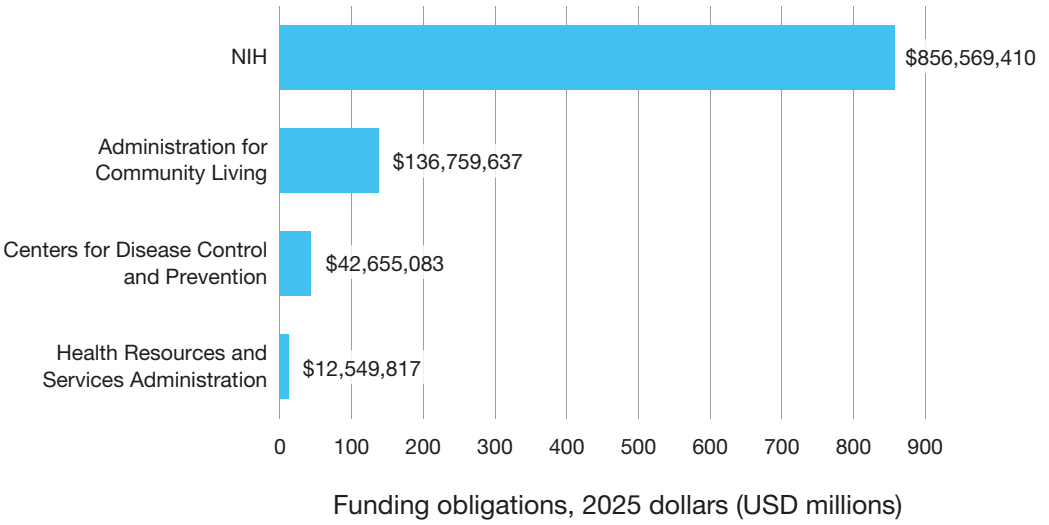
[3] Sidath Viranga Panangala, Jared S. Sussman, and Madeline E. Moreno, *Department of Veterans Affairs FY2025 Appropriations*, Congressional Research Service, R48608, July 24, 2025.

Resources and Services Administration, frequently in support of congressionally mandated programs, funds upgrades to existing systems for TBI diagnostics, treatment, rehabilitation, and patient welfare. Smaller grant programs not listed in Figure 4.2 include funding from the Office of the Assistant Secretary for Financial Resources (approximately $2.9 million), the Substance Abuse and Mental Health Services Administration (approximately $1.3 million), and the Agency for Healthcare Research and Quality (approximately $1.1 million).

Funding Trends

The size and scope of federal TBI-related research awards change annually, as illustrated in Figure 4.3.[4] Grant funding reached its peak in 2022; it rose 101 percent higher than funding in 2015. The number of grants rose as well, reaching its peak in 2024 with a total of 214 grants. The trends in funding from DOW compared with HHS funding since 2015, shown in Figures 4.4 and 4.5, reveal differing patterns that require further exploration.

FIGURE 4.2
HHS Subagency Grant Totals Greater Than $10 Million, 2015–2025

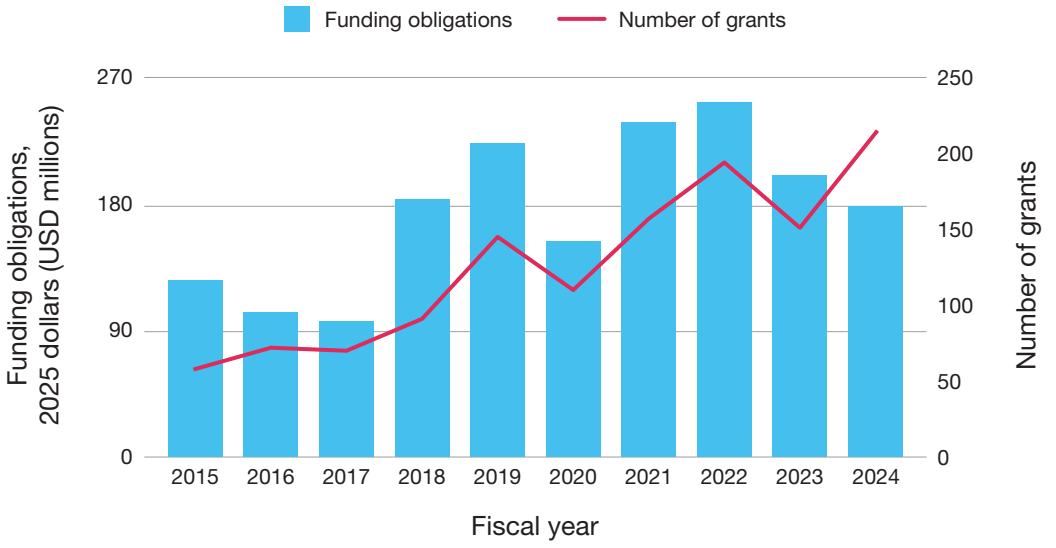


SOURCE: Authors' analysis of USAspending.gov data, July 15, 2025.

[4] U.S. federal fiscal years are October 1 through September 30. Data presented include only years for which we had a full year of data at the time of analysis (fiscal years 2015 to 2024, which encompass the period of October 1, 2014, through September 30, 2024).

FIGURE 4.3

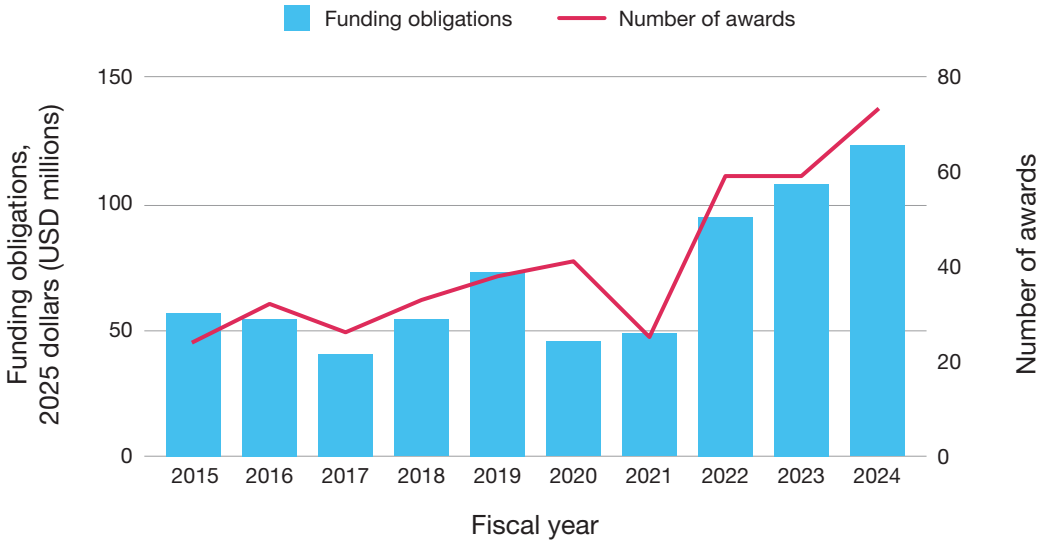
Trends in U.S. Federal TBI-Related Grant Contributions, Fiscal Years 2015–2024



SOURCE: Analysis of USAspending.gov data, July 15, 2025.

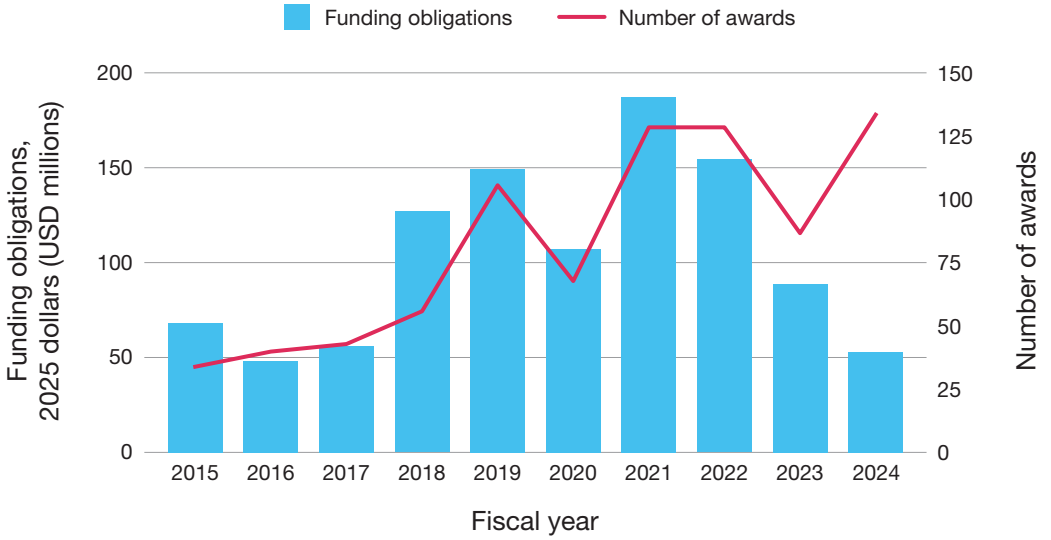
FIGURE 4.4

Trends in DOW Grantmaking for TBI Research, Fiscal Years 2015–2024



SOURCE: Analysis of USAspending.gov data, July 15, 2025.

FIGURE 4.5
Trends in HHS Grantmaking for TBI Research, Fiscal Years 2015–2024



SOURCE: Authors' analysis of USAspending.gov data, July 15, 2025.

Figure 4.6 illustrates a steady increase in private funding for TBI research until 2021. Examples of projects supported by philanthropic funds include genetic studies, novel treatment administration, caregiver support, and programs targeting specific subpopulations, such as SOF. With 241 unique grantmakers and a median grant value of roughly $13,000, there continues to be a trend toward solutions designed at the community level.

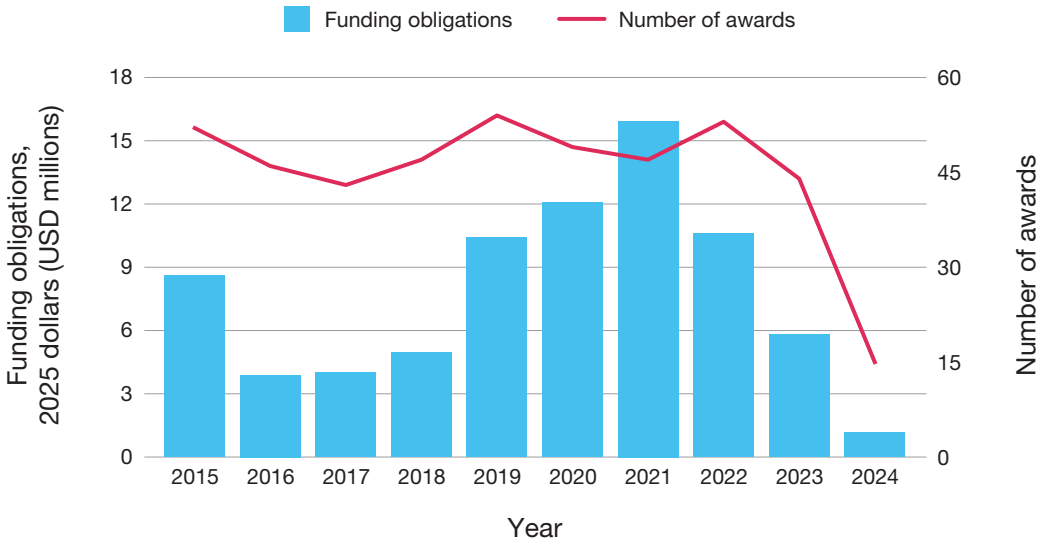
One measure of research impact is the number of publications linked to each grant. Figure 4.7 illustrates the publishing trends following receipt of federal funding, highlighting a nonlinear lag that is to be expected, as researchers need time to complete their studies and the peer review process. Additionally, the federal government funds programs that do not conduct research and development or that may not produce any publishable material, such as product development for the protection of military and civilian personnel, research symposia, and advocacy services for TBI awareness.

The SBIR program awards grants to small businesses for technological research with the potential of commercialization. Eleven federal agencies allocate a percentage of their research and development budget to answer a variety of research and development questions, including those involving TBI.[5] SBIR grant data were analyzed to identify private-sector innovations in TBI. Although SBIR data reveal the origin of funding opportunities, they do not indicate whether these solicitations were executed. DHA solicitations have emphasized diagnostic and molecular analysis platforms, whereas Army solicitations have focused on field medicine and wound care.

[5] U.S. Small Business Administration, "Frequently Asked Questions: General Questions," webpage, undated-b.

FIGURE 4.6

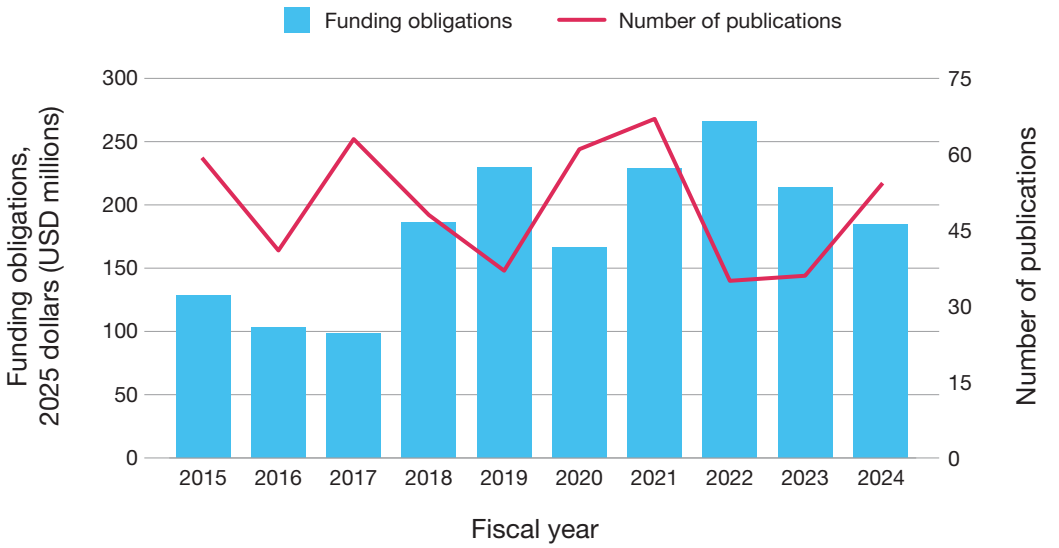
Trends in Philanthropic Grantmaking for TBI-Related Research, 2015–2024



SOURCE: Authors' analysis of Candid data, July 15, 2025.

FIGURE 4.7

Federal Funding Obligations and Publications Attributed to Federal Funding, Fiscal Years 2015–2024



SOURCE: Authors' analysis of USAspending.gov data, July 15, 2025.

CHAPTER 5

Mapping the Evidence: Opportunities for Aligning Research and Investment to Address Gaps in TBI Knowledge and Care

This chapter connects the study characteristics from the 480 publications we reviewed in Chapter 3 with the funding investments discussed in Chapter 4. We abstracted the funding source for each publication to describe publication trends by specific awarding agencies and examined how this aligned with overall research funding investments. Investment data for this chapter were focused on extramural funding; thus, we used the investment amounts for only the grants identified in Chapter 4.

Aligning Research and Investments: Key Findings in Brief

DOW and HHS lead federal grant-based investments in TBI research, dominating both funding and publication output.

Active-duty soldiers, veterans, and unspecified service members are well represented in TBI research, whereas SOF, airmen, and National Guard and reserve members remain underrepresented.

Blast-related injuries, TBIs, and multiple TBI types receive substantial attention, reflected in high publication volume and funding awards across agencies and years.

DOW and HHS funding has increased since 2015, coinciding with a rise in publications focused on mTBIs and blast-related TBIs.

Subconcussive and penetrating TBIs receive less research and funding, highlighting a significant gap and potential investment opportunity.

Grant funding for DOW and HHS has risen since 2020, resulting in more publications related to PTSD, sleep disorders, and other psychological and neurological conditions.

Observational and imaging studies are strongly emphasized across grant-awarding agencies, consistently producing a high volume of publications throughout the funding years.

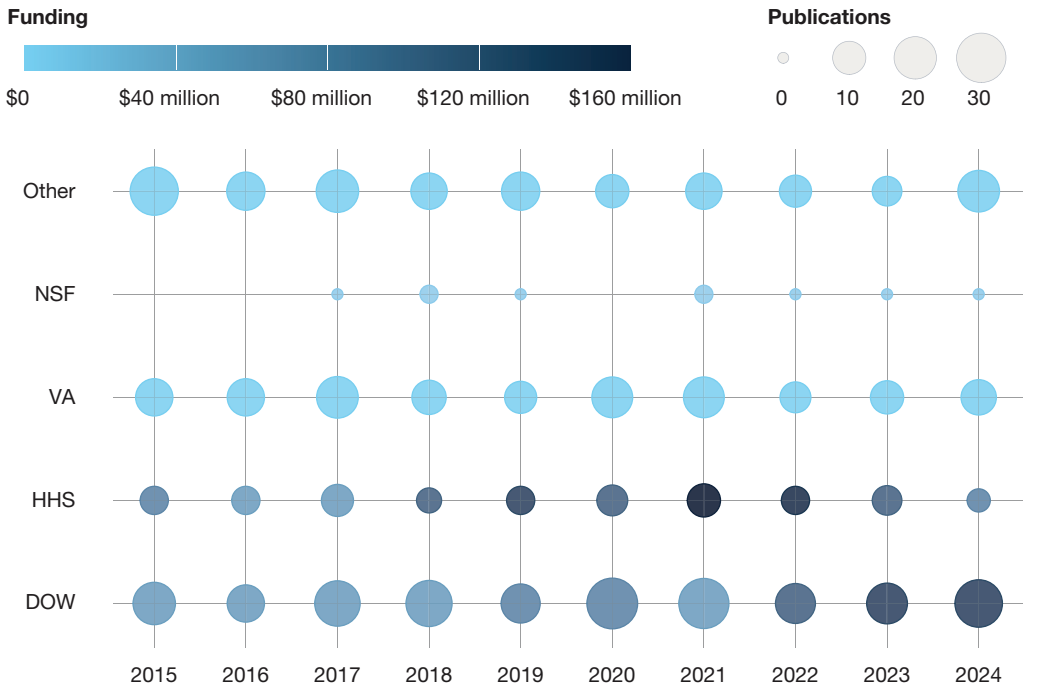
Awarding Agency Contributions

Analysis of extracted information from the funding acknowledgment sections of the included papers in Chapter 3 and the identified grant contributions from January 2015 to June 2025 from Chapter 4 revealed clear differences in both funding allocation and research outputs, shown in Figure 5.1. DOW and HHS emerged as the dominant contributors, consistently supplying substantial funding and generating the greatest volume of publications. Peak funding and publication activity occurred from 2020 through 2024, suggesting alignment with strategic priorities or programmatic expansions during this period.

To evaluate the impact of awarding agencies on literature output relevant to our scoping review, we conducted a correlation analysis. The results indicate that publication outputs

FIGURE 5.1

Funding and Publication Efficiency of Grant-Awarding Agencies



SOURCE: Authors' analysis of grant investment data presented in Chapter 4 and the publications identified in this scoping review and their associated awarding agencies as stated in the publications' funding acknowledgments.

NOTE: The chart's prominent dark bubbles, contrasted with the sparse and empty spaces, illustrate significant findings. This visual representation not only highlights areas of substantial research activity but also underscores gaps in funding and publication output.

did not consistently correlate with financial investment across agencies. Specifically, DOW funding showed only a weak association with publication outputs ($r = 0.09$). In contrast, HHS funding exhibited a stronger positive correlation with publication activity ($r = 0.54$), indicating a more direct relationship between financial investment and academic dissemination, although the relationship remained variable across years.

In contrast, NSF was minimally represented, with limited funding and few publications ($n = 2$). Correlation analysis revealed a negative association ($r = -0.34$), likely reflecting the small sample sizes and longer research timelines inherent to NSF-supported projects. VA was not included in the correlation analysis because of its unique funding mechanism, making it difficult to distinguish between the grant funding reported in Chapter 4 and the intramural funding captured in the scoping review.[1]

It is important to note that these findings are based on the literature captured in our scoping review and may not encompass all publications linked to awarded grants, representing a key study limitation. Agencies with strong funding commitments but weaker academic output, such as DOW, indicate potential blind spots in recognizing nontraditional outcomes, whereas such agencies as NSF demonstrate potential for greater returns if strategically resourced.

Military Characteristics

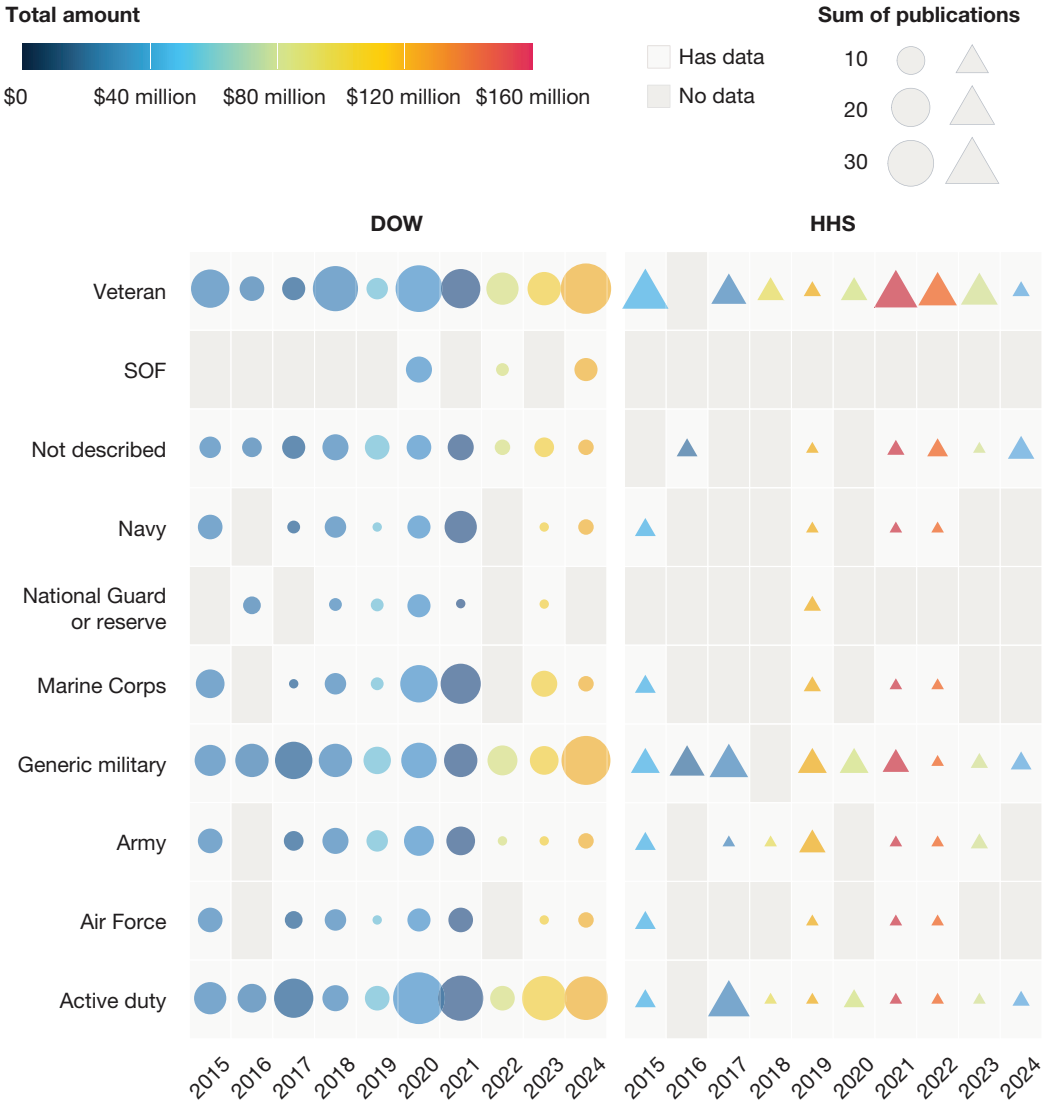
As illustrated in Figure 5.2, the amount of research funding and the number of publications differ depending on the population studied and the funding agency. DOW leads in both funding and publication output and demonstrates consistent investment over the years, particularly for veteran, active-duty, unspecified military, and Army populations. HHS has made significant contributions, especially from 2019 through 2023; however, this investment has resulted in fewer associated publications and focuses primarily on veteran, active-duty, and unspecified military populations.

Despite overall growth, several important gaps emerge. Such populations as SOF, sailors, airmen, and members of the National Guard and reserve are comparatively underrepresented, despite their high operational exposure and distinct health needs. This gap highlights an opportunity to investigate potential risk factors and prevalence of TBI in these populations to address critical capability gaps and better align research portfolios with disease burdens.

[1] VA, "VA ORD Funding Resources," webpage, last updated September 9, 2025.

FIGURE 5.2

Military Characteristics, by Awarding Agency

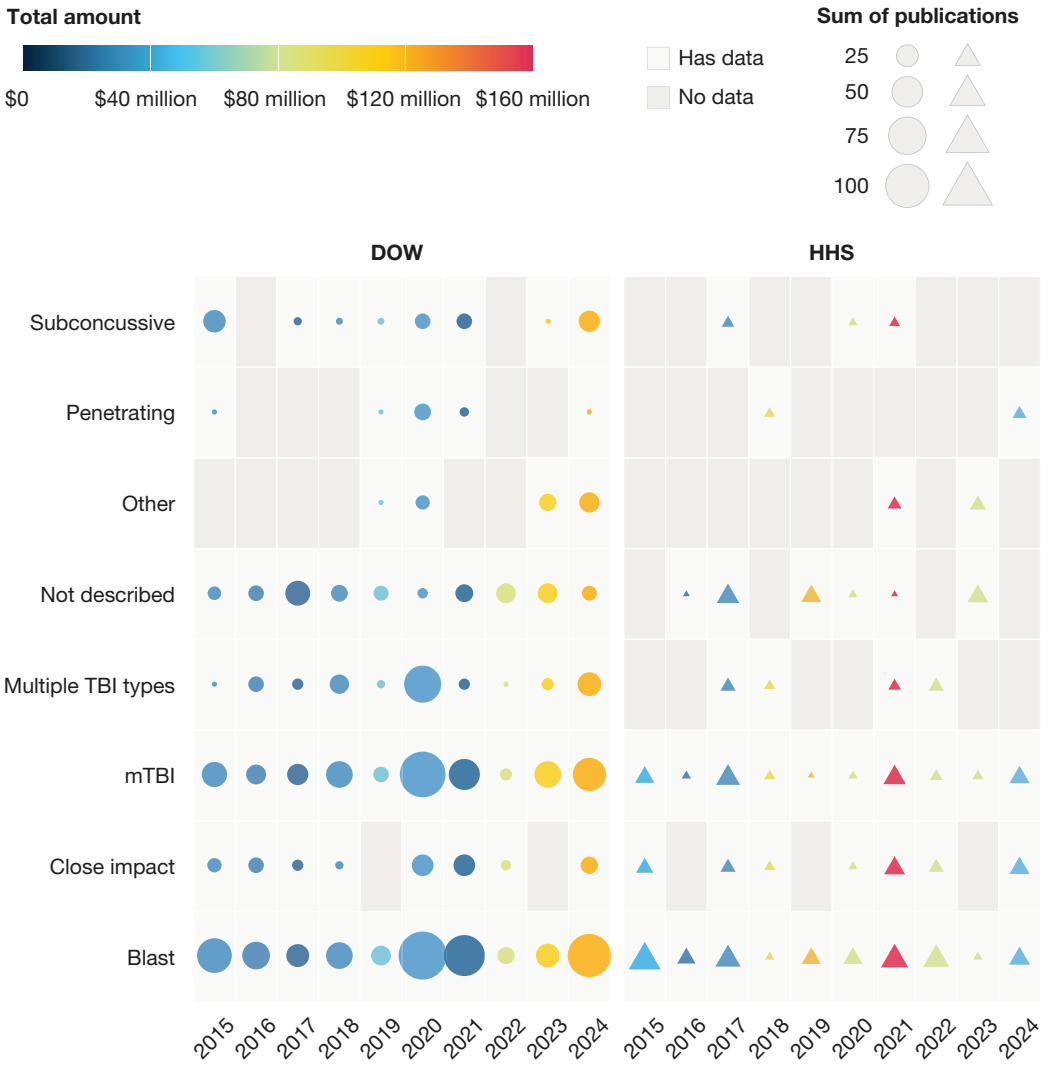


SOURCE: Authors' analysis of grant investment data presented in Chapter 4 and publications identified in this scoping review and the associated abstracted data, grouped by their associated awarding agencies as stated in the publications' funding acknowledgments.

Types of TBI

Across agencies, funding and publication activity varied by which TBI subtype was studied (Figure 5.3). DOW supported the broadest variety of studies, with significant investments in research on blast injuries, mTBI, and multiple TBI types and increasing attention to subconcussive TBIs after 2020. HHS focused primarily on blast injuries and mTBI, with publications

FIGURE 5.3
Type of TBI and Publication Output, by Awarding Agency



SOURCE: Authors' analysis of grant investment data presented in Chapter 4 and publications identified in this scoping review and the associated abstracted data, grouped by their associated awarding agencies as stated in the publications' funding acknowledgments.

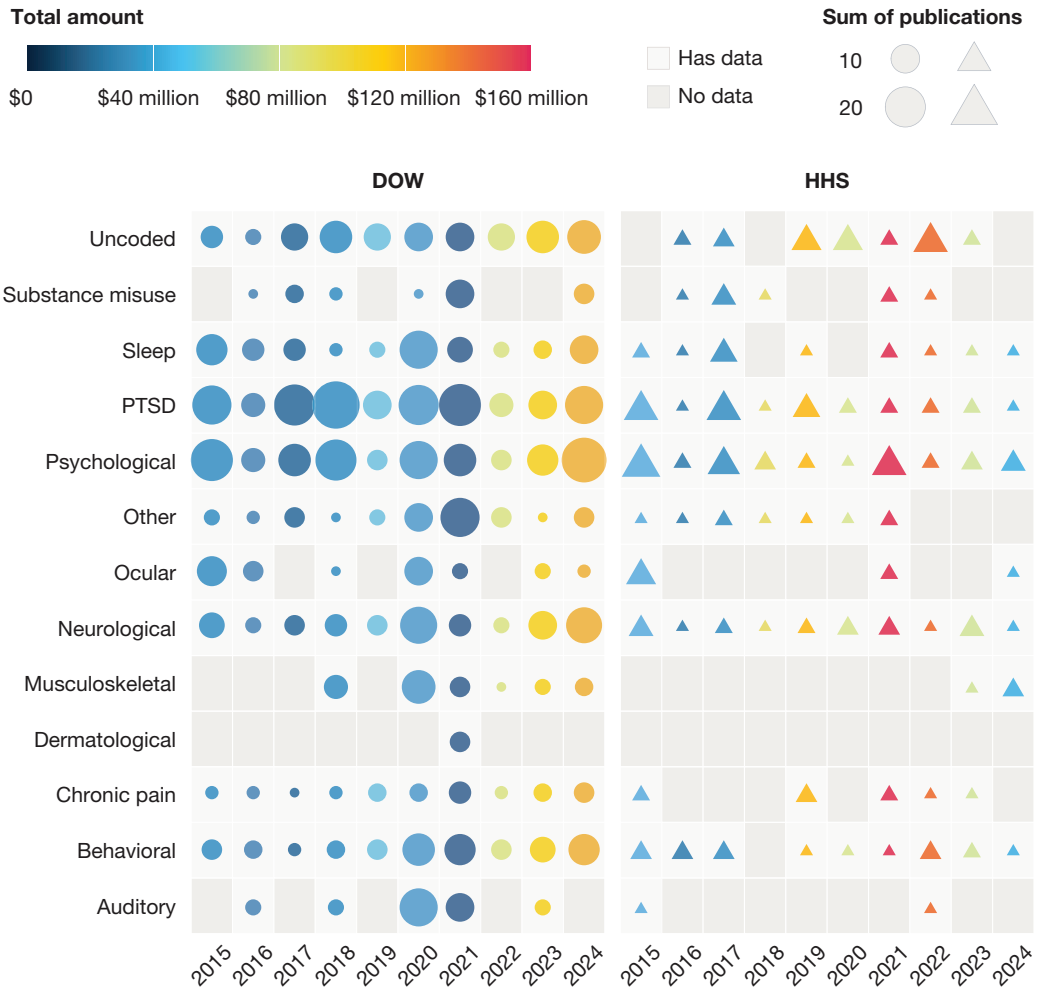
closely mirroring funding trends, particularly from 2019 through 2023. Research on subconcussive and penetrating TBIs remains underrepresented across funding agencies. Potential priority areas for investment to address the identified gaps include a greater focus on studies related to subconcussive and penetrating TBIs.

Comorbidity Trends

Funding and publication activity related to research on TBI comorbidities exhibited distinct patterns across agencies, as shown in Figure 5.4. DOW made the broadest investments, maintaining sustained activity across nearly all domains, with a particular focus on PTSD, sleep, psychological, and neurological comorbidities. HHS focused more selectively, channeling substantial resources into comorbid or co-diagnosed conditions—specifically, PTSD and neurological and psychological conditions. However, substance misuse and behavioral health received comparatively little attention. Across funding agencies, there was little research on sensory impairments, including auditory, ocular, and dermatological conditions. Targeted investment in areas that lack consistent publication outputs, such as substance misuse and auditory and ocular conditions, across agencies could help rebalance the portfolio to better address unmet needs.

FIGURE 5.4

Total Awarding Agency Investment per Year and Publication Output for Comorbidities



SOURCE: Authors' analysis of grant investment data presented in Chapter 4 and publications identified in this scoping review and the associated abstracted data, grouped by their associated awarding agencies as stated in the publications' funding acknowledgments.

CHAPTER 6

Conclusion

In this scoping review, we mapped a decade of research and investment in military service–related TBI, revealing both significant progress and ongoing fragmentation within the field. Substantial investments have advanced imaging techniques and biomarker identification and have improved our understanding of comorbidities, such as PTSD, depression, and sleep disorders. These achievements underscore a growing scientific understanding of the mechanisms of injury and the complex ways in which TBI intersects with broader neurological and psychological health challenges.

At the same time, critical gaps persist. According to our findings, research remains clustered around observational and imaging studies, underscoring the need to invest in longitudinal, scale validation, qualitative, and translational research that can capture lived experiences, as well as etiological studies that explore the underlying mechanisms of blast injury to the brain. Our scoping review identified 20 etiological studies that analyzed whether injuries

Service-Related TBI Research Gaps and Opportunities in Brief

Understudied populations. Little research since 2015 has focused on identifying and treating TBI among SOF, airmen, sailors, and members of the National Guard or reserve, even though these groups face high risks.

Injury types. Most studies and funding address blast-related TBI and mTBI. Subconcussive and penetrating TBI is less studied, and few studies examine links between injury characteristics and outcomes.

Comorbidities. There is recent growth in research on TBI and PTSD, sleep disorders, and neurological conditions, but little attention is paid to substance abuse and sensory impairments.

Rehabilitation and recovery. There is limited research on rehabilitation and long-term care for TBI and comorbidities, leaving a need for evidence-based recovery options.

Research focus. Most studies are based in observations or imaging. More longitudinal, qualitative, and translational research is needed, along with studies on injury mechanisms.

differed among blast, blunt, and penetrating injuries; examined the biomechanics of these injuries; and investigated how protective gear may attenuate these blast waves. However, the abstracted papers did not address correlations between injury and blast pounds per square inch, soldier positioning, or the source of the blast (e.g., breaching versus shoulder-mounted artillery), which is an additional gap and opportunity for future efforts.

In addition, rehabilitation and long-term care associated with the recovery from service-related TBI and comorbid conditions identified in this scoping review continue to receive less research attention, leaving service members and veterans without comprehensive recovery pathways. Subconcussive and penetrating injuries, though potentially life altering, remain underrepresented in the literature, as do comorbidities, such as substance misuse, and other secondary effects from TBI that shape quality of life.

Moreover, some populations, including SOF, National Guard and reserve members, and members of certain service branches, remain insufficiently studied despite their disproportionate exposure to blast injuries and unique occupational risks. Without targeted research in these populations, prevention and treatment strategies risk falling short of real-world needs.

Ultimately, by identifying where progress has been made and where opportunities exist, this review offers a road map for policymakers, funders, and researchers to recalibrate priorities and strategically close gaps. Doing so is not simply a matter of scientific advancement; it is an opportunity to build a more comprehensive and collaborative research agenda, which can advance prevention, sharpen diagnosis, improve treatment, and strengthen long-term recovery, ensuring that service members and veterans receive the care and support they deserve.

APPENDIX A

Inclusion and Exclusion Criteria and Definitions

This appendix presents the inclusion and exclusion criteria used in the review (Table A.1) and the definitions of the codes we used in the Covidence literature review software platform for data abstraction (Table A.2).

TABLE A.1
Inclusion and Exclusion Criteria

	Inclusion	Exclusion
Population	Individuals who were active duty and veteran military	Individuals who were not active duty or veteran military; entire study population was civilian individuals
Exposure	Studies focused on blast-induced, combat-related, close impact–related TBI	Studies focused on TBI induced by civilian-sector events—for example, sports-related TBI and car collision–related TBI
Comparator	Any	None
Outcomes	Any	None
Study characteristics	Studies with TBI as a primary focus of the research; studies discussing the full range from prevention through rehabilitation of TBI; studies focused on the root causes of symptoms associated with TBI; studies describing the biological response to TBI; studies on materials for the prevention of TBI in the military	Studies focused on the mechanisms and physics of blast exposure on in vitro models without discussing the biological response or cause of TBI symptomology; modeling studies focused on blast events and not on identifying root causes of TBI and its cascading comorbidities
Timing	Documents published on or after January 1, 2015	Any document published before January 1, 2015
Setting	Settings that included in theater, combat and noncombat conditions, and training settings that involved military personnel	Strictly civilian settings that did not involve any military personnel

TABLE A.2

Definitions of Codes Used in Covidence

Code	Definition
Military characteristics	
Active duty	Military members in full-time active military service of the United States
Veteran	Individual who has served in the active-duty military services and was discharged or released
SOF	Those active and reserve component forces of the military services that are specifically organized, trained, and equipped to conduct and support special operations
National Guard or reserve	State-based military force that serves as a reserve component of both the Army and the USAF and the reserve components of the Army, the USAF, and the Navy
USAF	Military organization that is primarily responsible for the conduct of air operations
Army	Military organization that is an organized land force trained for land operations
Marine Corps	Military organization that is trained for both land and sea operations
Navy	Military organization that is primarily responsible for the conduct of sea operations
Generic military	Designation used when the service branch is not specified (e.g., if 150 veterans were recruited at the VA Health Center, researchers may co-code this with other group[s] above)
Type of TBI	
Blast	TBI caused by exposure to the intense pressure wave generated by an explosion
Close impact	TBI induced by an impact leading to damage to the brain but no penetration to the skull
Penetrating	TBI that occurs when an object pierces the skull, often caused by shrapnel and bullets; can be combined with blast
Multiple TBI types	Multiple types of TBI studied without distinction
mTBI	Acute brain injury resulting from mechanical energy to the head from external physical forces
Subconcussive	Head injury in which a direct or indirect impact damages brain function but does not result in any clinical symptoms of a concussion or mTBI (i.e., repeated low-level blast exposure does not cause mTBI, but the aggregate may have impacts resulting from subconcussive TBI)
Not described	Code used when a paper mentions TBI but does not describe the severity or origin
Other	Code used when a type of TBI not referenced above is discussed
Type of study	
Animal	Study using animal models
Cell	Study using cellular models
3D cell culture	Study using tissue-mimicking models (e.g., in vitro study of organoids)

Table A.2—Continued

Code	Definition
Human postmortem	Study that allows researchers to study different brain diseases after the death of a patient
Biomarker	Study of a measurable marker or sign that tells medical professionals what is taking place inside a biological system (e.g., study that involved drawing blood to see changes in biological markers after blast exposure)
Imaging	Study in which imaging technology was used to study different aspects, including improved diagnostics, changes in functionality, and impacts to the brain (e.g., study in which MRI, functional MRI [fMRI], positron emission tomography [PET], DTI, or other neuroimaging was used)
Observational	Study in which individuals are observed or certain outcomes are measured without interventions taking place by the researchers to affect outcomes (e.g., study that compared predeployment assessments with postdeployment assessments, evaluations)
Trial or intervention	Study in which interventions are prospectively assigned to participants to evaluate the effects of those interventions on health outcomes (e.g., study that evaluated the efficacy of telephone-delivered problem-solving treatment on post-TBI psychological and physical symptoms)
Epidemiological	Study method used to investigate patterns, causes, and effects of conditions in defined populations
Etiological	Study focused on the origin and history of conditions
Qualitative	Study focused on understanding experiences, perspectives, and social processes rather than quantifiable data and that frequently involve interviews, focus groups, and observations
Literature review	Comprehensive summary and synthesis of literature to provide context, identify gaps in knowledge, and establish the significance of the existing research
Scale validation	Study that ensures that known measurement scales accurately assess the diagnosis or impact of TBI
Comorbidities	
Behavioral	Relating to changes in behavior, such as mood disorders
Dermatological	Relating to the treatment and diagnosis of skin conditions
Genitourinary	Relating to the genital or urinary organs; conditions resulting from a lack of bladder control, leading to the inability to control urination
Musculoskeletal	Having to do with the muscles, bones, tendons, ligaments, joints, and cartilage
Ocular	Having to do with the eyes or vision
Neurological	Having to do with disorders that affect the nervous system, including the brain, spinal cord, or nerves
Auditory	Having to do with hearing; can include tinnitus, which is the condition in which an individual hears phantom sounds, and any condition leading to hearing loss
PTSD	Mental health condition that can develop after a traumatic event involving actual or threatened death, serious injury, or sexual violence

Table A.2—Continued

Code	Definition
Psychological	Often referred to as mental disorders and mental illnesses and include conditions affecting thinking, feeling, mood, or behavior
Sleep	Sleep disorders, such as chronic insomnia
Substance misuse	Dependence on addictive substances—for example, alcohol or drugs
Chronic pain	Pain from an injury that lasts more than three months; types include headaches, nerve pain ("electric" or "burning" or "tingling" or hot or cold sensations), pain associated with spasticity, muscle pain, and bone pain
Specific neurological conditions and disorders	
Alzheimer's disease	The most common form of dementia; a brain disorder that slowly destroys a person's cognitive function and behavioral abilities
Frontotemporal dementia	Common form of dementia that affects behavior, cognition, and language
Parkinson's disease	Progressive nervous system disorder that affects movement
CTE	Neurodegenerative disease associated with repetitive TBI
Amyotrophic lateral sclerosis	Neurodegenerative disease that progressively reduces functionality between neurons and the muscles they supply
Epilepsy	Seizures that occur immediately after a TBI or develop as a chronic condition over time
Hydrocephalus	Abnormal buildup of fluid in the brain, potentially resulting in increased pressure
Vascular injury	Damage to blood vessels in the brain (e.g., stroke)
Communication disorders	Difficulty with language (e.g., aphasia), difficulty with speech (e.g., dysarthria), and difficulty with motor planning of speech (e.g., apraxia)
Time frame	
Longitudinal	Studies involving the repetitive collection of data from the same participants over an extended period, typically taking place in time frames of one year to several years
Medium term	Studies focused on evaluating outcomes in a defined period, typically ranging from months to a few years
Short term	Studies focused on evaluating outcomes within a relatively short period, typically a few days to a few months
Continuum of care	
Prevention	Actions taken to prevent the onset of TBI or reduce the occurrence of negative impacts of TBI
Diagnosis	Process of using signs and symptoms to identify the presence of TBI
Treatment, management, or mitigation	Interventions and services provided to address TBI
Rehabilitation and long-term care	Restoration of function and abilities lost because of TBI impacts

Abbreviations

3D	three-dimensional
CTE	chronic traumatic encephalopathy
DHA	Defense Health Agency
DOW	U.S. Department of War
DTI	diffusion tensor imaging
DTIC	Defense Technical Information Center
HHS	U.S. Department of Health and Human Services
MRI	magnetic resonance imaging
mTBI	mild traumatic brain injury
NIH	National Institutes of Health
NSF	National Science Foundation
PTSD	posttraumatic stress disorder
SBIR	Small Business Innovation Research
SOF	special operations forces
TBI	traumatic brain injury
USAF	U.S. Air Force
USD	U.S. dollars
USUHS	Uniformed Services University of the Health Sciences
VA	U.S. Department of Veterans Affairs

References

Cifu, David X., Jay P. Granier, Jamie Grimes, Tammy Crowder, Ajit B. Pai, and Henry L. Lew, "The History and Evolution of Traumatic Brain Injury Rehabilitation in Military Service Members and Veterans in the United States," in Jomana Amara and Ann M. Hendricks, eds., *Military Health Care: From Pre-Deployment to Post-Separation*, Routledge, 2013.

Covidence, homepage, Veritas Health Innovation, undated. As of October 1, 2025: https://www.covidence.org

Escolas, Sandra M., Margie Luton, Hamid Ferdosi, Bianca D. Chavez, and Scot D. Engel, "Traumatic Brain Injuries: Unreported and Untreated in an Army Population," *Military Medicine*, Vol. 185, Supp. 1, January–February 2020.

Farmer, Carrie M., Heather Krull, Thomas W. Concannon, Molly M. Simmons, Francesca Pillemer, Teague Ruder, Andrew M. Parker, Maulik P. Purohit, Liisa Hiatt, Benjamin Saul Batorsky, and Kimberly A. Hepner, *Understanding Treatment of Mild Traumatic Brain Injury in the Military Health System*, RAND Corporation, RR-844-OSD, 2016. As of October 23, 2025: https://www.rand.org/pubs/research_reports/RR844.html

Fish, Lauren, and Paul Scharre, "Protecting Warfighters from Blast Injury," Center for a New American Security, April 29, 2018.

McBirney, Samantha, "Repeated Exposure to Low-Level Military Occupational Blasts: An Overview of the Research, Critical Gaps, and Recommendations," testimony presented before the U.S. Senate Armed Services Committee, Military Personnel Subcommittee, RAND Corporation, CT-A3250-1, February 28, 2024. As of October 23, 2025: https://www.rand.org/pubs/testimonies/CTA3250-1.html

McEvoy, Cory, Adam Crabtree, John Case, Gary E. Means, Peter Muench, Ronald G. Thomas, Rebecca A. Ivory, Jason Mihalik, and James S. Meabon, "Cumulative Blast Impulse Is Predictive for Changes in Chronic Neurobehavioral Symptoms Following Low Level Blast Exposure During Military Training," *Military Medicine*, Vol. 189, Nos. 9–10, September–October 2024.

Military Health System, "DOD TBI Worldwide Numbers," webpage, last updated August 25, 2025. As of September 18, 2025: https://www.health.mil/Military-Health-Topics/Centers-of-Excellence/Traumatic-Brain-Injury-Center-of-Excellence/DOD-TBI-Worldwide-Numbers

National Academies of Sciences, Engineering, and Medicine, "Accelerating Progress in Traumatic Brain Injury Research and Care," webpage, undated. As of October 23, 2025: https://www.nationalacademies.org/our-work/accelerating-progress-in-traumatic-brain-injury-research-and-care

Panangala, Sidath Viranga, Jared S. Sussman, and Madeline E. Moreno, *Department of Veterans Affairs FY2025 Appropriations*, Congressional Research Service, R48608, July 24, 2025.

Simmons, Molly M., Charles C. Engel, Emily Hoch, Patrick Orr, Brent Anderson, and Gulrez Shah Azhar, *Neurological Effects of Repeated Exposure to Military Occupational Levels of Blast: A Review of Scientific Literature*, RAND Corporation, RR-2350-A, 2020. As of October 1, 2025: https://www.rand.org/pubs/research_reports/RR2350.html

Sousa, Éder M., Samantha McBirney, Emily Hoch, and Tepring Piquado, *Toward a Unified Multiscale Computational Model of the Human Body's Immediate Responses to Blast-Related Trauma: A Review of the Scientific Literature*, RAND Corporation, RR-A500-1, 2021. As of October 23, 2025:
https://www.rand.org/pubs/research_reports/RRA500-1.html

Tanielian, Terri, and Lisa H. Jaycox, eds., *Invisible Wounds of War: Psychological and Cognitive Injuries, Their Consequences, and Services to Assist Recovery*, RAND Corporation, MG-720-CCF, 2008. As of October 23, 2025:
https://www.rand.org/pubs/monographs/MG720.html

Tricco, Andrea C., Erin Lillie, Wasifa Zarin, Kelly O'Brien, Heather Colquhoun, Monika Kastner, Danielle Levac, Carmen Ng, Jane Pearson Sharpe, Katherine Wilson, et al., "A Scoping Review on the Conduct and Reporting of Scoping Reviews," *BMC Medical Research Methodology*, Vol. 16, February 9, 2016.

U.S. Bureau of Labor Statistics, "Consumer Price Index," webpage, undated. As of August 22, 2025:
https://www.bls.gov/cpi/home.htm

U.S. Department of Veterans Affairs, "VA ORD Funding Resources," webpage, last updated September 9, 2025. As of October 1, 2025:
https://www.research.va.gov/funding

U.S. Small Business Administration, "Contracts vs Grants," webpage, undated-a. As of September 18, 2025:
https://www.sbir.gov/tutorials/program-basics/tutorial-6

U.S. Small Business Administration, "Frequently Asked Questions: General Questions," webpage, undated-b. As of September 18, 2025:
https://www.sbir.gov/faq

VA—*See* U.S. Department of Veterans Affairs.

Wilk, Joshua E., Richard K. Herrell, Gary H. Wynn, Lyndon A. Riviere, and Charles W. Hoge, "Mild Traumatic Brain Injury (Concussion), Posttraumatic Stress Disorder, and Depression in U.S. Soldiers Involved in Combat Deployments: Association with Postdeployment Symptoms," *Psychosomatic Medicine*, Vol. 74, No. 3, April 2012.