Utilization Based Technology Assessment and Evaluation of Cognitive Assessments for Canadian Armed Forces Members with Mild Traumatic Brain Injury

by

Chelsea Jones

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Abstract

Canadian Armed Forces service members (CAF-SMs) have an increased risk of sustaining mild traumatic brain injuries (mTBI; Garber, Rusu, & Zamorski, 2014). MTBI can result in reduced cognitive functioning which may lead to barriers to participation in everyday occupations of CAF-SMs. Military contexts necessitate high levels of cognitive functioning; compromising this can potentially result in decreased efficiency and effectiveness, along with an increased risk of harm to self, the unit, and mission (Radomski, Davidson, Voydetich, & Erickson, 2009). Assessing cognitive functioning is necessary to ensure that CAF-SMs can perform their military duties safely and proficiently. Interventions to improve cognitive functioning are most effective when a reliable, valid, specific, and function-based cognitive assessments are employed (Radomski, Davidson, Voydetich, & Erickson, 2009; Soble, Critchfield, & O'Rourke, 2016). Despite this, healthcare professionals commonly assess cognition utilizing dated assessments with varying levels of validity and reliability, and only measure specific domains of cognition (Larner, 2017).

Neurocognitive computerized assessment tools (NCATs) are widely utilized in other global militaries and have multiple benefits including potentially increased inter- and intra-rater reliability, ease of administration, reduced time to administer, and ease of calculating and analysing results (Cernich, Brennana, Barker, & Bleiberg, 2007). Evidence-based research of cognitive assessments with the CAF context is required to increase the safety, productivity, and quality of life of those CAF-SMs affected by mTBI.

Even when cognitive assessment tools that embrace technology are utilized, significant gaps in research and clinical knowledge remain. In 2019, allied health professionals within the CAF initiated training to become certified in a Canadian-made, tablet-based, cognitive

assessment entitled BrainFX®. Questions regarding perceived need, acceptance, usability, and feasibility of BrainFX® in the CAF have arisen.

The overall purpose of this research is to investigate best practice approaches for the implementation of cognitive assessments for CAF-SMs who have sustained an mTBI. This will assist with advancing clinical practices within CFHS and improve healthcare services for this demographic. A pragmatic paradigm is the essence of this project and a mixed-methods research design will be employed throughout. By meeting the CAF organization at their point of current progress and aligning realistically with their current state of policy, procedure, and plans, a feasible implementation path will emerge leading to better healthcare for those CAF-SMs who experience cognitive dysfunction due to mTBI. The overall project will be guided by the Active Implementation Frameworks (AIFs; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005) and Utilization-Focused Evaluation Framework (UFE; Patton, 2013).

This PhD project will consist of 4 sections which follow the stages of AIFs and UFE and mixed-method research design:

1. A Model for Neurofunctional Health: The Canadian Model of Cognitive Skills
2. Neurocognitive Assessment Tools for Military Personnel with Mild Traumatic Brain Injury: A Scoping Literature Review
3. Perceptions of Canadian Armed Forces Healthcare Professionals on Cognitive Assessment Processes within Canadian Armed Forces Health Services: A Mixed Methods Analysis
4. Technology Acceptance of the BrainFX® SCREEN amongst Canadian Armed Forces Members and Veterans with Combat Related Posttraumatic Stress Disorder: Pre/Post Analysis

Preface

This dissertation is an original work by Chelsea Jones. All research studies involving Canadian Armed Forces personnel (Chapter 2 and 5) received Surgeon General Research Program Endorsement.

Research Ethics Board approval at the University of Alberta was attained for the study in Chapter 2: “PERCEPTIONS OF CANADIAN ARMED FORCES HEALTHCARE PROFESSIONALS ON COGNITIVE ASSESSMENT PROCESSES WITHIN CANADIAN ARMED FORCES HEALTH SERVICES: A QUALITATIVE THEMATIC ANALYSIS”
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Chapter 5 was embedded within a larger research project led by Dr. Suzette Brémault-Phillips. Health Research Ethics Board approval from the University of Alberta was attained for this project: “MOTION-ASSISTED, MULTI-MODAL MEMORY DESENSITIZATION AND RECONSOLIDATION VIRTUAL-REALITY BASED TREATMENT FOR INDIVIDUALS WITH CHRONIC COMBAT-RELATED POST-TRUAMATIC STRESS DISORDER: A RANDOMIZED WAITLIST CONTROL STUDY”
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Chapters 2, 3, 4, and 5 of this manuscript are currently in submission to academic journals. No parts of this manuscript have been accepted for publication at this time.

Chapter 2 involved collaboration with Tracy Milner and Health Condello who were the creators of the Milner and Condello Model of Cognitive skills (Milner & Condello, 2012). Their collaboration with Chelsea Jones and Dr. Suzette Brémault-Phillips facilitated the creation of the manuscript introducing the Canadian Model of Cognitive Skills.

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Thank you to my parents, Rick and Wendy Weiman who have always supported me in my academic and professional endeavors. Thank you for instilling in me the value of education early on and providing me with the privilege that made academic success a possibility.

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Abbreviations

AIF – Active Implementation Framework

ANAM – Automated Neuropsychological Assessment Metric

AVE - average variance extracted

BI – Behavioral Intention

bTBI – blast traumatic brain injury

CAF - Canadian Armed Forces

CAF-SMs - Canadian Armed Forces service members

CAOT - Canadian Association of Occupational Therapists

CMCS - Canadian Model of Cognitive Skills

CFHS - Canadian Forces Health Services

CB – covariance based

CBA - Certified BrainFX® Administrator

CFB – Canadian Forces Base

CAPS5 - Clinician-Administered PTSD Scale for DSM-5

CNS-VS – CNS-Vital Sign

NCATs - Computerized neurocognitive Assessment Tools

cr – combat related

DANA – Defense Automated Neurobehavioral Assessment

DND – Department of National Defense (Canadian)

DSM-5 – Diagnostic and Statistical Manual of Mental Disorders 5th Edition

EE – Effort Expectancy

EFs – executive functions

FC - Facilitating Conditions

FDA – Food and Drug Administration

HCPs - healthcare professionals

FITT - Fit between Individuals, Task and Technology framework

FTE - Full-Time Equivalent

HTMT - Heterotrait-Monotrait Ratio

ImPACT - Immediate Post-Concussion Assessment and Cognitive Testing

ICF - International Classification of Functioning, Disability, and Health

mTBI – mild traumatic brain injury(ies)

MGA - multi-group analysis

MOI – mechanism of injury

NATO - National Atlantic Treaty Organization

NFL - National Football League

NHL - National Hockey League

NIRN - National Implementation Research Network

OSOT - Ontario Society of Occupational Therapists

OSI - Operational Stress Injury

OEF - Operation Enduring Freedom

OIF - Operation Iraqi Freedom

PEO - Person Environment Occupation Model

PE – Performance Expectancy

PDSA - Plan-Do-Study-Act

PLS – partial least square

PCS - post-concussion symptoms

PRISMA-ScR - Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews

PRT – prolonged reaction time

PTSD - post-traumatic stress disorder

SEM - structural equation modelling

SI – Social Influence

SRT – single reaction time

TBI – traumatic brain injury

TTF - Task-Technology Fit Model

U – Use

UFE – Utilization Focused Evaluation

UTAUT - Unified Theory of Acceptance and Use of Technology

UTAUT2 - Unified Theory of Acceptance and Use of Technology 2

VAC - Veterans Affairs Canada

VCA – Virtual Care Assessment

VIF - variance inflation factor

WHO – World Health Organization

1. Introduction

1.1. Background

The Canadian Armed Forces (CAF) takes pride in being a fit and ready force. This necessitates that CAF service members (CAF-SMs) remain employable, deployable, and fit - physically, mentally, emotionally, cognitively, and spiritually (Department of National Defense, 2016). In many circumstances, CAF-SMs are individually and collectively at heightened risk of physical and psychosocial injuries, including those that affect their cognitive functioning (Jones, Pike, & Brémault-Phillips, 2019). High-risk activities are common in military service whether during physical training, engagement in daily trade-related tasks, overseas deployment, or response to natural disasters. Compromised cognitive functioning within military contexts can potentially result in decreased efficiency and effectiveness, along with an increased risk of harm to self, the unit, and a CAF mission (Radomski et al. 2015).

Baseline levels of cognitive functioning are required in all areas of life, functioning, and relationships for those who are ready for operations as well as those who are recovering from injuries (American Journal of Occupational Therapy, 2013; Radomski et al. 2015; Doneva, 2018). Heightened cognitive functioning is essential for operations. Conversely, reduced cognitive functioning can make even seemingly simple tasks problematic (American Journal of Occupational Therapy, 2013; Radomski et al. 2015; Doneva, 2018). For those with physical or psychosocial injuries, cognitive functioning is required to execute daily tasks including managing a medical condition, adhering to medication regimes, attending appointments, and engaging in rehabilitation programs (American Journal of Occupational Therapy; Radomski et al. 2015). Success in these tasks enable self-stabilization and regulation, which are foundational to more cognitively demanding activities (Radomski et al. 2015).

An individual's cognitive functioning can be adversely impacted by a variety of psychosocial and physical variables, either in isolation or combination. Psychosocial variables that are prevalent at an elevated rate in the CAF population compared to the Canadian civilian population include increased geographical isolation, alcohol consumption, mental health diagnoses (i.e., depression, anxiety, and post-traumatic stress disorder (PTSD)), chronic pain, and sleep disturbances (Department of National Defense, 2016). Cognitive functioning within military contexts has been explored in relation to a number of physical conditions, but most notably in regard to mild traumatic brain injuries (mTBI) which can significantly impact cognitive functioning. MTBI is defined as a temporary change in brain functioning caused by an insult to the head with a period of post-traumatic amnesia lasting less than a day (Garber, Rusu, & Zamorski, 2014; McCrory, et al., 2017). Post-concussive symptoms, defined as 3 or more symptoms related to mTBI lasting more than 3 months (Garber, Rusu, & Zamorski, 2014) are common amongst military populations (Doneva, 2018; Rona, Jones, Fear, Hull, Murphy, Wessely, et al., 2012). Rates of PCS amongst global militaries have been estimated between 25 to 33% (Robinson-Freeman, Collins, Garber, Terblanche, Risling, Vermetten, E., Besemann, Mistlin, Tsao, 2020).

The frequency of mTBIs among service members is of interest. Among CAF-SMs deployed to Iraq and Afghanistan for Operation Enduring Freedom (OEF) between 2009-2012, 5.2% self-reported experiencing an mTBI,15-21% of whom noted post-concussion symptoms (PCS; Garber, Rusu, & Zamorski, 2014). Comparatively, during OEF and Operation Iraqi Freedom (OIF), the United States military reports mTBI rates of 12-22.8% and PCS of 15.8-35%

in those soldiers engaged in similar conflicts (Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008). Additionally, the United Kingdom's Armed Forces report a 4.4% prevalence of mTBI among deployed SMs during the same conflicts (Rona et al., 2012). Due to the increased frequency of mTBI in sport and global military operations, interest in researching this injury resurged as an area of clinical and research interest in the first decade of the millennia.

MTBI can have short and long-term effects on CAF-SMs. Those who experience an mTBI during military service may be at risk of developing career-limiting medical conditions that can see them released from military service (Garber, Rusu, Zamorski, & Boulos, 2016). Moreover, as a CAF-SM transitions out of the CAF to veteran status, cognitive dysfunction may continue to contribute to challenges not only during the transition process, but to family relations, civilian employment, leisure activities, and self-care. These challenges may endure for the remainder of an individual's life and have significant consequences.

Identifying if cognitive dysfunction is related to mTBI and/or a concurrent mental health diagnosis is difficult and widely debated among scholars studying military members (Doneva, 2018; Garber, Rusu, & Zamorski, 2014; Roberge, Baker, Ely, Bryan, Bryan & Rozek, 2020; Merritt, Jurick, Sakamoto, Crocker, Sullan, Hoffman, Davey et al., 2020). Current literature suggests that mTBI and PTSD can both arise from the same or separate traumatic incidents and co-occur (Garber, Rusu, & Zamorski, 2014; Rona, et al., 2012). Such co-occurrences can make identification of co-morbidities and their treatment problematic. A reliable, valid, specific, and function-based cognitive assessment is essential to determination of effective interventions to improve cognitive functioning (Radomski et al. 2015; Soble, Critchfield, & O'Rourke, 2016).

Despite knowledge that reliable, valid, specific, and function-based cognitive assessment are necessary, healthcare professionals commonly assess cognition utilizing dated assessments with varying levels of validity that measure only specific domains of cognition (Larner, 2017). This can be problematic for various reasons. Such cognitive assessments may be susceptible to type 1 and 2 errors as they involve outdated tasks (e.g., filling out a money order) which may identify generational differences as opposed to true functional shortcomings. Real-world translation of assessment results to functional tasks are also questionable and do not always assist clinicians with treatment planning (Larner, 2017). In addition, the frequent use of multiple assessments to address various cognitive domains of functioning is time-consuming for both the clinician and the client, causing patient engagement to decline (Milner & Condello, 2017). Further, sensitivity issues increase the chances of type 2 errors especially with milder forms of executive cognitive dysfunction which is commonly experienced as a symptom of mTBI (Milner & Condello, 2017, Doneva, 2018). Finally, attempts to digitize cognitive assessments have been met with reliability and sensitivity issues which complicates the establishment of a client-friendly standardized reliable and validated assessment tool (Milner & Condello, 2017). A concerted effort to determine current, evidence-based cognitive assessments for use with military members is necessary so as to address cognitive dysfunction early, minimize suffering, and enable individuals to regain function as soon as possible.

Computerized Neurocognitive Assessment Tools (NCATs) [1] developed in recent years hold much promise for use with the Canadian military population. Such assessments may have multiple benefits, compared to traditional neuropsychological tests, including better inter- and intra-rater reliability, ease of administration, reduced time to administer, and ease of calculating results (Cernich, Brennana, Barker, & Bleiberg, 2007). Such tools are also closer to those used in other developed global militaries. Data storage is also convenient and subject or patient

[1] NCAT is the common and accepted abbreviation currently utilized for computerized neurocognitive assessment tools in evidence-based publications.

information can easily be de-identified and secured to meet ethical and regulatory requirements (Cernich, Brennana, Barker, & Bleiberg, 2007). Although promising, the reliability and validity of these tests has been called into question (Searles, 2015; Resch et al., 2013; Randolph, McCrea, Barr, & Macciocchi, 2005). The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) has been trialed with CAF-SMs at a test site but feasibility, sensitivity, and logistical issues prevented widespread utilization beyond the trial. (ImPACT Applications Inc., 2011).

One cognitive assessment tool which has sought to address the above issues are the Brain FX® assessments. The Brain FX® 360 Assessment, Screen, and Virtual Care Assessment (VCA) are function focused, Canadian made assessments and screen that address neurofunctioning through a digital interface on a tablet (Milner & Condello, 2017). It is more contemporary than predecessor assessments and provides a comprehensive report addressing multiple domains of cognitive functioning. The current evidence-based literature demonstrates that this tool has promising validity, reliability, and sensitivity, with a focus on neurofunctioning (Searles, 2015; Sergio, & Gage, 2014). Brain FX® is based on the Canadian Model of Cognitive Skills (CMCS), which is an emerging model in cognitive rehabilitation that has yet to be published in the evidence-based literature (Milner & Condello, 2012). Canadian Forces Health Services (CFHS) has chosen the Brain FX® assessments to be utilized within a future mTBI management processes and policies. As a result, CFHS healthcare professionals (HCPs) have engaged in training to become Certified Brain FX® Administrators (CBAs). As they have done so, questions of perceived need, feasibility, technology acceptance, and usability of the technology in the CAF context have been raised.

Adoption and integration of NCATs into practice within the Canadian military context necessitates consideration from both clinical and research perspectives, particularly in light of current knowledge gaps and the imperative to employ best-practices in service delivery. To meet these objectives, it is important that assessments and interventions be researched and evaluated within the unique policies, procedures, and culture of the CAF. For example, CAF-SMs who require cognitive assessments are on average younger than those who require cognitive assessment in civilian healthcare (Department of National Defense, 2016). In addition, as a lack of standardization, validity, reliability, and sensitivity of assessment procedures has historically existed, care needs to be taken to ensure that the introduction of an NCAT is effectively implemented within the CFHS as an effective and evidence-based tool.

1.2. Purpose

The overall purpose of this research is to investigate best practice approaches for conducting cognitive assessments of CAF-SMs who have sustained an mTBI with resulting cognitive dysfunction. This will assist with advancing clinical practice within the CFHS and improve healthcare for this demographic. This project will employ a pragmatic paradigm and a mixed-methods research design. Implementation science will provide an over-arching framework regarding the process of implementing NCATs in the CFHS. Components of this research will be nested within the framework.

1.3. Implementation Science

The field of implementation science has developed to facilitate the spread of evidence-based practice and research, including both psychosocial and medical interventions (Bauer, Damschroder, Hagedorn, Smith, & Kilbourne, 2016). Implementation science is defined as the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and, hence, to improve the quality and effectiveness of, in this context, health services (Eccles & Mittman, 2006). The entirety of this project will be guided by 2 frameworks to assist with wider implementation of best-practice cognitive assessment policies, procedures, and tools within CFHS. These include the Active Implementation Frameworks (AIFs; Appendix 10.1; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005) and the Utilization-Focused Evaluation Framework (UFE; Appendix 10.2; Patton, 2013). The AIFs created and disseminated by the National Implementation Research Network (NIRN) are a common set of evidence-based, process-model frameworks utilized for implementation research and science. AIFs can be helpful when attempting to put into practice any innovation of known dimensions in a multitude of different industries (Blanchard, Livet, Ward, Sorge, Sorensen, & McClurg, 2017). The Stages AIF (Figure 1) consists of four stages: Exploration, Installation, Initial Implementation, and Full Implementation that interact with each other throughout the process (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

The Exploration Stage largely addressed the “fit” of the usable innovation, creation of implementation teams, and establishment of communication protocols or practice-policy loops. This is often where evidence-based knowledge is gathered, needs assessments, and environmental scans may take place. The Installation Stage involves preparations for the roll out of the usable innovation through the gathering and organization of infrastructure and resources, establishing readiness and providing training for the practitioners and implementation drivers, and developing fidelity measures for the measurement and evaluation of the innovation and implementation process. The Initial Implementation Stage may include a small pilot study or trial of the usable innovation where implementation drivers are maximized, fidelity is assessed, communication and practice-policy cycles are utilized, and improvement cycles are initiated.

Pending success as the previous stage, the Full Implementation Stage is where sustainability, fidelity maintenance, evaluation, and innovation development and improvement remains ongoing.

Figure 1: The Stages Active Implementation Framework (AIF)

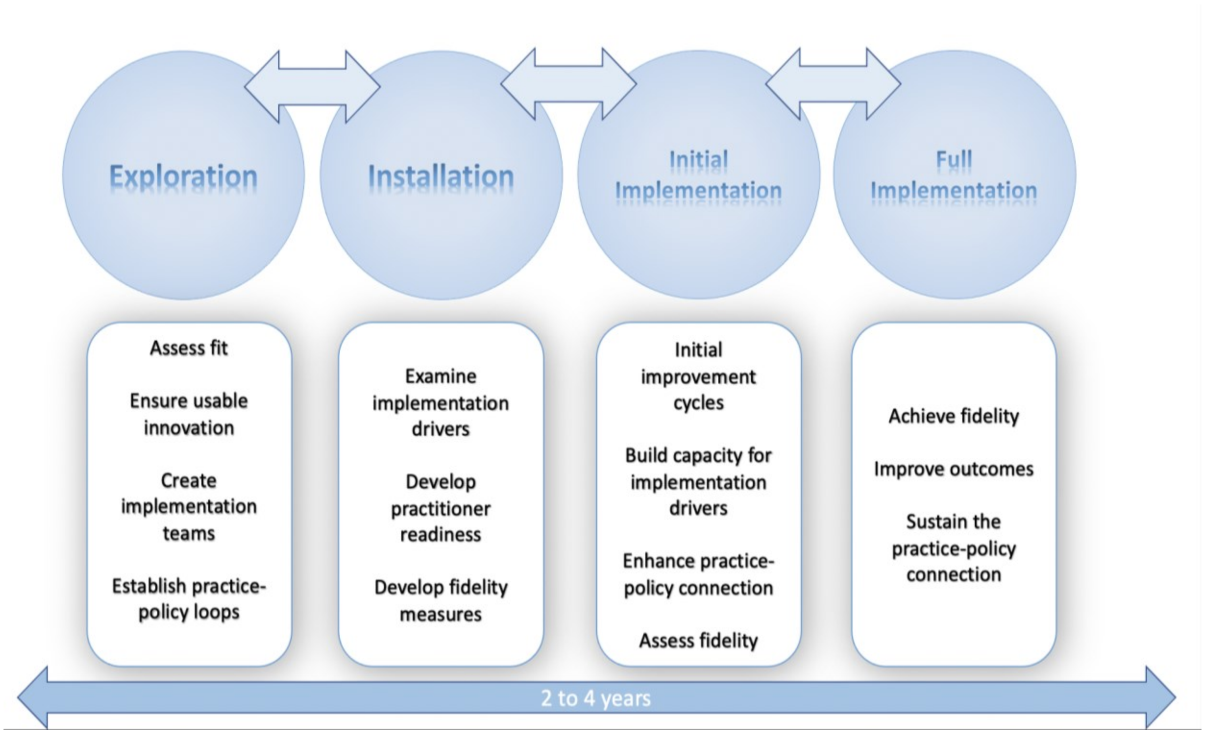

Figure 1: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

The UFE is a 17-step approach based on the principle that an evaluation should be judged on its usefulness to its intended users by actively involving primarily those users (Patton, 2013). The basis and main strength of the UFE is that intended users are more likely to use evaluations if they understand and feel ownership of the evaluation process and findings. There are two key elements of a UFE: (1) The primary intended users of the evaluation must be clearly identified and personally engaged at the beginning of the evaluation process, and; (2) Evaluators must ensure that these intended uses of the evaluation by the primary intended users guide all other decisions that are made about the evaluation process (Better Evaluation, 2019). The first 4 stages of UFE correlate with the Exploration Stage of the AIFs (Figure 2).

Figure 2: Exploration Stage AIF and Utilization Focused Evaluation Crossover

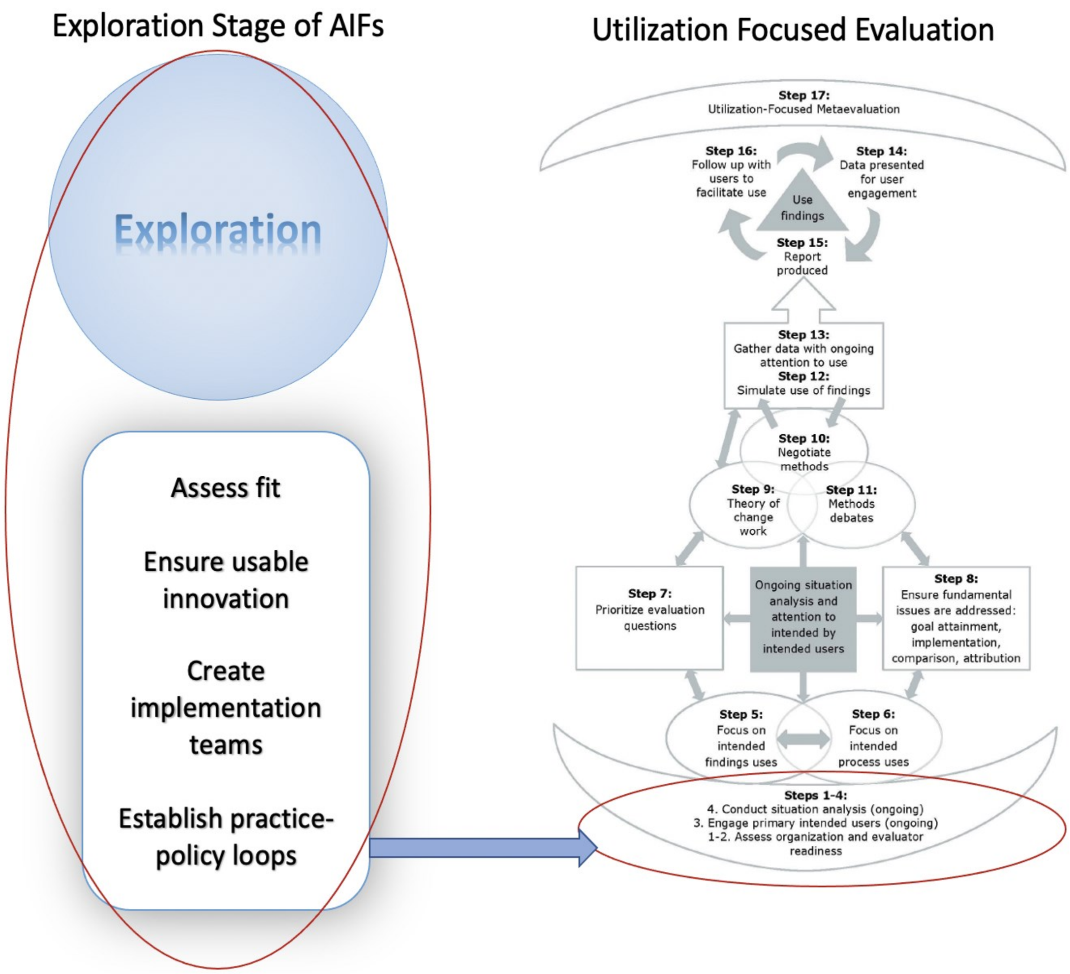

Figure 2: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005; Patton, 2013).

Currently, CFHS is in the Exploration and Initial Implementation Stages of improving the process of cognitive assessments which may indicate the need for revised policy and procedures, knowledge translation, stakeholder education, and implementation of practices which includes NCATs. By meeting CFHS in its current state and aligning realistically with relevant policies, procedures, and plans, a feasible implementation path will emerge, thereby leading to better healthcare for CAF-SMs who experience cognitive dysfunction due to mTBI.

This PhD project will consist of 4 individual manuscripts, one per chapter, which follow the stages of AIFs and UFE. Three will fit within the Exploration Stage of the "Stages" AIF and corresponding first 4 steps of the UFE, including the process of identifying stakeholders, assessing fit, ensuring a usable innovation, creation of implementation teams, and establishing a practice-policy loop (Figure 2; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005; Patton, 2013). "Assessing fit," includes an environmental scan, needs assessments, and information gathering from stakeholders.

The initial steps of the UFE include: (1) Assess and build program and organizational readiness for utilization-focused evaluation, (2) Assess and enhance evaluator readiness and competence to undertake a utilization focused evaluation, (3) Identify, organize, and engage primary intended users, (4) Conduct situation analysis with primary intended users, and; (5) Identify primary intended uses by establishing the evaluation's priority purposes (Figure 2).

The studies that correlate with this stage and steps include (Figure 3):

1. A Model for Neurofunctional Health: The Canadian Model of Cognitive Skills
2. Neurocognitive Assessment Tools for Military Personnel with Mild Traumatic Brain Injury: A Scoping Literature Review
3. Perceptions of Canadian Armed Forces Healthcare Professionals on Cognitive Assessment Processes within Canadian Armed Forces Health Services: A Qualitative Thematic Analysis

Figure 3: Projects within the Exploration Stage of the AIF

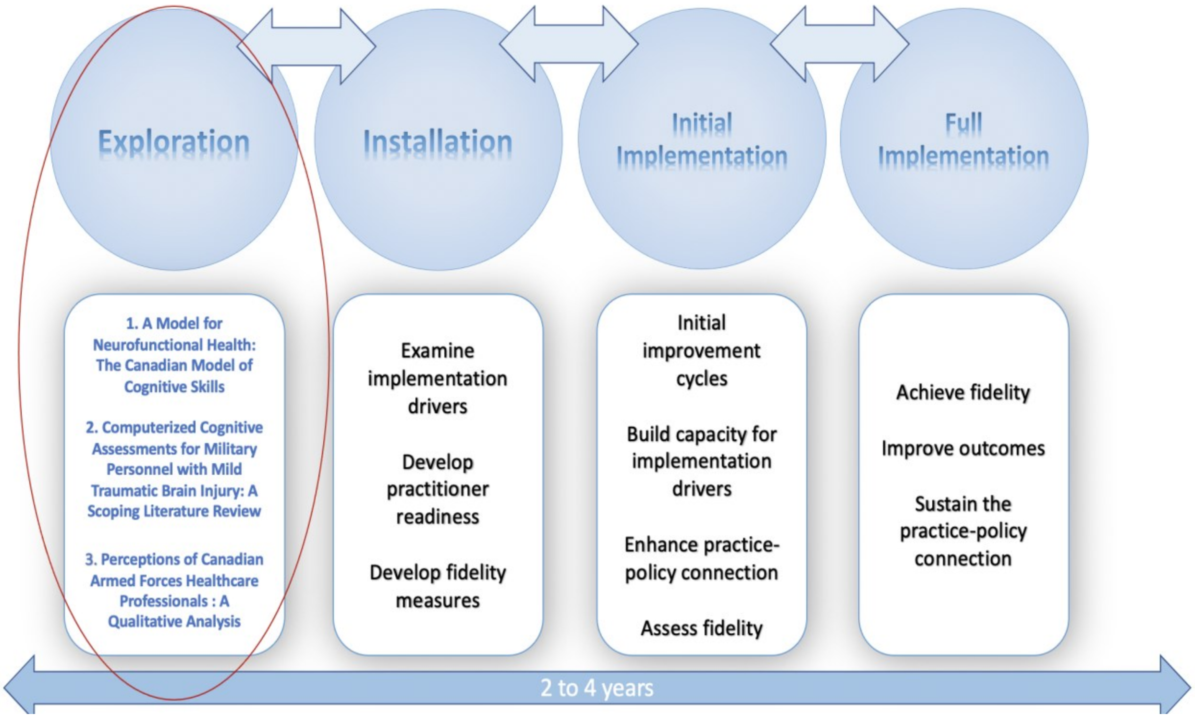

Figure 3: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

The Initial Implementation Stage begins when the new program or practice is first being put to use. The goals of this stage are continual evaluation and improvement to assess the quality of implementation, identify problems and solutions, and inform decision making going forward (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). Projects within the Initial Implementation Stage of the Stages AIF include:

4. Technology Acceptance of the Brain FX® Screen amongst Canadian Armed Forces Members and Veterans with Combat Related Posttraumatic Stress Disorder: Pre/Post Analysis

1.4. Mixed-Methods Research

This project will employ a mixed-methods research approach in its entirety. Mixed- methods is defined by Creswell and Plano Clark (2011) as a method that:

> "focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone."

Characteristics of mixed-methods research include collecting and analyzing quantitative and qualitative data, establishing priority to one or both forms of data, and combining the data in a single or multiple phase study (Creswell & Plano Clark, 2011). This research method is widely practiced and accepted in many areas of health care research (Sale, Lohfeld, & Brazil, 2002). The paradigmatic, ontological, epistemological, linguistic, and theoretical conflicts of mixed-methods research have been considered in depth. Utilizing mixed-methods research under the umbrella of a pragmatic research paradigm allows for the acknowledgement of multiple ontologies and epistemologies throughout the project to maximize completeness of data gathering and analysis. Specific mixed-methods research designs have been considered and utilized where appropriate in different phases of the project correlating with the stages of AIFs and UFE. The combined mixed methods and implementation science approach will ideally assist CFHS by providing preliminary evidence and a road map that can be utilized to continue to explore and implement policies, protocols, and practices at the micro (CAF-SM), meso (healthcare provider and clinic), and macro (organizational) levels for cognitive assessment use across the CAF.

2. A Model for Neurofunctional Health: The Canadian Model of Cognitive Skills - Exploration Stage

Submitted to: Disability and Rehabilitation

2.1 Abstract

Cognitive functioning is essential for independent living, quality of life, self-care, productivity and leisure pursuits in all populations. A lack of comprehensive and practical models and frameworks to conceptualize the range of cognitive functions and associated skills needed in daily life, however, has resulted in fundamental challenges with cognitive assessments and interventions. Cognitive modelling that incorporates a function-based approach into rehabilitation and recovery is needed to facilitate healthcare service delivery, education of patients and families, training of healthcare professionals and research. The Canadian Model of Cognitive Skills (CMCS) was developed to provide greater clarity around and enhanced awareness and conceptualization of cognitive skills. The authors of the CMCS intended that its use would improve the delivery of healthcare services, and lead to better cognitive and occupational performance outcomes for various populations experiencing cognitive challenges. The model may also provide better conceptual understanding of cognitive skills for students, patients, and caregivers.

The purpose of this paper is to introduce the CMCS as a tool in guiding understanding, education, assessment, and rehabilitation of cognitive skills. Created using an evidence-based *a priori* process guided by implementation science frameworks, development of the CMCS drew on the Active Implementation Frameworks. This process included 4 Stages with 6 phases: (1) Needs Assessment (Exploration Stage), (2) Environmental Scan (Exploration Stage), (3) Development of a Prototype Model (Exploration Stage), (4) Key Stakeholder Engagement

(Exploration Stage), (5) Facilitation of Practitioner Readiness (Installation Stage), and; (6) Improvement Cycles (Initial Implementation Stage) leading to the Full Implementation Stage. Addressing assessment and treatment of cognitive dysfunction through a holistic, interdisciplinary and evidence-based lens is imperative for the well-being of the individuals affected by conditions that compromise cognitive functioning and the families and communities who support them.

2.2. Introduction

In 2011, the National Hockey League (NHL) and National Football League (NFL) acknowledged concussions and mTBI as an athlete health issue. Sydney Crosby, among other professional athletes, were showcased in the media as having challenges returning to competition following concussions (Boylen, 2017). This happened to coincide with both mTBI being labelled the "signature injury" of the War on Terror in the North American context and an increased recognition of chronic traumatic encephalopathy, second impact syndrome, and post-concussion symptom syndrome by researchers, clinicians, and the general public (Armistead-Jehle, Soble, Cooper, & Belanger, 2017; McKee, Cantu, Nowinski, Hedley-Whyte, Gavett, Budson, et al., 2009). As cognitive dysfunction is a well-known symptom of mTBI, these events heightened the clinical and scientific communities' awareness of the importance of cognition in independent living, quality of life, and functioning in self-care, productivity and leisure pursuits.

2.2.1. Cognition and Cognitive Dysfunction

Cognition is a broad construct that refers to information-processing functions carried out by the brain (Diller & Weinberg, 1993). Such functions include attention, memory, executive functions (EFs), comprehension, speech (Sohlberg & Mateer, 1989), calculation ability (Roux, Boetto, Sacko, Chollet, & Trémoulet, 2003), visual perception (Warren, 1993), and praxis skills (Donkervoort, Dekker, Stehmann-Saris, & Deelman, 2001; American Journal of Occupational Therapy, 2013). Integral to effective performance across the broad range of daily occupations such as work, educational pursuits, home management, and leisure, cognition is instrumental in human development and the ability to learn, retain, and use new information in response to everyday life (American Journal of Occupational Therapy, 2013).

Cognitive dysfunction, defined as functioning below expected normative levels, can manifest as a loss of ability in one or more cognitive domains and functional challenges in daily activities and can be debilitating for some (American Journal of Occupational Therapy, 2013). The dysfunction can be transient or permanent, progressive or static, general or specific, and of different levels of severity (American Journal of Occupational Therapy, 2013). A variety of physical and psychosocial variables, either in isolation or combination, can adversely impact cognition (Doneva, 2018; Radomski, Davidson, Voydetich, & Erickson, 2009). Cognitive dysfunction, which may be symptomatic of a mental health challenge, can be adversely affected by disruptions of the structures, circuitry, and neurotransmitters of the brain, an insult to the head, or neurological conditions (American Occupational Therapy Association, 2013; Ozga, Povroznik, Engler-Chiurazzi, & Haar, 2018; Diamond, 2013; American Journal of Occupational Therapy, 2013). Cognitive dysfunction is most commonly recognized as associated with conditions such as mTBI, organic brain conditions, such as tumors or cerebrovascular events, neurological disorders, and mental illnesses. However, multiple other factors and conditions can also affect cognitive functioning throughout the lifespan including age, education, gender (Koran, Wagener, &Hohman, 2017; Wang, & Xiao, 2016; Kim, 2010; Lin, O'Connor, Rossom, Perdue, Burda, Thompson, et al., 2020), health life factors such as drinking and smoking (Kim, 2010), depression and other mental illness (Barnes & Yaffe, 2011), and social factors such as social activity and occupation, history of disease, and body mass index (Oh & Yee, 2016; Kim & Park, 2017). These conditions and factors, which are common amongst the population, may lead to or exacerbate cognitive impairment and dysfunction. Regardless of the cause, even mild cognitive dysfunction can be life-altering.

Cognitive impairment can be subtle and present as milder dysfunction, especially when the illness or injury primarily affects the frontal lobe where executive cognitive functions (EFs) operate. EFs are a set of top down cognitive processes that are necessary for the cognitive control of behavior. EFs are typically categorized into the three core categories of, (1) inhibition and interference control, (2) working memory, and; (3) cognitive flexibility (Diamond, 2013; American Journal of Occupational Therapy, 2013). Higher-order EFs, such as reasoning, problem solving, and planning are built from the core EFs (Diamond, 2013; Ozga, Povroznik, Engler-Chiurazzi, & Haar, 2018). Utilizing EFs is effortful and makes possible mentally molding ideas, thinking before acting, managing spontaneous or unexpected stimuli, resisting temptation, and staying focused (Diamond, 2013; Ozga, Povroznik, Engler-Chiurazzi, & Haar, 2018). Without diagnostic imaging it can be difficult to distinguish EF cognitive processes from attentional or memory processes as all of these are complex, interdependent, and utilized simultaneously in daily tasks (Diamond, 2013; Ozga, Povroznik, Engler-Chiurazzi, & Haar, 2018; Mateer & Sohlberg, 2001).

While dysfunction of EF may or may not be as noticeable to others, the person with compromised EF may be keenly aware and affected by it (American Occupational Therapy Association, 2013; Larner, 2017).

Reduced cognitive functioning can detrimentally affect all areas of a person's life, overall function, and relationships (Radomski, Davidson, Voydetich, & Erickson, 2009) and cause mental and emotional distress (American Occupational Therapy Association, 2013). Seemingly simple tasks such as organizing and following through on daily routines, navigating one's community, and managing finances can become problematic as a result of cognitive impairment (Radomski, Davidson, Voydetich, & Erickson, 2009; American Occupational

Therapy Association, 2019). Baseline levels of cognitive functioning in domains such as memory, attention, and organization are required for executing daily tasks such as management of medical conditions, including adherence to medication regimes, appointments, and rehabilitation programs (Radomski, Davidson, Voydetich, & Erickson, 2009; American Occupational Therapy Association, 2019). Success in such cognitive tasks enables self-stabilization and regulation which are foundational to more cognitively demanding activities (Radomski, Davidson, Voydetich, & Erickson, 2009). Impacts of performance and safety can be particularly troublesome. Among athletes who had sustained an mTBI, athletic performance was reduced, as was the safety of the athlete returning to play. Slow executive cognitive skills such as decision making and problem-solving lead to increased errors. Poor “on field” positioning was noted to compromise athlete safety and increase the risk of further injuries including additional mTBIs (McCrory, Meeuwisse, Dvořák, Aubry, Bailes, Vos et al., 2017). Reduced cognitive functioning becomes all the more problematic in high risk/high stakes contexts, circumstances and occupations.

Identifying areas of cognitive dysfunction and maximizing cognitive functioning is essential when working with those with mTBI and other conditions with cognitive impairment. This requires assessing cognitive skills, also referred to as cognitive functions, which refers to the mental processes associated with the ability of an individual to perform various mental activities involved in the acquisition of knowledge, manipulation of information, and reasoning (Kiely, 2014). Further, functional cognitive skills can be defined as specialized mental processes of varying complexity that are needed to perform life’s activities or occupations, including personal care, school/work, leisure/sport, social activities (Kiely, 2014; Law, Cooper, Strong, Stewart, Rigby, & Letts, 1996). A person’s functional cognitive skill level is the individual’s capacity or ability to perform particular functional cognitive skills that are needed to engage in specific life activities. This level can vary over time, be influenced by a number of non-cognitive factors, and be an area of strength or challenge with unique facilitators and barriers. Assessing cognitive skills, function and level is needed for determination of personalized and targeted treatment planning.

Assessment and screening tools used to both assess post-mTBI cognitive status in the athlete and military context and inform Return to Play or Duty were observed by the authors to have a strong focus on physical factors and neglect of true cognitive measures. Further, acknowledgement of functional cognitive skill performance was lacking. Fundamental flaws in the way clinicians, researchers, patients, and their families address and understand cognition, cognitive dysfunction and functional cognitive skills, regardless of the diagnosis causing the dysfunction, became apparent. The authors' recognized that, prior to being able to improve cognitive screening, assessment, and treatment in clinical practices, a knowledge gap regarding functional cognitive skills needed to first be addressed and guided by a cognitive model or framework.

2.2.2. Issues with Current Healthcare Models in Addressing Functional Cognition

Theoretical models and frameworks are frequently constructed to enable clinicians and researchers to conceptualize health (or the absence of health) from various perspectives (Tamm, 1993). Holistic healthcare models are typically used to define disability, function, activity, and environmental impacts of a condition. Application of a model or framework then allows clinicians to more comprehensively examine patterns and relationships related to clinical questions, data, and processes and formulate appropriate treatment approaches.

Existing healthcare models are not always ideal for understanding functional cognitive skills and informing cognitive assessment and intervention practices. While the International Classification of Functioning, Disability, and Health (ICF; World Health Organization, 2001) includes "function" as a domain, it can be challenging to incorporate cognitive skills in the Activities domain. Likewise, while the Person Environment Occupation (PEO) Model (Law et al., 1996) acknowledges the intersection of factors that affect occupational performance, it is not specific to skills. Neurocognitive models, similar to traditional neuropsychological assessments, often address areas of cognition from a neuroanatomic structural perspective which does not always transfer to functional performance. This is especially true when complexities such as mental illness, medication, and environmental factors cannot easily be localized to specific parts of the brain and begin to affect cognitive functioning and performance. Further, functional psychological models which offer an increased focus on function lack focus on specific skills (Milner and Condello, 2012). It has also been noted that an occupation-based perspective is lacking in models from these disciplines and areas of study (Milner, 2014).

Existing models of cognition, while instructive, tend to lack comprehensiveness and specificity. For example, the Dynamic Interactional Model of Cognition (Toglia, 1992) emphasizes that cognition is a continuous product of the dynamic interaction between the individual, task, and environmental factors, has similarities to the ICF (World Health Organization, 2001) and PEO (Law et al., 1996) models. Toglia's model addresses cognition, tasks and person from an occupational and holistic lens but lacks a visual interpretation and does not classify individual cognitive skills. This makes it difficult to use as a teaching tool and process model for planning cognitive assessment and interventions. Regarding EF, while multiple models exist (e.g., the Model of Information Processing, (Luria, 1966), Clinical Model of Executive Function (Mateer, 1999), and Norman & Shallice Cognitive Model (Norman & Shallice, 1986)), these aim to organize and explain cognitive processes and do not recognize specific functional skills. Critically, most models of cognition do not share an interdisciplinary perspective. Further, the currently utilized models of disability and function do not always fit with, conceptualize, or organize cognitive skills. A more standardized, efficient, and accessible approach is needed for clinicians, researchers and the public at large to frame and organize cognitive skills so as to facilitate rehabilitation and recovery for those affected by cognitive dysfunction.

Review of cognitive models revealed a paucity of appropriate models and frameworks to conceptualize the range of cognitive skills needed for daily life, and fundamental challenges and knowledge gaps with the comprehensiveness, organization and utility needed for guiding clinical understanding, assessment and intervention. Current cognitive modelling utilizes biomedical and neuroanatomical lenses for cognitive function without specifying how these relate to cognitive processes, function or skills, and may be organized. Although some models and frameworks make mention of function and neuro-impairment, the activities that link these two concepts are ill-defined. Cognitive modelling that incorporates a more function-based approach to inform clinicians, patients, students, family members and researchers in rehabilitation and recovery is needed. The development of the Canadian Model of Cognitive Skills (CMCS) may be a step towards gaining a greater understanding of cognitive functioning and skills that cognitively healthy individuals take for granted every day.

2.2.3. Purpose

The purpose of this paper is to introduce the CMCS as a tool for guiding the understanding, education, assessment, and rehabilitation of cognitive skills.

2.2.4. Objectives

1. Demonstrate the need for models that address cognitive skills and function as a foundation to further facilitate assessment and treatment of cognitive dysfunction.
2. Present the process of the CMCS development.
3. Discuss the utility, limitations, and future directions of the CMCS model.

2.3. Methodology

Development of the CMCS was informed by the Active Implementation Frameworks (AIF; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). AIFs are a group of evidence-based frameworks commonly used in implementation science practices. Implementation science is the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and improve the quality and effectiveness of, in this context, health service delivery to those experiencing cognitive dysfunction (Eccles & Mittman, 2006). The field of implementation science has developed to facilitate the spread of evidence-based practice and research, including both psychosocial and medical interventions (Bauer, Damschroder, Hagedorn, Smith, & Kilbourne, 2016). Explanation of the iterative evolution of the CMCS through the lens of the AIFs aims to demonstrate the processes and rigour involved in its development.

The development of the CMCS followed AIF Stages of Exploration through Full Implementation (Figure 4). The developmental processes and steps undertaken, with integrated knowledge translation woven throughout the entire process, included: (1) Needs Assessment (Exploration Stage), (2) Environmental Scan (Exploration Stage), (3) Development of Prototype Model (Exploration Stage), (4) Key Stakeholder Engagement (Exploration Stage), (5) Facilitation of Practitioner Readiness (Installation Stage), and; (6) Improvement Cycles (Initial Implementation Stage) leading to the full implementation of the CMCS. These are expanded upon in the discussion that follows.

Figure 4: The Stages Active Implementation Model (AIF)

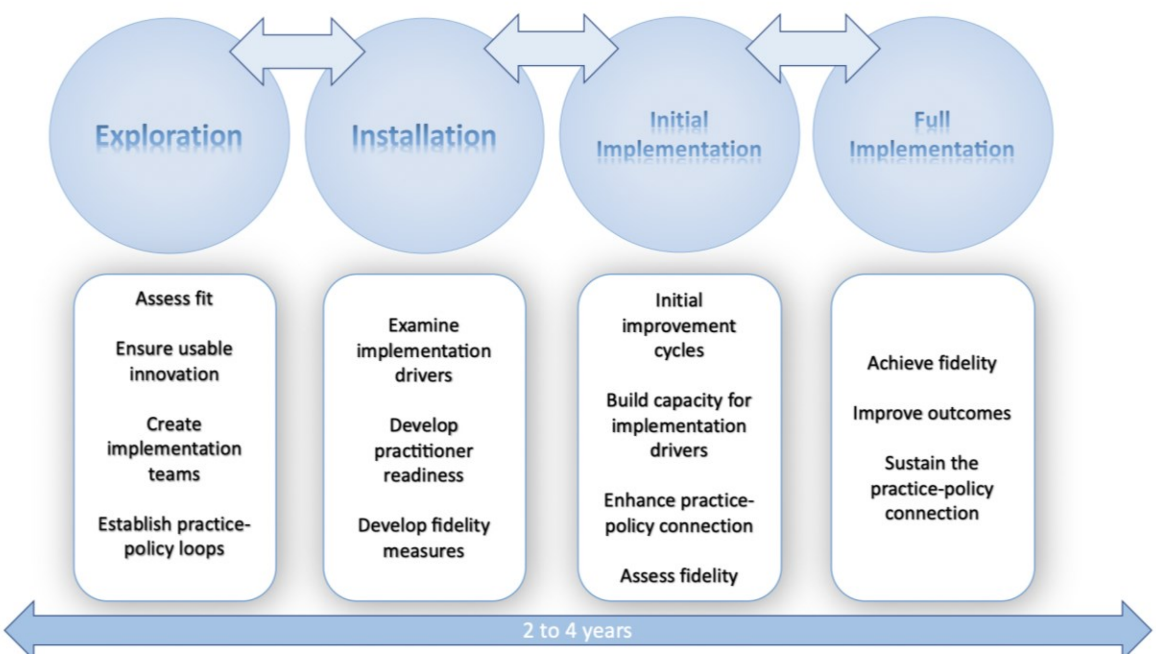

Figure 4: The Stages Active Implementation Model (AIF) by the National Implementation Research Network (NIRN; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

2.3.1. Needs Assessment (Exploration Stage)

Assessing the need for and fit of a specific innovation such as a new model of cognition is an integral step in the implementation process (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Consideration of the current state of the field of cognitive impairment by the authors revealed the need for a cognitive model and lens that incorporated a systematic and deliberate approach to cognitive skills in rehabilitation, education, and healthcare systems. Recognition of the shortcomings of current models of cognition as the foundation of how cognitive assessment and intervention is addressed highlighted additional questions such as: What are cognitive skills? Is there a hierarchy for cognitive skills? How can functional tasks be bridged with neuropsychology? Can a holistic model that captures cognitive functioning and its relationship to physiological and physical tasks and processes be developed? How might barriers and facilitators of cognitive skills be incorporated into a model? These queries, which identified more specific research questions and parameters integral to a more comprehensive Environmental Scan, framed the next steps of model development.

2.3.2. Environmental Scan (Exploration Stage)

The Exploration Stage began with an environmental scan and literature review to both isolate key domains of cognitive skills and assess the potential fit of a model of cognition. Regarding determination of cognitive skills, eight domains were identified through review of neuropsychology reports, including, (1) sustained attention, (2) response inhibition, (3) speed of information processing, (4) cognitive flexibility and control, (5) simultaneous attention, (6) working memory, (7) category formation, and; (8) pattern recognition (Harvey, 2019). A review of the literature initiated in February, 2012 offered an opportunity for review and critical appraisal of existing cognitive frameworks, models, and theories found in the published and grey literature (Table 1). These included the PEO Model (Law et al., 1996), Piaget's Theory and Stages of Cognitive Development (Piaget, 1936), International Classification of Function (WHO, 2001), Domains of Neuropsychological Testing, Bloom's Taxonomy (Bloom, 1956), Interactionist Theory (Jackson, 1878), Model of Human Occupation (Kielhofner, 2008), Framework for Assessing Executive Function (Lazek, 1982), Clinical Model of Executive Function (Mateer, 1999), Cognitive Learning Theory (Piaget, 1936; Wadsworth, 1971), and Theory of Mind concepts (Coulacoglou & Saklofski, 2017; Baron-Cohen, Lombardo, Tager-Flusberg, 2013). Scans of the literature continued throughout the remaining stages of implementation.

Table 1: Models, Theories, and Frameworks Incorporated into Canadian Model of Cognitive Skills

Models, Frameworks, and Theories	**Component Incorporated into Canadian Model of Cognitive Skills**
PEO Model (Law et al., 1996).	Incorporation of person-environment-occupation overlay. Holistic underpinnings.
Piaget's Theory and Stages of Cognitive Development (Piaget, 1936).	Assisted with determining the target age group.
International Classification of Function (WHO, 2001).	Blended with PEO model to frame neurofunctional model Structure-Skill-Function. This biopsychosocial conceptualization demonstrates that these constructs can influence the performance of other skills. A health condition can affect all constructs.
8 Domains of Neuropsychological Testing (Harvey, 2019)	Incorporation of cognitive processes and targeted skills
Bloom's Taxonomy (Bloom, 1956).	Higher-order/ lower-order thinking skills. More complex skills require foundational skills. Often use a pyramid or stair design to demonstrate a hierarchy.
Interactionist Theory (Jackson, 1878).	Nervous system is organized into lower and higher-order functions. Hierarchical design of cognitive skill. Higher and lower-order thinking skills.
Model of Human Occupation (Kielhofner, 2008).	Occupational Therapy Activity Analysis that addresses occupation, activities, and tasks. Can fit with Structure-Skill-Function as well as goal setting, organize, plan, do, review and reflect.
Framework for Assessing Executive Function (Lazek, 1982).	Represented goal, plan, do, and review approach to executive functioning. Adapted for current conceptualization of model to goal setting, organize, plan, do, review and reflect.
Clinical Model of Executive Function (Mateer, 1999).	Connection of EF domains to specific functions that can then be linked to specific cognitive skills.
Cognitive Learning Theory (Wadsworth, 1971; Piaget, 1936).	Internal and external factors influence an individual's mental processes to supplement learning. More complex skills require foundational skills.
Theory of Mind (Coulacoglou & Saklofski, 2017; Baron-Cohen, Lombardo, Tager-Flusberg, 2013).	Insight, metacognition, emotions and the role this plays in EF.

Table 1: Components of models, theories, and frameworks identified through the literature review of the Environmental Scan phase that influenced the content and design of the CMCS.

While examination of the models, frameworks, and theories isolated particular cognitive skills, these were neither organized nor defined. Notably, the literature review identified deficiencies regarding explanation of more complex cognitive skills, such as those that utilize EFs, which were not being well detected by cognitive assessment tools. As EF skills are commonly affected by mTBI or mild to moderate mental health disorders which are highly prevalent in society, this was determined to be particularly problematic when attempting to address cognitive dysfunction through rehabilitation strategies. Even when mild, EF challenges and neurological impairments can have significant adverse effects on the person in their workplace, educational environment, leisure pursuits, relationships and overall quality of life. This can be especially challenging in light of the increasing demand for cognitive over physical labour in the workplace (Milner, 2014).

Literature review findings coupled with those from the environmental scan were critically appraised by the authors. Drawing on their clinical skills, knowledge and experience as Occupational Therapists and academics, consideration was given to cognitive skills to include in the CMCS, and whether a functional model of cognitive skills would have utility in educational, clinical and research specific contexts. Once components of a potential model were compiled, it was hypothesized that a functional model of cognitive skills would likely be well-received by students, clinicians, clients, and researchers, and that a new perspective on functional cognition may facilitate learning, understanding and treatment planning. More particularly, it was determined that addressing the cognitive skills knowledge and practice gap identified during the Exploration Stage was critical to facilitating treatment for and enhancing the function of those experiencing cognitive dysfunction.

2.3.3. Development of Prototype Model (Exploration Stage)

A prototype model of cognitive skills was developed based on the Needs Assessment, Environmental Scan and theories, frameworks, and models identified during the literature review. The PEO Model (Law et al., 1996), with the overlap of *personal* (i.e., an individual with a unique set of characteristics), *environmental* (i.e., comprised of physical, social, cultural, and socio-economic factors), and *occupational* (i.e., functional tasks and activities that the individual engages in) factors that facilitate participation in aspects of life, provided particular inspiration for the evolving model (Law et al., 1996). A good fit between these constructs increases the likelihood of meaningful participation increases, while a poor fit can threaten engagement or performance (Wong and Leland, 2018). Attentiveness to these domains ensured that the prototype model was holistic and encompassed the broad complexities and overlap of factors affecting cognitive skills and performance.

The inclusion of neurofunction with the PEO - the intersection of person, environment and occupation with a person's functional cognitive skills - highlighted the importance of considering the impact of this component on function and engagement (Figure 5). Neurofunction refers to a person's functional status as it relates to a neurological condition, whether healthy or dysfunctional. This includes a person's abilities (physical, cognitive, psychosocial), activity participation, as well as quality of life. Elucidating this component emphasizes the significant impact that (dys)function in this domain can have.

Figure 5: The Person-Environment-Occupation (PEO) Model

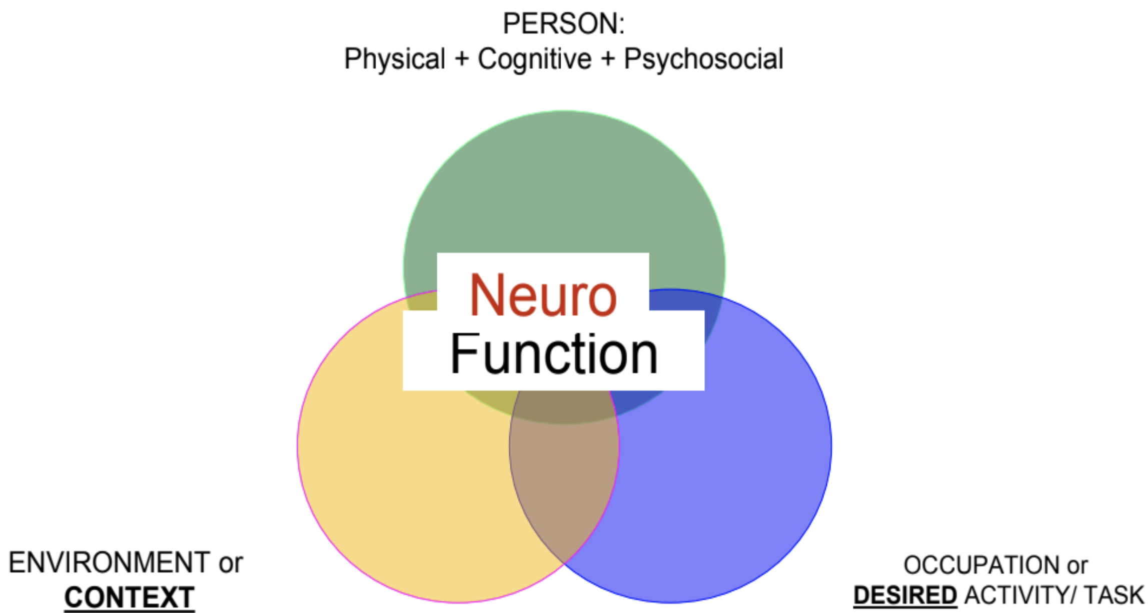

Figure 5: The Person-Environment-Occupation (PEO) Model by Law et al. (1996) with neurofunction in the intersection of the 3 concepts (Milner, 2014).

The prototype model of cognitive skills further evolved through superimposing the eight domains of cognitive skills isolated from neuropsychology onto the PEO Model. While this added greater depth and clarity, however, it was determined that barriers, facilitators, and complexities associated with confounding factors needed to be made more explicit. Inspired by models commonly used to conceptualize and plan clinical interventions for physiological, neurological, and musculoskeletal impairments, such as the ICF, a Structure-Skill-Function approach was introduced (Figure 6). The authors' intent in adopting such an approach was to explicitly acknowledge these factors and frame a decision-making process that would allow for better cognitive rehabilitation planning based on function and cognitive skills.

Figure 6: Structure-Skill-Function approach for Cognition

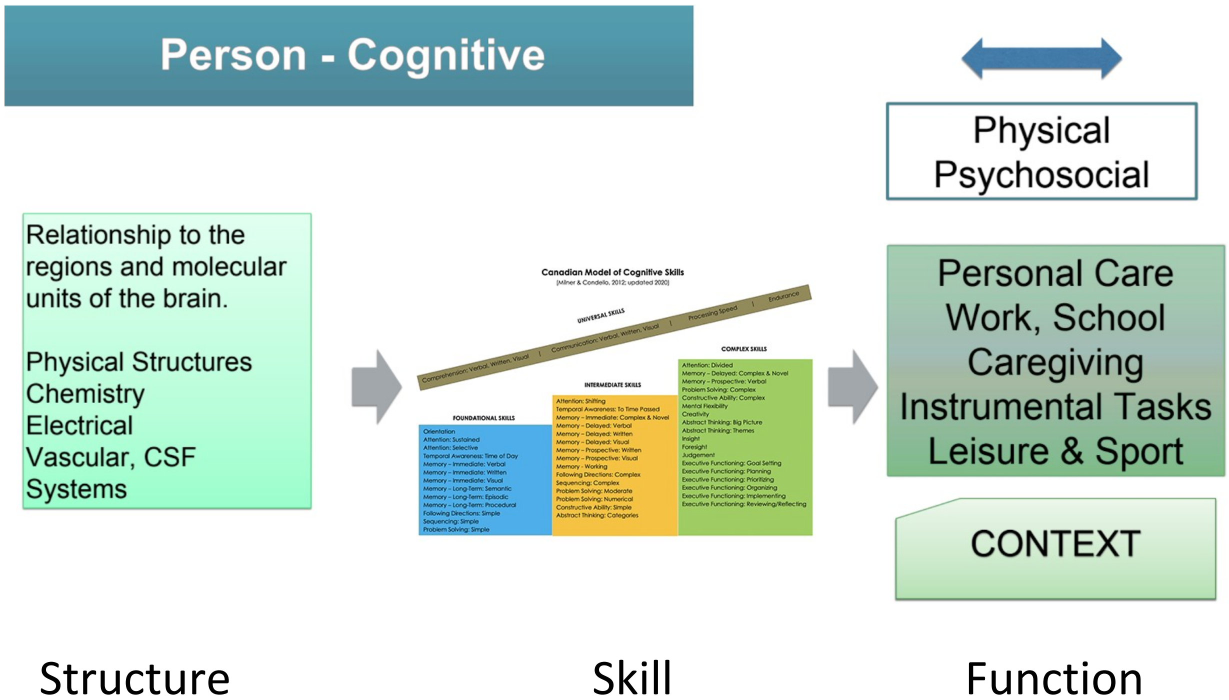

Figure 6: Example of a Structure-Skill-Function approach for Cognition within the Person domain (Milner, 2014). Physical and psychosocial aspects of the Person are also affected by and can affect cognition and, along with the specific environment and contexts of the individual, can affect an individual's ability to function. The CMCS helps bridge the gap between Structure and Function for cognition.

With the PEO model and Structure-Skill-Function context in mind, the authors analyzed, identified and isolated the cognitive skills within the aforementioned 8 domains. Thirty cognitive skills were then amalgamated, arranged from a lower to higher-order, and included in the evolving prototype model of cognitive skills. In determining the order of the cognitive skills, consideration was given to cognitive domains that are frequently associated with early cognitive decline or symptoms of mTBI. It was recognized that complex (higher-order) cognitive skills such as those that require EF were often dependent on fundamental (lower-order) cognitive skills being intact (Diamond, 2013; Ozga, Povroznik, Engler-Chiurazzi, & Haar, 2018). To effectively convey this concept, 4 universal skills (i.e., comprehension, communication, processing speed and endurance) and 30 cognitive skills were divided into 3 categories: (1) Foundational, (2) Intermediate, and; (3) Complex, while acknowledging that certain universal skills can affect the performance of all other cognitive skills of higher complexity (Milner & Condello, 2012). The resulting original prototype model entitled Milner and Condello's Model of Cognitive Skills was released in 2014 (Figure 7; Milner & Condello, 2014).

Figure 7: The Milner and Condello Model of Cognitive Skills

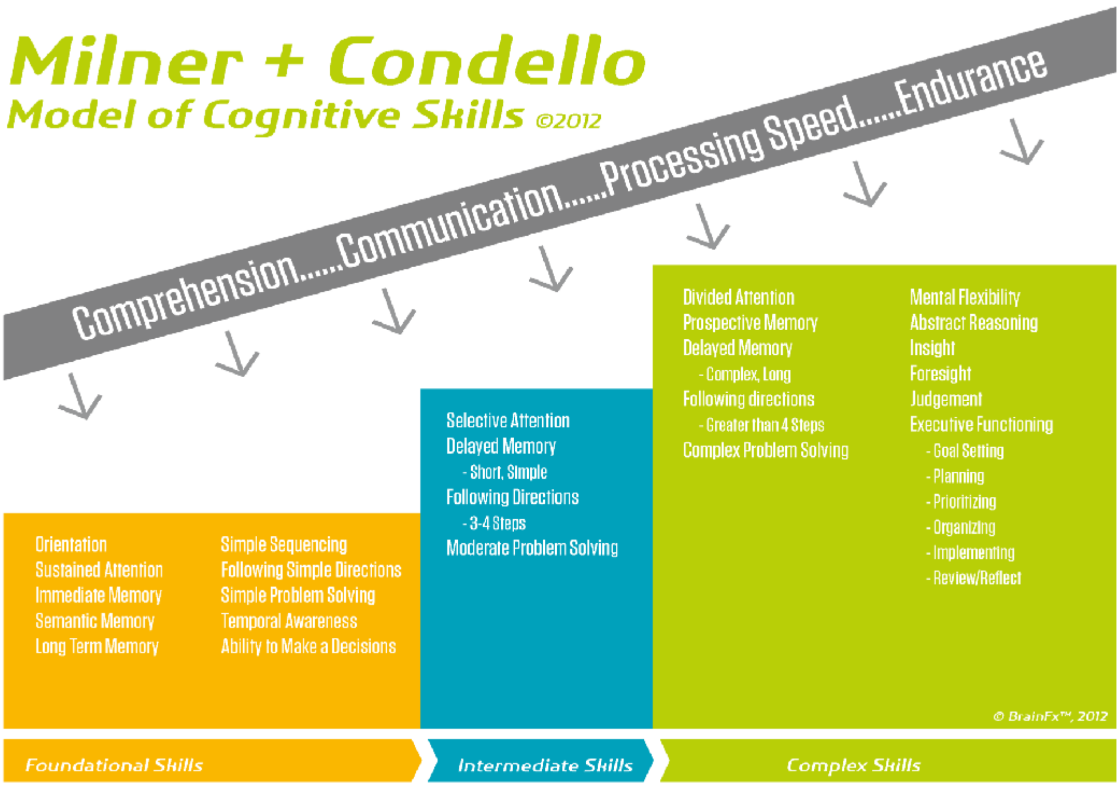

Figure 7: The Milner and Condello Model of Cognitive Skills (Milner and Condello, 2012) was the prototype model to the Canadian Model of Cognitive Skills.

2.3.4. Key Stakeholder Engagement (Exploration Stage)

The Milner and Condello Model of Cognitive Skills was introduced to Key Stakeholders as a key component of the Exploration Stage of the AIF (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005) so as to determine fit and obtain feedback from users and subject matter experts. "Fit" of the prototype model was evaluated using a modified Delphi method involving focus groups and expert consultation with key stakeholders. A modified Delphi method was employed as it offers a structured yet flexible way to both gather consensus of opinion, attitudes and choice about a topic from a selected panel and synthesise individual judgements and opinions from focus groups (Raine, Sanderson, Hutchings, Carter, Larkin, & Black, 2004). This consensus method has been used extensively in health-related research to synthesize information and derive quantitative estimates through qualitative approaches (Teijlingen, Pitchforth, Bishop, & Russell, 2006; Raine et al., 2004).

The focus group sessions were used to capture data and feedback on cognitive assessments and the prototype model from Key stakeholders and Subject Matter Experts. Interdisciplinary mixed-methods focus groups (n = 41) of 3-to-4-hour duration were comprised of occupational therapists (n =18), speech language pathologists (n = 12), primary care physicians (n = 2), academic researchers (n = 2), registered social workers (n = 2), a case manager (n = 1), a teacher (n = 1), a chiropractor (n = 1), a parent (n = 1), and an individual who had sustained an mTBI (n = 1). Neuropsychology and physiatry experts in Toronto, Ontario, Canada, with extensive knowledge and clinical experience working with patients with brain injury of various severity, were also consulted. Both qualitative and quantitative data (surveys) collected were analyzed, triangulated, and summarized.

The results of the interdisciplinary focus groups and expert consultation were essential to the further development of the model and set the stage for its Installation and Initial Implementation. Their confirmation of the existence of knowledge gaps regarding neurofunction and cognitive skills, indication that a new model could assist in addressing this gap in clinical and educational contexts, and validation of the need for and fit of such a model of cognitive skills informed next steps, while their critical feedback informed improvements to the model. All information collected was incorporated into the final rendition of the model and informed the remaining phases of its implementation.

2.3.5 Facilitation of Practitioner Readiness (Installation Stage)

Introducing the Milner and Condello Model of Cognitive Skills to healthcare professionals and readying them to adopt it in practice occurred through engagement with practitioners at national academic conferences. More particularly, discussions followed presentations made at the 2014 Ontario Society of Occupational Therapists (OSOT) Conference, 2016 Canadian Association of Occupational Therapists (CAOT) National Conference, and the 2013 and 2014 Traumatic Brain Injury Conferences in Washington, D.C. These venues afforded the authors unique opportunities to heighten awareness of the deficits of existing models of cognition and lay the foundation for model adoption. By introducing clinicians and researchers to the new model, the Installation Stage was initiated. Heightening awareness among stakeholders, clinicians and researchers regarding knowledge gaps that lead to the development of the model was a first step in facilitating practitioner readiness to utilize this innovation in practice. The conferences also enabled further key stakeholder engagement, ongoing evaluation and further model revision.

In addition to being introduced to clinicians, the prototype model was shared with occupational therapy graduate students at a Canadian University. This initial implementation of the model in the academic environment enabled the authors to trial the model with the next generation of practitioners who were in need of learning about functional cognition and their role in assessment and treatment of cognitive dysfunction. Readying these early career clinicians with a more thorough understanding of functional cognition aimed to increase the quality of rehabilitation services provided to those experiencing cognitive dysfunction. It also afforded additional feedback that improved the prototype model and informed Full Implementation of the model within the academic context.

2.3.6 Ongoing Evaluation and Revision (Initial Implementation Stage)

Once the prototype model was introduced and released, its ongoing evaluation and revision was key to ensuring its relevance, validity, alignment with the most current evidence-based literature and appropriate use. As well, it was important that the model be used with fidelity for cognitive assessment and treatment.

Ongoing evaluation and revision of the model employed the Plan-Do-Study-Act (PDSA) AIF (Figure 8; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). The PDSA AIF is an improvement cycle that facilitates identification of an implementation plan (do), barriers or challenges (study), as well as plans to move programs or innovations forward (act). After having introduced the model (do), reception of the model and feedback offered by practitioners, key stakeholders, students, and researchers was studied and adaptations made accordingly (act). Plans were made to integrate and disseminate changes, which were then put in place or implemented. Measures identified during the planning phase enabled further assessment of uptake, use of the model, fidelity, and tracking of progress (study). Iterative changes ongoingly improved the model and its implementation (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Figure 8: Plan Do Study Act (PDSA) AIF

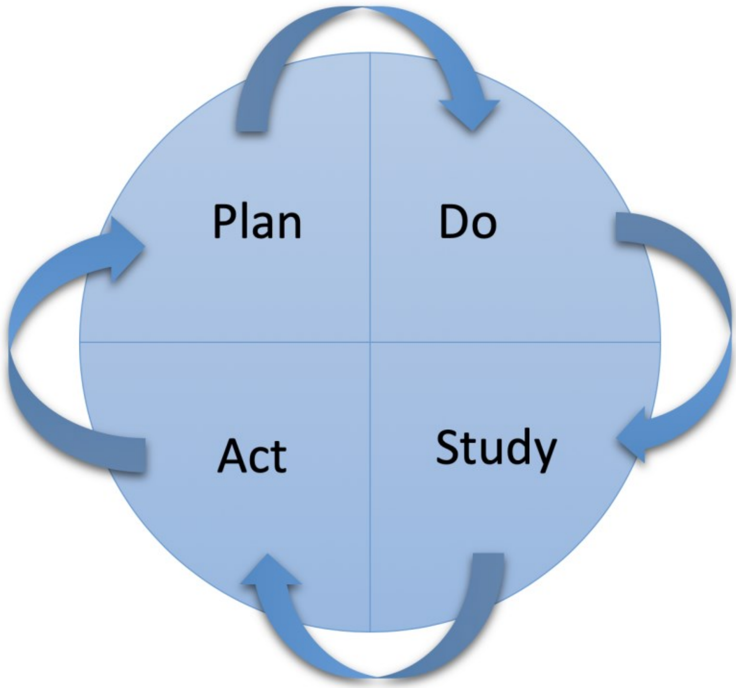

Figure 8: Plan-Do-Study-Act (PDSA) AIF is utilized in the Installation and Full Implementation Phases of innovation Implementation (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Following numerous improvement cycles, changes were incorporated into the final iteration of the model. This included shortening of the title and adaptation of the model to reflect the country of origin as well as for ease of pronounceability and translation. Cognitive skills were also expanded to include 50 skills rather than 30. Graphic design elements were adjusted to improve visibility and readability. As the Full Implementation Stage is iterative and ongoing, PDSA cycles will continue so that the model continues to evolve in keeping with current best practices, evidence-based literature regarding neurofunction and cognitive skills, and application within rehabilitation contexts.

2.4 Results

The iterative process undertaken as part of model development resulted in the CMCS (Figure 9). The CMCS categorizes 50 cognitive skills into 4 subsets: Universal, Foundational, Intermediate, and Complex. Potential factors that can promote or confound cognitive performance are considered universal skills and are labeled in a grey ascending line that represents a handrail. This acts as a guide from foundational to complex skills, including comprehension, communication, processing speed, and endurance. A staircase was purposefully chosen to demonstrate both the steps involved in more complex cognitive skill performance and that missing skills in intermediate or foundational skills could create a misstep in the ability to perform more complex skills. Such a hierarchy of skills acknowledges that acquisition of foundational and intermediate skills is generally required before more complex skills can be performed. The hand rail for universal skills acts as a reminder that these skills can either enable or disable the performance of the cognitive skills on the stairs. The steps may also guide clinicians through cognitive rehabilitation planning (e.g., remediation of a complex skill is unlikely until a lower-order skill has been remediated or compensated for).

Figure 9: The Canadian Model of Cognitive Skills

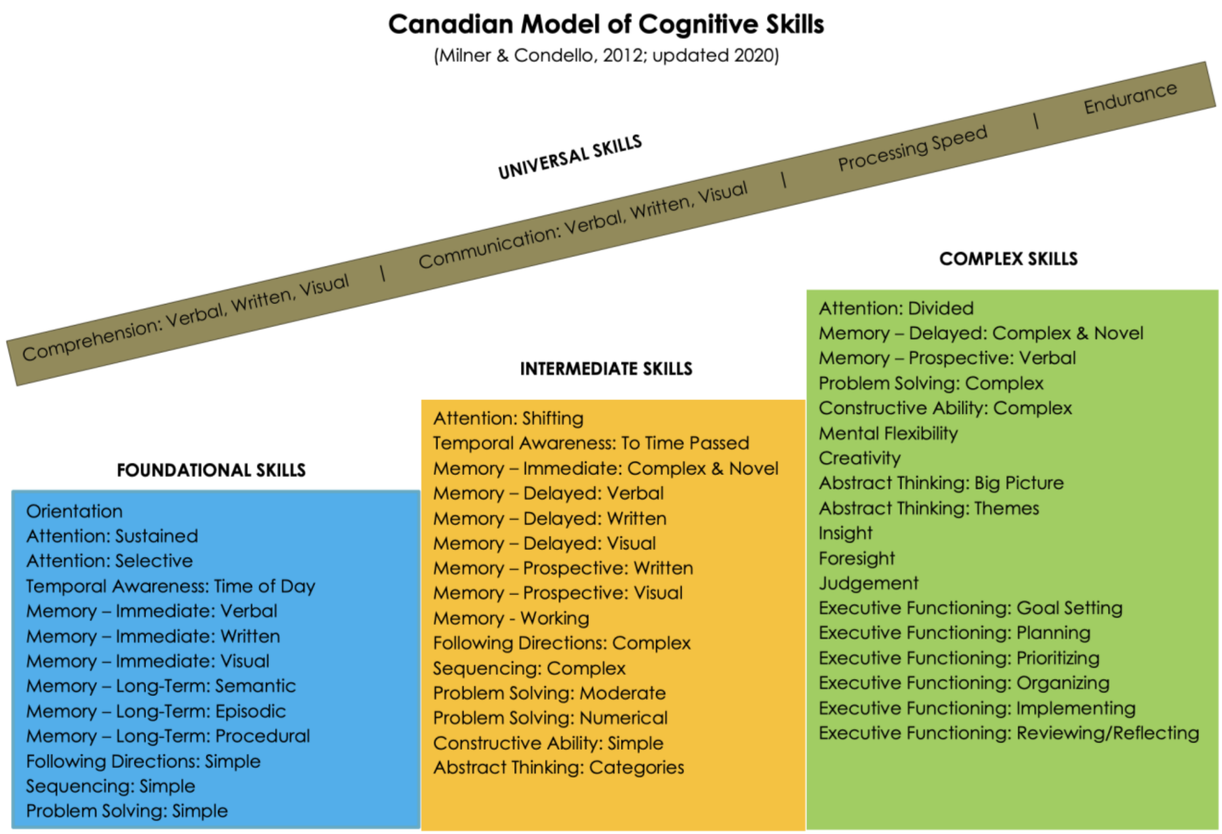

Figure 9: The current 2020 version of the Canadian Model of Cognitive Skills (CMCS).

2.5 Discussion

2.5.1 The Canadian Model of Cognitive Skills

The CMCS was developed out of an identified need for a cognitive model that could guide clinicians from various healthcare disciplines when conducting cognitive assessment and offering interventions. While the CMCS is designed from an occupational perspective, it can be used by multiple disciplines. Prior to the introduction of the CMCS, a clear way of conceptualizing, organizing and visualizing cognitive skills was lacking. The CMCS is successful in categorizing skills and providing a visual representation that is simple for clinicians, educators, and clients to understand. Rooted in the PEO model, this new model considers how multiple variables affect cognitive skills, acknowledges the complexity of cognitive domains, and orders cognitive processes hierarchically as they apply to overall occupational performance.

The CMCS is unique in identifying potential factors that confound cognitive performance. Labeled in the grey ascending line and building from foundational to complex skills, the model emphasizes that cognitive functions such as comprehension are required before processing speed and cognitive endurance can be addressed and enhanced. Universal Cognitive Skills, skills that can broadly either positively or negatively influence the performance of all foundational, intermediate or complex skills, are also highlighted. It was hypothesized that milder or early brain disorders impact the more complex or universal skills *first* before even the foundational or intermediate cognitive skills.

The utility of the CMCS in various multidisciplinary contexts is one of its most noteworthy strengths, addressing the uni-disciplinary nature observed in previous models of cognition and EF. In the clinical environment, the model can inform both assessment and treatment of those with cognitive dysfunction. With previous models not prompting a bottom-up approach or consideration of complex and universal skills, clinicians may be more likely to leave a person's areas of cognitive strength unacknowledged or overlook cognitive dysfunction altogether. As early interventions for cognitive dysfunction are effective, this could lead to missed opportunities for leveraging cognitive skills of strength, early intervention, and rehabilitation as well as improper utilization of healthcare resources such as diagnostic imaging when they are not required (Larner, 2017). Physicians and allied health professionals alike may find the CMCS clinically useful as a foundational guide for cognitive assessment and treatment planning. Clinicians using the model have reported that it is clinically relevant and useful in rehabilitation planning and care (e.g., the development of Individualized Education Plans for school settings, developing return to work plans, and in comparing cognitive skills to cognitive demands of a specific role). Effective assessments and interventions can enable practitioners to better facilitate increased occupational performance among the populations they serve.

The CMCS may also have utility in a number of industries and organizations for which cognitive function is central. This may include education, science, youth to high performance athletics, technology, and innovation. With its visual organization and holistic understanding of functional cognition, the CMCS may also aid in education and training efforts, be that with patients, families, students, and teachers. Presented in a post-graduate level educational setting, the CMCS has served as a segway between academic learning, clinical practice and research. The new perspective, framing and conceptualization of cognitive skills, cognitive function and occupational performance offered by the CMCS, could lead to new innovations, theories, and novel clinical research initiatives that could improve client outcomes for those who experience mild to severe cognitive dysfunction. Technological innovations in the area of cognitive assessments, particularly computerized neurofunctional assessments and screens, may be informed by the CMCS.

The model has already led to innovations in teaching, clinical assessment, rehabilitation, care planning and digital healthcare due to its holistic incorporation and hierarchical organization of cognitive skills in a digestible, visual format. It may also have future utility in understanding the impact of cognitive demands for those who experience conditions such as mental illnesses, chronic pain, addiction, and other neurological disorders, each of which can affect neurofunction. As a model of cognitive skills, the CMCS lays a solid foundation for future clinical, practical, educational, technological and research exploration, innovations and advances.

2.5.2 Limitations of Model

The CMCS is a novel model that requires ongoing evaluation and revision through continued PDSA cycles. Further research is needed to evaluate the applicability of the model with a variety of populations including athletes, military personnel, and individuals of all ages. As well, the model will require trialing in different cultural contexts, healthcare organizations, and academic environments. Translation of the CMCS in multiple languages beyond its current English and French iterations (currently in process) is also warranted so as to enable it to be more widely available, implemented, scaled and spread.

2.6 Conclusion

The CMCS was developed through an *a priori* yet iterative process guided by implementation science frameworks. The aim of developing the model was to enhance the understanding, awareness, and organization of cognitive skills; the ultimate goal of the authors was to improve healthcare services as well as cognitive and occupational performance outcomes in a variety of populations experiencing cognitive challenges. This was a priority given that optimal cognitive functioning is essential for maintaining safety, efficiency, and effectiveness in day-to-day lives, schools, workplaces, and the society as a whole (American Journal of Occupational Therapy, 2013). Further, addressing assessment and treatment of cognitive dysfunction through a holistic, interdisciplinary, and evidence-based lens is imperative for the well-being of the individuals affected by conditions that compromise cognitive functioning as well as their families and communities. Improving models and frameworks of cognition is foundational to advancing clinical practice, education and training, innovation and research.

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4. Neurocognitive Assessment Tools for Military Personnel with Mild Traumatic Brain Injury: A Scoping Literature Review

Accepted: Journal of Medical Internet Research: Mental Health

3.1 Abstract

Background: Mild traumatic brain injuries (mTBI) occur at a higher frequency among military personnel than civilians. A common symptom caused by mTBI is cognitive dysfunction. Neuropsychological assessments are used by healthcare professionals as part of a multidisciplinary and best practice approach for mTBI management. Such assessments support clinical diagnosis, symptom management, rehabilitation, and return-to-duty planning. Military healthcare organizations currently use computerized neurocognitive assessment tools (NCATs). NCATs and more traditional "pen and paper" neuropsychological assessments present unique challenges both in clinical and military settings. Many research gaps remain regarding psychometric properties, usability, acceptance, feasibility, effectiveness, sensitivity, and utility of both types of assessments in military environments. Objectives: (1) To explore what evidence exists regarding the use of NCATs among military personnel who have sustained mTBI; (2) evaluate the psychometric properties of the most commonly tested NCATs for this population, and; (3) synthesize the data to explore the range and extent of NCATs among this population, clinical recommendations for use, and knowledge gaps requiring future research. Methods: Studies were identified using MEDLINE (Medical Literature Analysis and Retrieval System Online), EMBASE (Excerpta Medica dataBASE), APA (American Psychological Association) PsycINFO, CINAHL (Cumulative Index of Nursing and Allied Health Literature) Plus with Full Text, Psych Article, Scopus, and Military & Government Collection. Data were analyzed via descriptive analysis, thematic analysis, and the Randolph Criteria. Narrative synthesis and the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guided reporting of findings. Criteria proposed by Randolph et al. (2005) were utilized to evaluate the psychometrics of currently utilized NCATs. Results: Of 104 articles, 33 studies met the inclusion criteria for this scoping review. Thematic analysis and NCAT psychometrics were reported and summarized. Conclusion: The psychometric properties of the most commonly used NCATs in military populations have yet to demonstrate adequate validity, reliability, sensitivity, and clinical utility among military personnel with mTBI. Additional research is needed to further validate NCATs within military populations, especially for (1) those living outside of the US and (2) individuals experiencing other conditions known to adversely affect cognitive processing. Knowledge gaps remain warranting further study of psychometric properties and the utility of baseline and normative testing for NCATs.

3.1 Introduction

Mild traumatic brain injuries (mTBI), also known as concussions, are generally defined as a temporary change in brain functioning caused by an insult to the head with a period of posttraumatic amnesia lasting less than a day (McCroy et al., 2017). Symptoms of mTBI may include cognitive dysfunction, which can compromise overall functioning at home, work, and during other activities (Radomski, Goo-Yoshino, Hammond, et al., 2015). Within military populations, the mechanism of injury (MOI) for mTBI varies, with some occurring as a result of motor vehicle collisions, falls, sports, explosions, or other forces related to combat and military training. Among Canadian Armed Forces members deployed to Afghanistan during Operation Enduring Freedom (OEF), 5.2% self-reported experiencing an mTBI, 21% noted post-concussion symptoms (PCS), which refers to symptoms lasting longer than 3 months post MOI (Garber, Rusu, & Zamorski, 2014; McCroy et al., 2017). In comparison, studies among the United States (US) military populations report mTBI rates of 12% to 22.8% during OEF and Operation Iraqi Freedom (OIF), with PCS rates of 15.8% to 35% (Armistead-Jehle, Soble, Cooper, & Belanger, 2017; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Schwab, Terrio, Brenner, Pazdan, McMillan, MacDonald, et al., 2017). The United Kingdom (UK) Armed Forces report a 4.4% mTBI prevalence among SMs deployed into these global conflicts (Rona, Jones, Fear, Hull, Murphy, Wessely, et al., 2012). Although the reported rates of mTBI vary between militaries, the evidence base consistently demonstrates higher mTBI and PCS rates in military personnel versus civilian populations. Incidences of PCS are prevalent at an elevated rate among military populations, with global estimates for civilians approximately 15% and military estimates ranging from 15.8% to 35% (Marshall, Bayley, McCullagh, Berrigan, Fischer, Ouchterlony, et al., 2018; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Rona et al., 2012). Factors such as a higher prevalence of mental health disorders, exposure to traumatic experiences, previous mTBI, stigma, and possible fear of career repercussions due to being injured have been identified as potential reasons that PCS is more common in military populations than civilian populations (Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Rona et al., 2012; Garber, Rusu, & Zamorski, 2014). It is widely accepted that these factors also contribute to an underreporting of mTBI, which contributes to underestimating the actual incidence of this injury among military personnel (Garber, Rusu, & Zamorski, 2014; Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013).

3.2.1 Neuropsychological Assessments in Military Populations

Premature return-to-duty after sustaining mTBI is inherently associated with heightened risk. This includes an elevated level of risk for a subsequent concussion before neurological recovery has occurred, thereby amplifying the risk for impaired performance, making mission failure more likely, and endangering the safety of self and others (Guskiewicz, McCrea, Marshall et al., 2003; McNeil & Morgan, 2010). Neurocognitive assessments for those who have sustained mTBI are needed to a) provide information on function in a timely fashion, b) assist with diagnoses of mTBI and/or impaired cognitive functioning, and c) provide healthcare professionals with the tools needed to understand and monitor phases of recovery after injury for better-informed clearance for a return to work, duty, and other activities (Baruch, Barth, Cifu, & Leibman, 2016). Measurement of neurobehavioral and cognitive functioning after mTBI, often referred to as neuropsychological testing, is considered a component of best practice mTBI management. Neuropsychological assessments provide valuable information that can have important implications for returning to these activities in acute and chronic mTBI scenarios

(McCroy et al., 2017; Arrieux, Cole, & Ahrens, 2017; Radomski, Goo-Yoshino, Hammond, et al., 2015).

Traditional neuropsychological assessments are generally composed of measures with large normative databases and demonstrate evidence of adequate psychometric properties (Arrieux, Cole, & Ahrens, 2017). These assessments are typically administered in one-on-one scenarios by a trained healthcare professional with paper, pencil and stopwatch (Arrieux, Cole, & Ahrens, 2017). Neuropsychological assessments range in administration time from less than an hour to multiple sessions over days. These assessments are not meant to be executed on the sidelines in athletic scenarios and are not simply screens of symptoms or cognitive status. Rather, they are in-depth assessments that address behaviour, emotional status, and cognitive domains as well as neuropsychological symptoms. Neuropsychological assessments may or may not provide diagnostic information on mental health conditions, mTBI, or learning disabilities, however their diagnostic properties are still widely debated within the research (Baruch, Barth, Cifu, & Leibman, 2016).

Although neuropsychological assessments have been used in psychology for over 100 years, there remain many questions, logistical issues, and psychometric challenges around their use, especially in the military context. Traditional neuropsychological testing can be time intensive for both the healthcare professional and the patient, expensive, and have reduced feasibility in combat settings (Arrieux, Cole, & Ahrens, 2017). These cognitive assessments may also be dated. Some assessments use decades old normative data. Others ask the patient to complete tasks that are no longer relevant to the present day. Dated assessment tools can compromise the validity of the assessment and increase the chances of type 1 and type 2 errors (Larner, 2017). There are limits to the variations in stimuli that can be presented with traditional assessments and scoring (i.e., speed and accuracy) and a lack of ecological validity (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013). Traditional neuropsychological assessments tend to examine isolated components, or domains, of cognition and may not adequately predict overall functioning that relate to return to duty after mTBI (Larner, 2017; Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013). Assessment results do not always assist clinicians with treatment planning as performance during assessment tasks may not accurately reflect real-world performance (Larner, 2017).

3.2.2 Computerized Neurocognitive Assessment Tools (NCATs)

In the last 20 years, alternatives to traditional neuropsychological assessments have emerged in the form of computerized neurocognitive assessment tools (NCATs; Arrieux, Cole, & Ahrens, 2017). As the use of computers and handheld devices such as tablets and smartphones has become ubiquitous in society, neuropsychological assessment tasks on these devices may be closer to activities that are commonplace in real life. This may increase the acceptability of computerized assessments.

NCATs developed in recent years are promising for use within military populations, especially since they tend to be a younger demographic. Currently, NCATs are used by military healthcare providers to assess the effects of mTBI in both deployed and non-deployed settings (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016). In the US, military personnel are mandated to undergo assessment with a NCAT referred to as the Automated Neuropsychological Assessment Metrics 4 Traumatic Brain Injury - Military (ANAM4-TBI-MIL) so as to establish a baseline of cognitive functioning prior to deployment to a warzone (Department of Defense Instruction, 2013).

NCATs may have multiple benefits. Faster administration time, automated scoring and statistical analysis, easier reporting, and ease of de-identification of patients for research purposes are among the benefits (Cernich, Brennana, Barker, & Bleiberg, 2007; Arrieux, Cole, & Ahrens, 2017). NCATs may also allow for cognitive assessment to be obtained in geographic areas where traditional neuropsychological and cognitive assessment resources are limited (Arrieux, Cole, & Ahrens, 2017). Further, NCATs provide the benefit of delivering numerous combinations of stimuli systematically and the ability to precisely track speed and accuracy. This can help mitigate practice effects and possibly increase sensitivity to subtle changes in cognitive performance (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013; Arrieux, Cole, & Ahrens, 2017). he standardized tablet or computer interface, standardized script, and reduced conversation between the assessor and the participant may also enhance the inter-rater and intra-rater reliability of NCATs (Cernich, Brennana, Barker, & Bleiberg, 2007). Bias or issues with reliability that may be related to assessor variability or differences in rapport between the assessor and the patient may be reduced by standardized assessment delivery. Despite the potential benefits of NCATs, there are still many questions that remain regarding their effectiveness in both civilian and military populations with mTBI and other conditions that affect cognitive functioning.

Although NCATs are currently used within military healthcare practices, their feasibility, effectiveness, and psychometric properties are not well-understood. Due to the relatively recent digital evolution, NCATs generally have not undergone the same degree of rigorous evidence-based psychometric evaluation as has traditional neuropsychological testing. As a consequence, validity, reliability, specificity, and overall effectiveness may not be as well established for NCATs (Arrieux, Cole, & Ahrens, 2017). NCATs and traditional assessments may be limited regarding their ability to demonstrate cognitive functioning changes when individuals are immersed in stressful situations such as military combat; issues related to ecological validity also still exist (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013).

Diagnosing mTBI on an individual basis has to date not been possible using a single traditional or computerized assessment. This is largely due to potentially large variations in baseline neurophysiological function and the presence of transient interferences such as learning effects, fatigue, anxiety, and unrelated states of mental alertness or illnesses (Baruch, Barth, Cifu, & Leibman, 2016). Further, although NCATs are being utilized in clinical settings and researched regarding their utility within mTBI management, there is a lack of published literature on the use of these assessments among patients with other conditions known to adversely affect cognitive functioning (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016).

3.2.3 Previous Literature Reviews of NCATS

There have been a number of literature reviews published in the past 20 years focusing on the utilization of NCATs to assess sport-related mTBI (Randolph, McCrea, Barr, & Macciocchi, 2005; Resch, McCrea, Cullum, 2013; Iverson & Schatz, 2015; Arrieux, Cole, & Ahrens, 2017). In 2005, Randolph, McCrea, Barr, & Macciocchi established five criteria that must be satisfied with additional research to consider an NCAT for testing after mTBI. The 'Randolph Criteria' included: (1) test–retest reliability, (2) the sensitivity of the tests in the clinical issue of interest, (3) the validity of the measure, (4) reliable change scores and scoring algorithms for classifying impairment, and (5) determining the clinical utility of the measure (Randolph, McCrea, Barr, & Macciocchi, 2005). The NCAT literature reviews of sport-related mTBI after Randolph et al. (2005) have utilized these criteria. Still, the most recent conclusions suggest additional research is needed in order to further validate NCATs within mTBI populations (Arrieux, Cole, & Ahrens, 2017). These past literature reviews were not specific to military personnel.

It is essential that military personnel be considered a unique subset of the adult mTBI population for many reasons. Firstly, military personnel exhibit higher rates of conditions such as posttraumatic stress disorder (PTSD), depression, anxiety, sleep disorders, chronic pain, substance abuse disorders, and mTBI, which can cause and adversely affect the severity, longevity, and dysfunctionality of symptoms including associated cognitive dysfunction (Armistead-Jehle, Soble, Cooper, & Belanger, 2017; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Rona, et al., 2012). Specifically, traumatic brain injuries (TBI) and PTSD can arise from the same or separate traumatic incidents, and often co-occur, which adds complexity to the diagnosis, treatment, rehabilitation, and return to work planning (Armistead-Jehle, Soble, Cooper, & Belanger, 2017; Radomski, Davidson, Voydetich, & Erickson, 2009). Additionally, the MOI of the mTBI experienced by military members is not always similar to the impact sequelae seen in sport-related mTBI. Blast injuries, as an example, are more unique to military populations, with a portion of the mTBI sustained by military members during OEF and OIF being attributable to this MOI (Doneva, 2018; Bryden, Tilghman, & Hinds, 2019). A blast mTBI (bTBI) is an injury to the brain leading to dysfunction that is the result of an explosion or a blast (Doneva, 2018; Bryden, Tilghman, & Hinds, 2019). No significant variations in mTBI attributed cognitive symptoms caused by blast versus blunt force have been identified, however, research continues to investigate this (Doneva, 2018).

There is a need for improved detection of neurocognitive deficits in the military setting to assist with the diagnosis of mTBI, rehabilitation, recovery, and return to duty decisions while maintaining the productivity and safety of the military population and the civilians they may interact with at home and on deployment. An up-to-date scoping literature review of the current evidence related to NCAT utilization among military members who sustained mTBI is warranted due to the a) lack of specificity to military populations among previous literature reviews regarding NCATs and mTBI, b) the rapid development of NCATs, and c) the frequency of clinical utilization among military healthcare. This scoping review aims to fill this knowledge gap.

3.2.4 Purpose and Research Questions

The purpose of this scoping review is to (1) explore the existing evidence regarding the use of NCATs among military personnel who have sustained mTBI; (2) evaluate the psychometric properties of the most commonly tested NCATs for this population, and; (3) synthesize the data to explore the range and extent of NCATs among this population, clinical recommendations for use, and knowledge gaps requiring future research. This scoping review aims to answer the following research questions: (1) to what extent and which NCATs are being utilized within the military mTBI context? (2) what evidence exists regarding the validity, reliability, feasibility, technology acceptance, usability, and security of NCATs in the military and mTBI context? (3) what are the themes, clinical recommendations, and considerations in the evidence-based literature regarding the use of NCATs for military personnel who have sustained mTBI? and (4) what are the knowledge gaps and future directions of research that need to be addressed regarding the utilization of NCATs for military personnel who have sustained mTBI?

3.3 Methodology

A scoping review is a form of knowledge synthesis that addresses an "exploratory research question aimed at mapping key concepts, types of evidence, and gaps in research related to a defined area or field by systematically searching, selecting, and synthesizing existing knowledge" (Colquhoun, Levac, O'Brien, Straus, Tricco, Perrier, et al. 2014). While systematic reviews are used when answering narrow research questions, scoping reviews are used to answer a broad research question. A scoping literature review is often "conducted before the research begins, and sets the stage for this research by highlighting gaps in the literature, and explaining the need for the research to be conducted" (Grant & Booth, 2009). Similar to a systematic review, an a priori protocol must be developed for a scoping review (Peters, Godfrey, Khalil, McInerney, Parker, & Baldini Soares, 2015). Unlike a systematic or critical review, and due to the more iterative nature of a scoping review, deviations from the predetermined protocol may be necessary (Peters et al., 2015). This evidence-based scoping literature review design is ideal for addressing the research questions and assisting with an evolving implementation science strategy to improve cognitive assessments within military populations.

This scoping review employed the following overarching steps: (1) formulation of the research questions based on PICO (Population, Intervention, Comparison, and Outcome) guidelines, (2) identification of relevant studies, (3) selection of studies, (4) charting of the data, and (5) collation, analysis, summarization, and reporting of results (Arksey & O'Malley, 2005). As required for scoping reviews, a minimum of two reviewers were involved in study selection and analysis (Peters et al., 2015). The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) reporting guidelines (Tricco, Lillie, Zarin, O'Brien, Colquhoun, Levac et al., 2018) were followed.

3.3.1 Identification of Relevant Studies

Relevant studies were systematically identified. A description of the information sources, search strategy, inclusion and exclusion criteria and selection process follow in the next sections.

3.3.1.1. Information Sources and Search Strategy

A search strategy was developed based on specific inclusion and exclusion criteria and included the following databases: MEDLINE (Medical Literature Analysis and Retrieval System Online; Ovid MEDLINE ALL), EMBASE (Excerpta Medica dataBASE; Ovid interface), APA (American Psychological Association) PsycINFO (Ovid interface), CINAHL (Cumulative Index of Nursing and Allied Health Literature) Plus with Full Text (EBSCOhost interface), Psych Article (EBSCOhost interface), Scopus, and Military & Government Collection (EBSCOhost interface). The search consisted of an extensive list of keywords and subject headings covering 3 concepts: (1) NCATs, (2) military personnel, (3) mTBI. The 3 concepts were then combined with the Boolean AND. Studies were limited to peer-reviewed and grey literature articles in the English language such as journal articles, books, book chapters, conference papers, and unpublished theses. The initial search for articles took place on April 15 and April 21, 2020 within the aforementioned databases. The full search strategy is available in Appendix 3.8.1.

3.3.1.2. Inclusion and Exclusion Criteria

Articles selected for inclusion in this scoping review focused on military personnel who had a primary diagnosis of mTBI. Targeted articles specifically addressed the usability, feasibility, reliability, validity, sensitivity, and efficacy of one or more NCATs among military personnel who have sustained mTBI. Studies were excluded if the NCAT(s) were utilized to measure an outcome of an intervention such as cognitive rehabilitation therapy, hyperbaric oxygen, or psychotherapeutic interventions. If the published work included healthy participants or participants with comorbid conditions, such as other mental health disorders, disrupted sleep, chronic pain, or substance use disorder, it was included if the additional conditions were secondary to the mTBI diagnosis and not the primary focus of the specific research study. Cognitive assessment practices that incorporated virtual reality were permitted for inclusion.

The articles included in the data set were quantitative, qualitative, mixed methods, and meta-analyses, regardless of positive, negative, or neutral findings. Articles were excluded from the review if they did not meet the inclusion criteria. Studies that exclusively addressed civilians or veterans were also excluded.

3.3.1.3. Selection of Studies

The study selection phases followed a variation of the procedures used by Miguel Cruz, Ríos Rincón, Rodríguez Dueñas, Quiroga Torres, and Bohórquez-Heredia (2017). First, a member of the research team exported all of the identified studies to the reference manager software ProQuest Refworks. After deduplication, the references were imported to Covidence Systematic Review Software. Second, before the title and abstract evaluation phase, members of the research team were trained in applying the inclusion and exclusion criteria (calibration phase). Then, three independent researchers evaluated the titles and abstracts of the remaining studies and compared them with the inclusion and exclusion criteria. Differences between the choices of the independent researchers regarding the decision of whether or not to include a study in the next phase were addressed at subsequent meetings among the three researchers. During the full paper reading phase, at least two researchers reviewed the full texts of the selected studies. Each of the researchers independently assessed the studies to determine their suitability for inclusion in the data extraction phase. An article's inclusion or exclusion into the data set for analysis required a consensus from the research group. The reference lists of the included full-text studies were also reviewed for articles that the search may have missed.

3.3.2 Charting of Data

The research team extracted data from the final selected papers according to the following domains: population (medical condition, age, specific military conflict, condition, race or ethnicity, sample size [N], and mean age [SD] in years), study features, clinical assessment, assessment of technology usability, technology outcome measures, technology, duration, and data analysis strategies. The researchers met regularly and reconciled differences through discussion. In case of any disagreement, one of the researchers acted as a third rater.

3.3.3 Analysis, Summarization, and Reporting

All data were analyzed and validated by at least two team members involved in the analysis. The research team met regularly to discuss data extraction, analysis, and synthesis, which were iterative and, in some cases, concurrent. Any discrepancies in the analysis of quantitative or qualitative data were resolved through discussion. This nonlinear process served to improve the rigor and internal validity of the review.

A narrative synthesis was conducted to organize, describe, and interpret the results of the analysis (Pearson, 2008). A deductive analysis was guided by the research questions associated with the use of computerized cognitive assessments among military personnel who have sustained mTBI (Braun & Clarke, 2006). Inductive analysis was conducted from the information in the articles, particularly the recommendations and directions for future research. Further, each of the three most common NCATs and their psychometric properties were considered within the 5 criteria proposed by Randolph et al. (2005): (1) test–retest reliability, (2) the sensitivity of the tests in the clinical issue of interest, (3) the validity of the measure, (4) reliable change scores and scoring algorithms for classifying impairment, and (5) determining the clinical utility of the measure.

3.4 Results

3.4.1 Search Results

The search strategy yielded 372 articles (PRISMA diagram, Figure 1), with a further 2 studies identified through reference searches resulting in a total of 374 articles. Following deduplication, 104 articles were subjected to a title and abstract review, after which 53 were removed. A total of 51 full-text documents were reviewed, with 18 being excluded for several reasons. Studies that were not specific to the military population, such as those focusing on veterans, pediatrics, caregivers, or athletes were excluded. Studies were also excluded if the research team was unable to verify that the neurocognitive assessment tool was computerized, the assessment tool exclusively evaluated reaction time, or if the primary condition evaluated was not mTBI (e.g., spinal cord injury, emotional distress, chronic traumatic encephalopathy, suicidality, or PTSD). The remaining 33 studies were included in the review.

Figure 10: PRISMA Diagram for the Scoping Review

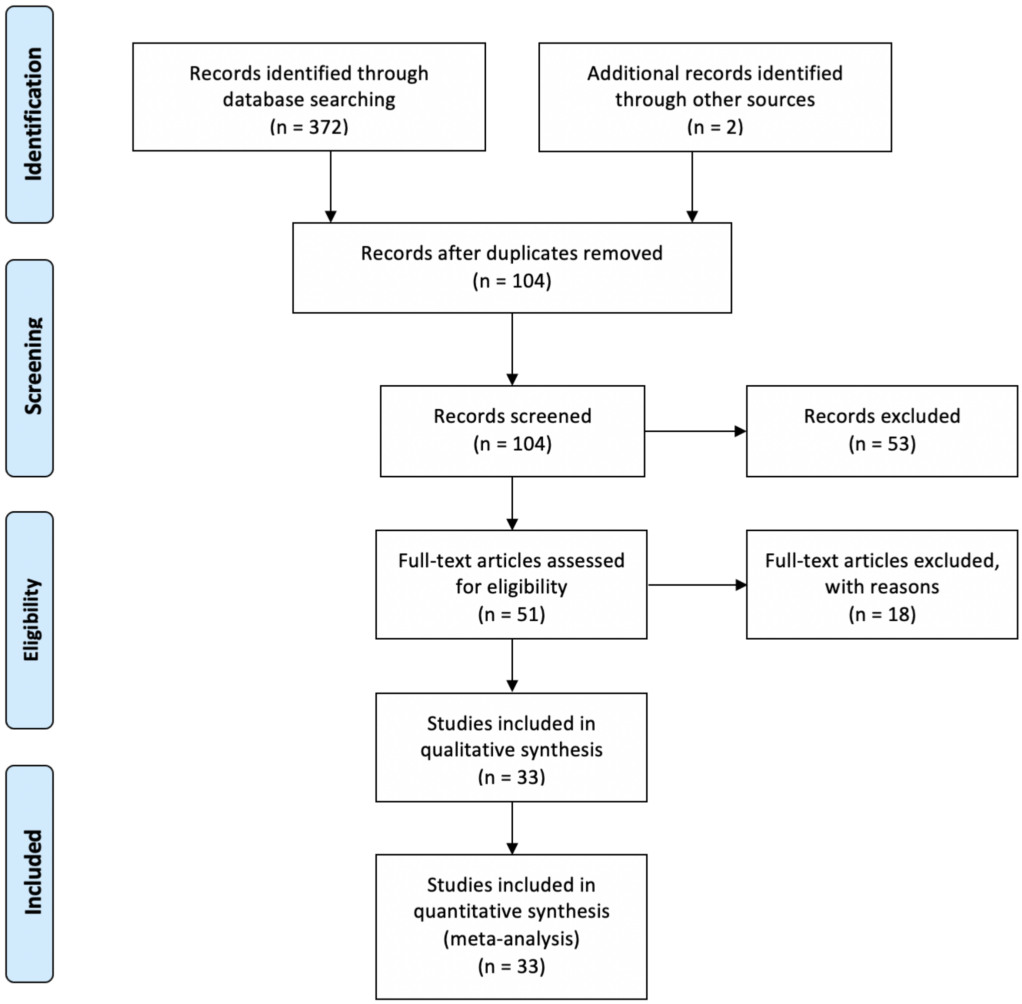

Figure 10: A PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) extension for Scoping Reviews chart of the scoping review study identification, selection, exclusion, and inclusion.

All included studies (n=33) were quantitative and the majority of studies were published in the the US and utilized US military personnel as participants (Appendix 3.8.2, Figure 3.8.2.2 and 3.8.2.3). The total number of participants included in the scoping review among all 33 studies was 36,872 (mean n = 1048.47 (2224.70)) with an overall mean age of 27.31(4.10). The vast majority of participants were healthy (n= 33,521) male (n= 31,587) participants with only 8.8% (n=3351) of all included participants having sustained a mTBI (Appendix 3.8.2, Figure 3.8.2.6).

MTBI was the primary condition of interest; however, 3 studies also included post-traumatic stress as a secondary condition of interest and 2 studies included other non-specified injuries (Appendix 3.8.2, Figure 3.8.2.9). The timeframe of the studies ranged from a single session to 5-year follow-up.

A summary of the outcomes of the 33 included studies is displayed in Table 2. The outcomes vary greatly depending on the research question, NCAT utilized, and study design. The most commonly utilized NCATs among the 33 studies were versions of the ANAM (n = 22; Appendix 3.8.3 Table 3.8.3.1), DANA (n=7; Appendix 3.8.3. Tables 3.8.3.2.1 and 3.8.3.2.2), and ImPACT (n=5; Appendix 3.8.3., Table 3.8.3.4) with a myriad of different secondary measures utilized throughout the studies with the most common including other neuropsychological assessments and screens related to mTBI (Appendix 3.8.2, Figure 3.8.2.10 and 3.8.2.11). The quantitative study design was not explicitly stated in all studies; however, most appeared to include cross-sectional cohort designs (Appendix 3.8.2, Figure 3.8.2.13). A multitude of constructs were measured using a variety of statistical methods throughout the studies, each with a unique purpose often specific to one NCAT (Appendix 3.8.2, Figures 3.8.2.12, 3.8.2.14, and 3.8.2.15).

Table 2: Summary of Included Studies (n=33)

Study	Study Design	Country	Population	Sex (%)	Mean Age (years ((SD))	Race (%)	Condition	Primary Assessment Utilized	Outcome of interest (NCAT) and construct outcome
Adam, Mac Donald, Rivet, Ritter, May, Barefield, et al., (2015)	Quantitative: prospective observational	USA	Military Members	Male (87.8) Female (12.2)	NR	NR	bTBI, healthy	ANAM4-TBI- MIL	PCS and performance on measures of posttraumatic stress disorder, depression, and neurocognitive performance at initial presentation correlate with return-to-duty time. Significantly greater impairment was observed in participants with mTBI vs controls. The largest effect size in ANAM performance decline was in Simple Reaction Time (SRT; $p < 0.001$). Time to return to duty correlated with ANAM SRT decline ($r = 0.49$, $p < 0.0001$).

Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013	Quantitative: validation study	USA	Military Members	Male (93.9) Female (6.1)	28.78 (2.23)	White/Caucasian (51.0) Black/African American (28.6) Pacific Islander (4.1) Other (14.3) Ethnicity (not Hispanic) (81.6)	Healthy	Virtual Reality Stroop Test (VRST)	Results supported convergent and discriminant validity of the VRST. VRST was moderately correlated with the D-KEFS Stroop test and highly with the ANAM Stroop test. The VRST conditions had significant correlations with the ANAM Procedural Reaction Time (PRT) and moderate correlations with the ANAM Code Substitution (CS). VRST conditions not correlated with ANAM Simple Reaction Time (SRT1), Math Processing (MATH), Tower Test or PASAT.
Baker, Moring, Hale, Mintz, Young-McCaughan, Bryant, Broshek, 2018	Quantitative	USA	Military Members	Male (86.0) Female (2.0) Missing (12.0)	NR	White/Caucasian (21.0) Black/African American (1.5) Hispanic/Latino (3.4) American Indian/Alaskan Native (0.5) Asian (0.6) Native Hawaiian/Pacific Islander (0.2) Other (1.1) Unknown (60.1) Missing (11.6)	bTBI, PTSD	ANAM4	ANAM4 significantly correlated with the PTSD Checklist Military version (PCL-M; $p < 0.01$) and Acute Stress Disorder Scale (ASDS; $p < 0.05$). Only the ANAM4 SRT1 ($p < 0.01$) and SRT2 ($p < 0.05$) subtest scores significantly correlated with the Combat Exposure Scale (CES). Strongest correlations among the neuropsychological measures were between the Cognitive Stability Index (CSI) factors and the ANAM4 subtests (0.51 to 0.58; $p < 0.05$).
Betthauser, Brenner, Cole, Scher, Schwab, Ivins, 2018	Quantitative: prospective observational	USA	Military Members	Male (100.0) Female (0.0)	26 (NR)	White/Caucasian (70.1)	mTBI, healthy, PTSD	ANAM4-TBI- MIL	SMs with PTS and/or mTBI performed worse on ANAM4 relative to controls with those with both conditions performing worst. Mean scores of these groups were generally in the average performance range (≥25th percentile) and well above cutoffs that are often deemed clinically meaningful in neuropsychology. Nearly one-third of soldiers who screened negative for both PTS and mTBI had at least 1 score that was unusually low or worse (<10th percentile) and 11.4% had a score that was extremely low (≤2nd percentile).
Brenner, Terrio, Homaifar, Gutierrez, Staves, Harwood, Warden, 2010	Quantitative: exploratory	USA	Military Members	Male (97.8) Female (2.2)	24 (5.6)	White/Caucasian (73.0) Other (27.0)	bTBI, PTSD	PASAT, ANAM4-TBI- MIL	No significant differences between SMs with and without PTSD and/or mTBI were identified. Findings suggested differences in mTBI symptom reporting based on military rank, with fewer higher enlisted individuals reporting sequelae. Significant differences in years of education were noted between those soldiers with mTBI and PTSD and those with mTBI and no PTSD.
Bryan & Hernandez, 2012	Quantitative	USA	Military Members	Male (92.2) Female (7.8)	27.74 (7.07)	White/Caucasian (72.4) Black/African American (13.8) Hispanic/Latino (10.3) Asian, (1.7) Unreported (1.7)	mTBI	ANAM4	SMs with TBI demonstrate greater declines in speed ($\chi 2s > 8.541$, $Ps < .036$, $s > 0.271$) and throughput ($\chi 2s > 11.513$, $Ps < .009$, $s > 0.316$) compared to SMs without TBI. Differences in accuracy were not significant ($2s < 2.286$, $Ps > .131$, $s < 0.175$). A significant proportion of SMs with TBI showed greater declines in speed across all ANAM subtests and greater than minimal declines on throughput SRT, PRT, Code Substitution-Learning (CLS), and spatial memory scores, with no significant differences on Code Substitution-Delayed (CSD) or Mathematical Processing (MATH). ANAM might be reasonably sensitive to TBI regardless of length of time from injury.
Coldren, Russell, Parish, Dretsch, & Kelly, 2012	Quantitative	USA	Military Members	Male (88.4) Female (11.6)	NR	White/Caucasian (65.2) Black/African American (9.7) Hispanic (9.7) Other (12.3)	mTBI, healthy	ANAM4-TBI- MIL	Significant differences in changes from baseline scores for almost all ANAM subtests when mTBI are compared to non-mTBI. At follow-up, none of the ANAM subtests showed statistically significant differences between groups. All components of the ANAM normalize following a concussive injury in the combat setting, within 5 to 10 days. Results demonstrate the ANAM's lack of utility as a

									diagnostic or screening test beyond the first 10 days following a single, uncomplicated mTBI.
Cole, Arrieux, Dennison, & Ivins, 2017	Quantitative	USA	Military Members	Male (79.4) Female (20.6)	34 (NR)	White/Caucasian (66.5) Black/African American: (18.0) Hispanic (10.7) Other: (4.8)	Healthy	ANAM4-TBI- MIL, CNS-VS, CogState, ImPACT	Statistically significant order effects for CogState and CNS-VS and marginal or absent order effects for ANAM4 and ImPACT with no clinically meaningful implications. No significant differences ($p < .05$) for any of the NCATs. CogState appeared to be most impacted by order of administration.
Cole, Arrieux, Ivins, Schwab, & Qashu, 2018	Quantitative: head-to-head	USA	Military Members	Male (83.1) Female (16.9)	34.4 (7.9)	White/Caucasian (65.3) Black/African American (16.7) Hispanic (13.2) Other (5.4) Unknown (0.2)	mTBI, healthy	ANAM4-TBI- MIL, CNS-VS, CogState, ImPACT	37 (0.6%) of the 5,655 correlations calculated between NCATs and neuropsychological tests are large (i.e., $r \geq 0.50$). The majority of correlations are small (i.e., $0.30 > r \geq 0.10$), with no clear patterns suggestive of convergent or discriminant validity between the NCATs and neuropsychological tests.
Cole, Gregory, Arrieux, & Haran, 2018	Quantitative	USA	Military Members	Male (86.0) Female (14.0)	NR	NR	mTBI, healthy	ANAM4-TBI- MIL	Mean and SD for the control group was significantly lower than the ISD (intraindividual standard deviation) mean for the mTBI group. Significant group differences in variability for control ($F(1,13,678) = 848.65$; $p < .0001$) and mTBI ($F(1,13,678) = 1,815.71$; $p < .0001$) groups. Significant interaction of group and time ($F(1,340)= 15.87$; $p = .001$; $\eta 2p = .03$). The main effects for group ($F(1,340) = 23.75$; $p = .001$; $\eta 2p = .07$) and time ($F(1,340) = 15.87$; $p = .001$; $\eta 2p = .05$) were also significant and exceeded the recommended minimum for a practical effect. Significant main effect for time that exceeded the recommended minimum for a practical effect for the mTBI group only ($F(1,340) = 11.49$; $p = .001$; $\eta 2p = 0.10$).
Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis	Quantitative: head-to-head	USA	Military Members	NR	NR	NR	Healthy	ANAM4-TBI- MIL, CNS-VS, CogState, ImPACT	Each NCAT had at least one reliability score (ICC) in the "adequate" range (.70–.79), only ImPACT had one score considered "high" (.80–.89). Overall test–retest reliabilities in four NCATs in a military sample are consistent with reliabilities reported in the literature and are lower than desired for clinical decision-making
Connor, Dain Allred, Cameron, Campbell, Lauro, Houston, et al., 2018	Quantitative: normative	USA	Military Academy	Male (76.1) Female 23.9)	19.4 (1.5)	White/Caucasian (75.0)	Healthy	ImPACT	Significant, but small, sex effects were observed on the ImPACT visual memory task where females performed worse than males ($p < 0.0001$, $p\eta 2 = 0.01$). While statistically significant differences may be observed on baseline tests, the effect sizes for competition and contact levels are very small, indicating that differences are likely not clinically meaningful at baseline.
Dretsch, Parish, Kelly, Coldren, & Russell, 2015	Quantitative	USA	Military Members	Male (84.0) Female (16.0)	26.4 (6.2)	White/Caucasian (62.5) Black/African American (11.3) Hispanic (6.3) Other (20.0)	Healthy	ANAM4-TBI- MIL	All but SRT (ICC = .57) had adequate or greater test-retest reliability (TRR) values (ICC =.72–0.86). ANAM has good temporal stability when the retesting intertrial interval is less than 11 days while in a deployed environment.
Haran, Alphonso, Creason, Campbell, Johnson, Young, & Tsao, 2013	Quantitative: longitudinal	USA	Military Members	Male (100.0) Female (0.0)	22.5 (3.4)	NR	mTBI, healthy	ANAM4-TBI- MIL	Significant differences in the total number of post-concussive clinical symptoms reported on the ANAM4-TBI-MIL from baseline. Declines in cognitive performance from the pre-deployment assessment (i.e., baseline) to the first post-deployment assessment which, except for SRT2, resolved by the second post-deployment assessment. Results suggest that cognitive declines during the chronic post-injury phase for some SMs with self-reported mTBI persist for periods as long as eight weeks post-deployment.

Haran, Alphonso, Creason, Campbell, Johnson, Young, & Tsao, 2016	Quantitative: retrospective analysis	USA	Military Members	Male (100.0) Female (0.0)	22.5 (3.4)	NR	mTBI, healthy	ANAM4-TBI- MIL	Both the mTBI and no mTBI groups performed similarly at baseline (ie, between; mean effect g = 0.05), and both groups had statistically significant decreases in scoring at follow-up testing when compared with their own group baseline (no MTBI groups, respectively. When performance was compared at follow-up, the mTBI group had significantly lower scores than the no mTBI group (ie, between) for 5 of the 7 subtests; however, the mean effect (g = 0.27) for these significant differences was below the recommended minimum practical effect size (RMPE) for group differences, suggesting no meaningful differences between groups.
Haran, Dretsch, & Bleiberg, 2016	Quantitative	USA	Navy Service Members	Male (100.0) Female (0.0)	34 (7.52)	NR	Healthy	DANA Brief	There were no significant practice effects observed for any subtest in any of the environmental conditions. No significant main effect for environmental condition (Λ = 0.996, F(3,10) = 0.14, p = .998, n2p = 0:004), suggesting there were minimal differences in mean throughput scores across the varying simulated environments. There were no significant differences between the simulated environmental conditions suggesting that performance on the DANA Brief is not impacted by thermal stress. No significant differences in performance within each simulated environmental condition associated with repeated administrations.
Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016	Quantitative: observational, retrospective analysis	USA	Military Members	Male (100.0) Female (0.0)	29.1 (5.0)	NR	mTBI, healthy	ANAM4-TBI- MIL	There were no statistical differences, (p > 0.05), between baseline-referenced approach over norm-referenced approach for determining decrements in ANAM performance following mTBI. When the area under the curve for the ROCs were averaged across sub-tests, there were no significant differences between either the norm-referenced (0.65) or baseline-referenced (0.66) approaches (p > 0.05).
Hettich, Whitfield, Kratz, & Frament, 2010	Quantitative: case review	USA	Military Members	Male (100.0) Female (0.0)	NR	NR	mTBI	ImPACT	Intra-test indicators demonstrated valid baseline and post-injury ImPACT assessments. One soldier had a complete resolution of symptoms and his ImPACT results returned to baseline within a couple of days, while the other took almost a week to see a return to baseline across all cognitive domains.
Iverson, Ivins, Karr, Crane, Lange, Cole, & Silverberg, 2020	Quantitative	USA	Military Members	Male (100.0) Female (0.0)	Healthy: 28.2 (6.8) mTBI:26.9 (6.5)	White/Caucasian (64.8) Black/African American (16.4) Hispanic (13.2) Other (5.6)	mTBI, healthy	ANAM4-TBI- MIL	Deficit scores showed larger group differences than the overall test battery mean (OTBM), but similar area under the curve (AUC) values. The deficit scores were highly correlated. All composites differed significantly between participants with and without mTBI (p < .001), with deficit scores showing the largest effect sizes (d = 1.32–1.47). Correlations between the symptom total score and the composite scores were all statistically significant and medium in size in the mTBI group. The correlations between cognitive symptoms and the composite scores were all statistically significant and small to medium in size in the mTBI group.
Ivins, Arrieux, Schwab, Haran, & Cole, 2019	Quantitative: noninferiority study	USA	Military Members	NR*	NR*	NR*	mTBI, healthy	ANAM4-TBI- MIL, CNS-VS, CogState, ImPACT	SMs who performed at the worst level on any given NCAT also had low scores on the other NCATs they completed but not necessarily at an equally low level. These four commercially available NCATs that are similar and used for assessing patients with mTBI are sensitive in varying degrees to the effects of mTBI. The

									association between mTBI and low score level 1 was statistically significant (p > 0.05) for ANAM, CogState, and CNS-VS. The association between mTBI and low score level 1 was not significant for ImPACT (95% CI = 0.91–3.96) however, would have been statistically significant with a larger sample size.
Kelly, Coldren, Parish, Dretsch, & Russell, 2012	Quantitative: validation study	USA	Military Members	Male (100.0) Female (0.0)	NR	White/Caucasian (74.0), Black/African American (6.0), Hispanic (17.0), Other (3.0)	mTBI, healthy	ANAM4-TBI- MIL	SMs with mTBI exhibited poorer performance than controls on all ANAM subtests, with significant differences on SRT, PRT, CS, and matching to sample (p <.001). Discriminant ability scores on SRT and PRT subtests was 71%, which improved to 76% when pre-deployment baseline scores were available. An exploratory clinical decision tool incorporating ANAM scores and symptoms improved discriminant ability to 81%. Results provide initial validation of the ANAM for detecting acute effects of battlefield mTBI.
Lathan, Spira, Bleiberg, Vice, Tsao, 2013	Quantitative, comparison	USA	Military Members	NR	NR	NR	Healthy	DANA Standard, Rapid, Brief	DANA was found to be a reliable instrument and correlated favorably (p < 0.001; 0.85) to other computer-based neurocognitive assessments with the exception of the CSD task. ICC ranged from 0.88 to 0.95 with the exception of CSD (0.54) indicated excellent TRR.
LaValle, Carr, Egnoto, Misistia, Salib, Ramos, & Kamimori, 2019	Quantitative	USA	Military Members	Male (100.0) Female (0.0)	30 (5.5)	NR	Healthy	DANA Rapid	The neurocognitive task appearing most sensitive to identifying performance change is the PRT which may involve a sufficient level of challenge to reliably detect a small, transient cognitive impairment among a healthy undiagnosed population. Statistically significant fixed effects in PRT for Time (Est. = 9.1, 95% CI [0.5, 17.8]), Peak Overpressure (Est. = 11.8, 95% CI [4.5, 19.2]), Service (Est. = 1.6, 95% CI [0.1, 3.2]), and Sleep (Est. = −7.5, 95% CI [-13.6, −1.3]). Greater peak overpressure exposure, less sleep, and more military service years were associated with less PRT performance improvement.
Meyers, 2019	Quantitative:longitudinal	USA	Military Members	Male (90.9) Female (9.1)	28.45 (6.81)	White/Caucasian (70.0) Black/African American (13.1) Hispanic (11.1) Native (1.1) Asian (2.0) Other/mixed (2.4)	Healthy	ANAM4	Results for individuals who were tested 1 year apart showed and at 3 years showed an ICC of .6 for SRT1 and SRT2 and .7 and above for all other scales. When the 5 year between testings data was examined, the ICCs for all scales except the SRT1 and SRT2 (ICC = .596) showed ICCs of .7 and.8 respectively. The ICC scores indicate that the ANAM scales appear stable over longer periods of time up to 5 years.
O'Connor, Dain Allred, Cameron, Campbell, Lauro, Houston, et al., 2018	Quantitative: normative	USA	Military Academy	Male (76.1) Female 23.9)	19.4 (1.5)	White/Caucasian (75.0)	Healthy	ImPACT	Significant, but small, sex effects were observed on the ImPACT visual memory task where females performed worse than males (p < 0.0001, pη2 = 0.01). While statistically significant differences may be observed on baseline tests, the effect sizes for competition and contact levels are very small, indicating that differences are likely not clinically meaningful at baseline.
Robitaille, Jackson, Hébert, Mercier, Bouyer, Fecteau, McFadyen, et al., 2017	Quantitative: proof of concept	Canada	Military Members	NR	Healthy: 30.3 (5.3) mTBI: 30.3 (8.6)	NR	mTBI	VRai	VR was tolerated by both groups. Walking fluidity was significantly different between groups for the 2 hostile block (p < .046) between groups with a condition by group interaction (p < .04). Fluidity was degraded for the control group within the more complex navigational dual tasking involving avatars, and appeared greatest in the dual tasking with the interacting avatar. This navigational

									behaviour was not seen in the mTBI group. Findings show proof of concept for using avatars to expose differences in executive functioning when applying context-specific protocols.
Roebuck-Spencer, Reeves, Bleiberg, Cernich, Schwab, Ivins, Warden, et al., 2008	Quantitative	USA	Military Members	Male (95.5) Female (4.5)	23.17 (4.68)	White/Caucasian (61.1) Black/African American (17.4) Hispanic (14.9) Native (1.2) Asian (1.6) Pacific Islander (1.1) Other (2.7)	Healthy	ANAM3	Performance differences between men and women were minimal on most ANAM subtests, but there was a clear speed/accuracy trade-off, with men favoring speed and women favoring accuracy on the Continuous Performance Test (CPT) subtest. Reaction time increased with age on most subtests, with the exception of MATH. Higher education resulted in significant but minimal performance increases on CDS, Matching to Sample (MSP), and Memory Search (STN) subtests. In contrast, substantial performance differences were seen between education groups on the MATH subtest. These data reveal that it is important to consider demographic factors, particularly age, when using ANAM to draw conclusions about military samples.
Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, 2013	Quantitative: validation study	USA	Military Members, Civilians	Male (93.3) Female (6.7)	29.7 (8.6)	White/Caucasian (58.3) Other (35.0) Unknown (6.7)	BI	ANAM4	ANAM scores differed between groups with simulators scoring the highest. ROC curve analysis indicated excellent discriminability of ANAM scores ≥5 to detect simulators versus controls (AUC =0.858; odds ratio for detecting suboptimal performance =15.6), but resulted in a 27% false-positive rate in the clinical sample. When specificity in the clinical sample was set at 90%, sensitivity decreased (68%), but was consistent with other embedded effort measures. Results support the ANAM as an embedded effort measure and demonstrate the value of sample- specific cut-points in groups with cognitive impairment.
Roebuck-Spencer, Vincent, Schlegel, & Gilliland, 2013	Quantitative	USA	Military Members	Male (91.0) Female (9.0)	26.5 (6.4)	NR	Healthy	ANAM4-TBI- MIL	Overall rates of atypical performance were comparable across these 2 methods. However, these methods were highly discordant in terms of which individuals were classified as atypical. When norm-referenced methods were used, 2.6% of individuals classified as normal actually demonstrated declines from baseline. Further, 65.7% of individuals classified as atypical using norm-referenced scores showed no change from baseline (i.e., potential false-positive findings).
Roebuck-Spencer, Vincent, Twillie, Logan, Lopez, Friedl, Gilliland, et al., 2012	Quantitative	USA	Military Members	Male (91.7) Female (8.3)	26.2 (6.4)	NR	mTBI, healthy	ANAM4-TBI- MIL	All groups performed similarly at pre-deployment. The group reporting TBI with active symptoms performed worst at post-deployment and included the highest percentage of individuals showing significant decline in cognitive performance (30.5%). Of those reporting a TBI injury during deployment, 70% demonstrated no significant change in cognitive performance compared with baseline. 4.3% of controls showed significant decline in ANAM performance, compared to 18.5% of all SMs reporting a deployment-related mTBI. Performance decline in the mTBI group was statistically significant ($X2 = 42.4$, $p < .0001$). Control group showed significant improvement in ANAM performance from pre- to post-deployment ($p<.0001$).
Russo & Lathan, 2015	Qualitative: longitudinal	USA	Military Academy	Male (100.0) Female (0.0)	NR	NR	Healthy	DANA Rapid	The reliability coefficient measured for DANA, for matching subjects across test and retest sessions, is found to be higher than those from the ANAM and ImPACT, and

									comparatively, the DANA exhibits a reliability coefficient within tighter upper and lower bounds than both ANAM and ImPACT. The test–retest reliability of the DANA was found to be consistent between test and retest sessions administered within approx.77 days. The MD (minimum difference) for DANA per subtest is approximately 17% of the mean throughput, suggesting that with a small homogenous population in this time period (about 77days), test-retest reliability consistent for DANA.
Thomas, Brown, Gur, Moore, Patt, Risbrough, & Baker, 2018	Quantitative, longitudinal	USA	Military Members	Male (100.0) Female (0.0)	NR	White/Caucasian (91.0) Black/African American (4.0) American Indian/Alaskan (2.0) Asian (2.0) Hawaiian/Pacific Islander (1.0)	TBI	PFMT, PWMT, VOLT	Signal detection–item response theory (SD-IRT) models adequately fitted recognition memory item data across all modalities. Face and word memory tests had two meaningful dimensions along which individual differences could be characterized. The object learning data appeared to have just one meaningful dimension.
Vincent, Bleiberg, Yan, Ivins, Reeves, Schwab, Warden, et al., 2008	Quantitative: normative	USA	Military Members	Male (91.0) Female (9.0)	26.0 (5.8)	NR	Healthy	ANAM3	Variability of the performance measures between genders differed according to age for all tests (p < 0.01). A general decline in performance with age should be expected on most tests in the ANAM battery.
Wright, Handy, Avcu, Ortiz, Haran, Doria, & Servatius, 2018	Quantitative	USA	Navy Service Members	Male (80.6) Female (19.4)	Healthy: 25.95 (4.48) mTBI: 33.57 (7.93)	NR	Healthy	DANA Standard	No significant difference in overall neurocognitive performance as a function of lifetime mTBI (F(9, 21) = 1.52, p = 0.21). No group differences in throughput for any single neurocognitive assessment contained in the DANA battery (p < 0.05). No group difference in overall neurocognitive performance for any single neurocognitive task (all p < 0.05).

Table 2: bTBI (traumatic brain injury due to blast); ANAM (Automated Neuropsychological Assessment Metrics); DANA (Defense Automated Neurobehavioral Assessment); ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing); CogState (Axon Sports' CogState Sport); CNS-VS (CNS Vital Signs); VRST (Virtual Reality Stroop Test); VRai (Virtual Reality avatar interaction); PASAT (Paced Auditory Serial Addition Test); PFMT (Penn Face Memory Test); PWMT (Penn Word Memory Test); VOLT (Visual Object Learning Test); D-KEFS (Delis-Kaplan Executive Function System); SRT (single reaction time); PRT (procedural reaction time); CS (Code Substitution); MATH (Math Processing); PCL-M (PTSD Checklist Military version); ASDS (Acute Stress Disorder Scale). CES (Combat Exposure Scale); CSI (Cognitive Stability Index); CSL (Code Substitution-Learning); CSD Code Substitution-Delayed); TRR (test retest reliability); ICC (intraclass correlation coefficient); RMPE (recommended minimum practical effect size); ROC (receiver operator curve); OTBM (overall test battery mean); AUC (area under the curve); VR (virtual reality); CPT (Continuous Performance Test); MSP (matching to sample); STN (memory search); SD-IRT (signal detection–item response theory); GNG (Go No/Go)

3.4.2 Thematic Analysis and Narrative Synthesis

Thematic analysis and narrative synthesis revealed a number of topics related to the facilitators and barriers of NCATs utilization among military populations. The 3 main themes that emerged through the studies included, (1) comparing "apples to oranges," (2), reliability issues, and; (3) issues with validity. The narrative synthesis was framed in relation to the aforementioned criteria suggested by Randolph, McCrea, Barr, & Macciocchi (2005).

3.4.2.1 Comparing "Apples to Oranges"

A number of challenges around the approaches and comparisons used to establish the psychometric properties of current NCATs was discussed throughout the studies. Multiple studies noted that the comparisons made in research when assessing NCATs have important implications on the results and conclusions garnered from the current literature. These can have the potential to adversely affect reliability, validity, sensitivity, detection of reliable change, and overall clinical utility.

Since a "gold standard" NCAT does not yet exist, comparisons between NCATs and traditional neuropsychological assessments are often used to determine how well tests relate to similar cognitive measures (convergent validity) and differ from dissimilar cognitive tests (discriminant validity; Cole, Arrieux, Ivins, Schwab, & Qashu, 2018). Simply adapting traditional neuropsychological tests to a computer platform fundamentally changes the test, rendering direct comparisons to the non-computerized version inappropriate (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018; Bauer, Iverson, Cernich, Binder, & Naugle, 2012). Some of the included studies aimed to address possible correlations with other traditional neuropsychological assessments as well as other secondary outcome measures related to a range of constructs (Appendix 3.8.2 Figures 3.8.2.11 and 3.8.2.12).

Similarly, to the issues identified when comparing NCATs to traditional neuropsychological assessments, comparing different NCATs among each other was also problematic when trying to establish validity. Although these assessments may aim to measure similar domains of cognition or constructs, often tests or categories of the same name measure calculate scores for that construct differently (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018). One NCAT may measure a cognitive domain or construct with an individual subtest whereas another NCAT may use an index score based on a combination of multiple subtests (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018). NCATs that utilize normative data, whether specific to military or general populations, have their own data set from which they generate standardized scores (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018). The variation among each NCAT makes it challenging for researchers to perform head-to-head comparisons or develop a hierarchy of these assessments.

The included studies compared the participants' results to their baseline data, normative data, or both. Among the studies in this review, there was conflicting evidence and discussion regarding whether baseline or normative data comparisons were the most effective for establishing change in performance among military personnel who had sustained mTBI. Two papers specifically discussed this issue at length (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016; Roebuck-Spencer, Vincent, Schlegel, & Gilliland, 2013). This will be discussed further in the following theme and subsequent discussion.

Finally, even the comparison of those who have sustained mTBI to healthy control groups can affect the results of studies related to NCATs. If a portion of the mTBI group is asymptomatic, clinically meaningful differences between controls and those with symptoms can be washed out leading to limited effect sizes (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018). It was noted that very few studies in this scoping review addressed within group differences for the cohort with mTBI.

3.4.2.2 Test–retest reliability

Four studies specifically addressed test-retest reliability for various NCATs among military populations. Dretsch, Parish, Kelly, Coldren, & Russell, (2015) reported that, with the exception of the Simple Reaction Time (SRT) test, the ANAM had adequate or greater test-retest reliability values (ICC 0.72–0.86) in the deployed environment, suggesting good temporal stability when the retesting interval is less than 11 days. Meyers (2019) also addressed the temporal stability of the ANAM in a longitudinal study with follow-up sessions at 1, 3, and 5 years. In this study, the ICCs for all scales except the SRT1 and SRT2 showed ICCs of 0.7 and 0.8 (Meyers, 2019). Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, (2013) found that of the ANAM, CogStat, ImPACT, and CNS-VS, each NCAT had at least one reliability score (ICC) in the "adequate" range (0.70–0.79) and that only the ImPACT had a score considered "high" (0.80–0.89). Using the data from the previously mentioned study, Russo and Lathan (2015) compared the DANA to the ANAM, CogStat, ImPACT, and CNS-VS. They found the reliability coefficient measured for DANA, for matching subjects across test and retest sessions, was higher than those from the ANAM and ImPACT (Russo & Lathan, 2015). These four studies were conflicted in their conclusions on whether test-retest reliability was maintained over varying lengths of time.

Other types of reliability, such as internal consistency, were challenging to establish or not of an adequate quality. Differences in the characteristics of test batteries, the design of test–retest studies, and insufficiently explained and non-standardized methods of analysis have made defining the reliability of NCATs challenging (Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013; Russo & Lathan, 2015). Multiple studies reviewed indicated the reliability coefficients of NCATs were below what would be considered clinically acceptable for a clinical assessment (Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013; Randolph, McCrea, Barr, & Macciocchi, 2005; Resch, McCrea, Cullum, 2013).

3.4.2.3 Sensitivity of the tests in the clinical issue of interest

One study specifically addressed the sensitivity of the DANA to small changes in neurofunctioning related to sub-concussive blast pressure. LaValle, Carr, Egnoto, Misistia, Salib, Ramos, & Kamimori, (2019) reported procedural reaction time (PRT) construct may have sufficient sensitivity to reliably detect a small, transient cognitive impairment among a healthy undiagnosed population.

3.4.2.4 Validity of the measure

Multiple studies included in the scoping literature review commented on the issues with validity among NCATs both within military and non-military populations who have sustained mTBI. Studies discussed criterion, convergent, discriminant, and performance validity. Factors that can affect the construct validity of NCATs and traditional neuropsychological assessment include mental fatigue, physical environment, participant effort, practice effects, and the Monte Carlo effect among others that were discussed in the manuscripts (Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, 2013; Dretsch, Parish, Kelly, Coldren, & Russell, 2015; Ivins, Arrieux, Schwab, Haran, & Cole, 2019). Test-retest reliability can affect validity and has been repeatedly found to be moderate at best and generally lower than desired for NCATs (Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013). Without an established, "gold standard," criterion validity cannot be established, which leads to the aforementioned issues caused by comparing NCATs to other NCATs, or traditional neuropsychological assessments (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018).

The included manuscripts discussed some of the threats to validity that arise with the variability of normative data sets which NCAT scores are compared. For example, some NCATs, such as the ANAM, have normative data specific to the military population while others, such as the ImPACT are compiled from the general population. Many of the studies included in this review discussed the problems that can occur when comparing military and civilian populations (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016; Roebuck-Spencer, Vincent, Schlegel,

& Gilliland, 2013). As previously discussed, military personnel experience mental health disorders, sleep disorders, chronic pain, substance abuse disorders, and other conditions that can adversely affect cognition and neuropsychological functioning. Observed decreases in neurocognitive performance in both military personnel with and without mTBI suggest that the environmental stressors of deployment may affect post deployment neurocognitive performance (Haran et al., 2016). Haran, Drestch, & Bleiberg (2016) also noted that cognitive performance also correlates and changes with the deployment cycle as military members are more likely to have mental health challenges at specific times.

Recent evidence suggests that PCS are not specific to mTBI and that symptoms following deployment are better accounted for by mental health diagnosis, such as PTSD, than by history of mTBI (Garber, Rusu, & Zamorski, 2014; Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013; Rona et al., 2012). As it is not uncommon for healthy service members to have low scores on a cognitive test battery, it is beneficial to understand how many low scores and what cut-off scores are necessary to be clinically meaningful for patients who have sustained mTBI or other conditions (Brenner, Terrio, Homaifar, Gutierrez, Staves, Harwood, Warden, et al. 2010). Brenner et al. (2010) found that military members who screened negative for both post-traumatic stress and mTBI had at least one low score on the ANAM shortly after returning from deployment. Another issue with normative data is the lack of consistency in demographic factors as some are based on age and gender whereas others are based on one or the other (Ivins, Arrieux, Schwab, Haran, & Cole, 2019).

Many of the reviewed studies discussed the question of ecological validity among NCATs. Both NCAT and neuropsychological assessments are traditionally administered in controlled clinical or research settings and aim to obtain the best possible performance of the patient (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013). It is unknown if, and how well, this performance will transfer to a combat or deployed environment. It is also important to know how well executive functions measured during these assessments, such as decision-making, translate to an individual's performance in stressful situations. In the military context, where premature return to duty can have dire consequences, valid neuropsychological assessments that are specifically designed for use with military populations would be particularly useful (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013). The incorporation of virtual reality within NCATs may be a novel component to explore further (Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013; Robitaille et al., 2017). NCATs with increased ecological validity would better assess operational performance and assist healthcare professionals in predicting risk for PCS as well as facilitating rehabilitation, recovery, and return to duty decision post mTBI (Adam, MacDonald, Rivet, et al. 2015; Bryan & Hernandez 2012).

Four studies specifically addressed convergent, discriminant, and performance validity for various NCATs including the Virtual Reality Stroop Test (VRST; Armstrong, Reger, Edwards, Rizzo, Courtney, Parsons, 2013), ANAM (Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, 2013), CNS-Vital Signs (CNS-VS), ImPACT, CogStat (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018), and single item measures (Thomas, Brown, Gurd, Moored, Patt, Risbrougha, & Bakera, 2018). Armstrong, Reger, Edwards, Rizzo, Courtney, & Parsons (2013) found the VRST correlated with Stroop tests from other NCATs and traditional neuropsychological tests. It was also reported that the VRST conditions correlated significantly with the ANAM PRT and moderately with the ANAM Code Substitution (CS; Armstrong, Reger, Edwards, Rizzo, Courtney, & Parsons, 2013). Thomas, Brown, Gurd, Moored, Patt, Risbrough, & Baker (2018) utilized signal detection–item response theory models to provide initial validation of the Penn Face Memory, Test Penn Word Memory, Test Visual Object Learning Test among US Marines who had experienced mTBI. Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, (2013) addressed an embedded performance validity measure for the ANAM which had moderate success. This demonstrated the potential value of performance validity measures and sample specific cut-points in groups with cognitive impairment. The authors recommended higher cut-points for those expected to have more severe cognitive impairment (Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, 2013). Cole, Arrieux, Ivins, Schwab, & Qashu (2018) found no clear patterns suggestive of convergent or discriminant validity between the 4 aforementioned NCATs.

3.4.2.5 Reliable change scores and scoring algorithms for classifying impairment

Only one study specifically addressed reliable change estimates for the ANAM4-TBI-MIL (Haran, Alphonso, Creason, Campbell, Johnson, Young, & Tsao, 2016). The authors suggested that reliable change cut-off scores and the base rates of meaningful change, can be used to assist with the identification of post-deployment cognitive issues but should be interpreted with caution.

3.4.2.5 Determining the clinical utility of the measure

Very few of the included studies addressed the clinical utility of the NCAT. Three studies addressed the utilization of NCATs in varying environments concluding that the DANA and ANAM did demonstrate utility in battlefield and deployment settings (Haran, Dretsch, & Bleiberg, 2016; Kelly, Coldren, Parish, Dretsch, & Russell, 2012). A single study addressed feasibility of using virtual reality for cognitive assessment (Robitaille et al. 2017). The studies generally did not address issues of clinical utility such as acceptability, feasibility, security, appropriateness, practicability, accessibility, or usability from the perspectives of patients or healthcare professionals (Smart, 2006).

3.5 Discussion

The purpose of this scoping literature review was to systematically explore the evidence regarding the use of NCATs among military personnel who have sustained mTBI, evaluate the psychometric properties of the most commonly utilized NCATs for this population, and synthesize the data around clinical recommendations for use, knowledge gaps, and future research directions. In total, 33 studies were included in this literature review covering a range of constructs and topics related to NCATs. Three NCATs, the ANAM, ImPACT, and DANA, were the most commonly analyzed within the 33 studies.

This scoping review was specific to military personnel who had sustained mTBI. There exists a multitude of other published literature regarding NCATs within the civilian population that address the psychometric properties, such as reliability, validity, and sensitivity, and clinical utility, as it pertains to mTBI in the general civilian population. While this evidence was reviewed at length and used to lay the foundation of this manuscript, it did not meet the inclusion criteria to be included among the final 33 selected articles.

The 5 criteria proposed by Randolph, McCrea, Barr, & Macciocchi (2005) acted as a guide for evaluating the psychometric properties of the NCATs. Even with the paucity of information specific to military personnel with mTBI, these criteria allowed consideration and discussion of the studies included in the scoping review and paves a way for making recommendations for future research on this topic.

For the first criterion of test-retest reliability, preliminary evidence demonstrates good test-retest reliability for the ImPACT and DANA among healthy military personnel and those with mTBI, and good to excellent test-retest reliability for the ANAM (Dretsch, Parish, Kelly, Coldren, & Russell, 2015; Meyers, 2019; Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013; Russo and Lathan, 2015; Vincent, Roebuck-Spencer, Fuenzalida, & Gilliland, 2018). This finding is consistent with reliabilities reported in the literature regarding mTBI and sport-related mTBI, and are lower than desired for clinical decision-making (Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013). Although studies varied in test methods and time between testing, ICC were promising for most of the constructs within these tests (Dretsch, Parish, Kelly, Coldren, & Russell, 2015; Meyers, 2019; Cole, Arrieux, Schwab, Ivins, Qashu, & Lewis, 2013; Russo and Lathan, 2015). It must be noted that the time between testing sessions varied, especially among the ANAM, and the available evidence conflicts with regard to how long temporal stability is maintained (Dretsch, Parish, Kelly, Coldren, & Russell, 2015; Meyers, 2019; Vincent, Roebuck-Spencer, Fuenzalida, & Gilliland, 2018). Additional studies addressing test-retest reliability with a standardized amount of time between tests, and studies with larger sample sizes (especially for the DANA, ImPACT, CNS-VS, and CogSport) would assist healthcare professionals with clinical decision making regarding their choice of NCAT.

The second criterion is the sensitivity of the tests in the clinical issue of interest. This was addressed by one study in relation to the DANA, which showed favourable results among a group of healthy male military members (n=202; LaValle, Carr, Egnoto, Misistia, Salib, Ramos, & Kamimori, 2019). Studies addressing sensitivity with NCATs among general populations have demonstrated good sensitivity of the ANAM, suggesting that it may have potential for diagnostic utility with acute mTBI (Arrieux, Cole, & Ahrens, 2017). Two domains of the ImPACT that accurately classified individuals as concussed or not concussed with a high sensitivity and specificity were memory and speed (Schatz & Maerlender, 2013). Despite this, there has not been universal evidence that the ImPACT adequately differentiates between healthy controls and individuals who have recently sustained mTBI (Arrieux, Cole, & Ahrens, 2017). Overall, the sensitivity of NCATs has not been demonstrated in the literature to have enough diagnostic accuracy for mTBI or other conditions that affect cognition (Arrieux, Cole, & Ahrens, 2017).

Validity is the most important aspect of test construction and must be considered when evaluating the clinical utility of a clinical assessment (Arrieux, Cole & Ahrens, 2017). Due to its importance, establishing the validity of a measure is the third criterion considered by Randolph, McCrea, Barr, & Macciocchi (2005). For the ANAM, studies among military and general populations generally demonstrate some construct validity demonstrating that this NCAT is testing the constructs it was designed to test, although a review by Arrieux, Cole, & Ahrens, (2017) stated this was “questionable at best”. A study by Alsalaheen, Stockdale, Pechumer, Broglio, (2016) using data from the general population, concluded that there is strong evidence for convergent validity of ImPACT, but weak or inconclusive evidence for discriminant validity, criterion validity, or diagnostic accuracy and utility. That is, there is evidence that NCATs measure similar cognitive constructs as traditional neuropsychological tests. Some evidence exists suggesting specific components of each NCAT can distinguish between individuals with acute concussion and healthy individuals, or between individuals with and without mTBI symptoms (Arrieux, Cole, & Ahrens, 2017). Overall, literature to date is yet to provide definitive evidence in support of the convergent, discriminant, criterion, or internal validity of any of the NCATs included in this study (Arrieux, Cole, & Ahrens, 2017). It was also noted that predictive validity of future symptoms has not been established for any of the NCATs, which is unhelpful for healthcare professionals assisting patients with recovery from mTBI (Arrieux, Cole & Ahrens, 2017).

Criterion 4 includes establishing reliable change scores and scoring algorithms for classifying impairment. One of the 33 studies addressed reliable change scores for the ANAM, however, a reliable change index was established in 2018 for the ANAM utilizing norms from the general population (Haran et al., 2016; Vincent, Roebuck-Spencer, Fuenzalida, & Gilliland, 2018). Reliable change criteria is lacking for many NCATs and should be addressed in future research with military and civilian populations to enable healthcare professionals to recognize meaningful changes in performance.

The fifth criterion, clinical utility, reveals the most significant knowledge gaps pertinent to patients, healthcare professionals, and healthcare organizations. Although psychometric properties of any clinical outcome measure or assessment are important to establish among the population and condition in question, so too is discussion of feasibility, accessibility, acceptability, usability, appropriateness, specificity, and other factors (Smart, 2006). The results of the studies included in the scoping review are generally psychometric and research-focused. This may be due to the fact that, for the vast majority (n=30) of the conclusions and discussions within the 33 articles reviewed, knowledge gaps and recommendations for future research are easy to identify. However, facilitators and barriers to utilization of NCATs as well as clinical recommendations are generally absent from the manuscripts.

There were a number of other issues observed regarding the collective studies included in this scoping review. Firstly, the classification or diagnosis of mTBI was quite variable across all studies. Some studies relied on self-report to categorize participants into either a mTBI group or a healthy group which is problematic for a few reasons. It is known that mTBI and other injuries are widely underreported among military personnel. Participants may under-report mTBI, whether intentionally or because they do not possess the health literacy to determine that they have experienced a possible mTBI. It is also possible some participants simply did not remember the event, or pushed through it in a combat situation without recognizing it as a mTBI. Some studies either classified mTBI as sustaining loss of consciousness or utilized symptom reporting to determine the incidence of mTBI. Other studies used outcome measures with a set threshold to determine if participants would be in the mTBI or healthy group. Many of these outcome measures, which largely depend on self-report of somatic symptoms, do not have clear cut-offs to suspect mTBI and do not have diagnostic utility. Still, further studies reviewed medical records and relied on diagnosis of mTBI issued by a healthcare professional. The variability in methods and inclusion criteria for the mTBI group could affect validity and potentially facilitate the inclusion of those with mTBI in the healthy group which increases the chances of type 2 error.

There was also variation throughout the studies regarding how and if both the mTBI and healthy groups were screened for other conditions, such as depression, PTSD, fatigue, and pain, that are known to adversely affect cognitive performance and could act as confounding variables (Coffman, Resnick, Drane, Lathan, 2018). Numerous studies have demonstrated that severity of PTSD was negatively correlated with performance on multiple neuropsychological test batteries, including the DANA and ANAM, among military and civilian populations (Spira, Lathan, Bleiber, & Tsao, 2014; Coffman, Resnick, Drane & Lathan, 2017). Some studies included in the scoping review explicitly stated that if a participant was enrolled in the military organization, it was assumed that they were a healthy individual which is an inaccurate assumption (Coffman, Resnick, Drane & Lathan, 2017). In the study by Brenner et al. (2010), participants with mTBI symptoms were screened for other conditions and were found to be significantly more likely to have a mental health diagnosis than those without mTBI symptoms. Given the evidence that PCS are not specific to mTBI and that symptoms following deployment are better accounted for by mental health diagnoses rather than by mTBI, researchers must consider the consequences of neurobehavioral disorders that likely affect military members at a rate greater than that of the general population (Spira, Lathan, Bleiber, & Tsao, 2014; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Coffman, Resnick, Drane, Lathan, 2018). The implications of the increased occurrence of conditions that adversely affect cognitive function among military populations may also change how normative data is used and interpreted for NCATs in research and clinical practice.

The baseline-referenced comparison approach has minimal supportive evidence from clinical trials, but is the standard approach in sports mTBI management and is favoured by the US military particularly with the ANAM (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016; Department of Defense Instruction, 2013). Baseline referencing is thought to improve sensitivity and specificity of NCAT scores as it controls for some intra-individual factors (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016). This approach is quite resource intensive and has multiple administrative and logistical barriers for many healthcare, athletic, and military organizations (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016). Normative referenced approaches are less resource intensive, and require establishment of a criterion-referenced standard that test results are compared to. Some NCATs utilize normative data compiled from the general civilian population, such as the ImPACT, while others, such as the ANAM, have multiple sets of norms, one of which is specific to the US military population (ImPACT

Applications, 2011; Reeves et al., 2006; Vincent et al., 2008; Reeves, Winter, Bleiberg, & Kane, 2007).

When comparing results from a military cohort on the ANAM to both the normative and baseline data, no statistical differences, ($p > 0.05$), between baseline-referenced approach over norm-referenced approach for determining decrements in ANAM performance following mTBI were observed (Haran, Dretsch, Slaboda, Johnson, Adam, & Tsao, 2016). In another study, no significant differences were found between the two approaches with the ANAM; however, both approaches were noted to be highly inconsistent in identifying military members who were found to have decreases in cognitive performances providing both false positives and negatives. (Roebuck-Spencer, Vincent, Schlegel, & Gilliland, 2013). These findings suggest there is no clear advantage of using the baseline referenced approach over a norm-referenced approach.

In a 2017 paper, Coffman, Resnick, Drane & Lathan considered the task of establishing a normative dataset for the DANA in the context of the active-duty military population, focusing on which population-specific features should be accounted for in the process of defining a normative dataset. This dataset would consider the effect of conditions that adversely affect scores of cognitive performance on NCATs. Extending beyond the issue of what population should be used to define normative neuropsychological data among active-duty military personnel, this study also recognized the challenge of identifying which features of a population to measure and control for so as to ensure that a normative data set truly represents the performance of normally functioning individuals.

Aside from the aforementioned occurrences of certain comorbidities within the military population, normative data based on a general adult civilian population tend to include wider age ranges from 18 to 85. The military population is much younger, often within the age of 18 to 60.

Within this scoping review, the average age of the participants included was 27.31(SD=4.10); much younger than the normative age included in the general population norms. Studies addressing norm-based and baseline comparisons within military populations demonstrate variable results and raise more questions on what is best-practice for clinical interpretation of cognitive performance scores on NCATs. This requires future consideration and research with military populations.

3.5.2 Recommendations

A number of key recommendations were isolated from the studies that could be helpful for healthcare professionals. Most prominently, NCATs should be used cautiously and only as one source of information from among many other types of clinical tools. It is not advisable that NCATs be used as a definitive or standalone diagnostic tool (Ivins, Arrieux, Schwab, Haran, & Cole, 2019). Cole, Arrieux, Ivins, Schwab, & Qashu, (2018) recommended that healthcare professionals should use the test they feel best fits their needs and targeted population for screening and follow-up assessments. Studies addressing how different demographic factors also noted that healthcare professionals should expect a decline in cognitive performance as age increases on the ImPACT and ANAM (Roebuck-Spencer et al., 2008, Vincent et al., 2008; O'Connor et al, 2018). As well, the level of education of participants may have an effect on cognitive performance scores (Roebuck-Spencer et al., 2008, Vincent et al., 2008) As the evidence-based literature on NCATs evolves, it is important that healthcare professionals remain aware of forthcoming recommendations and healthcare organizations and researchers assist with concise and accessible knowledge translation of this information to promptly facilitate improvements in clinical practice.

3.5.2 Future Research

Through the process of this scoping review, a number of key recommendations for future research were formulated. First, it is apparent that more research is needed to better establish the psychometric properties of NCATs among military and civilian populations from a global perspective. As well, studies conducted in countries or military organizations outside of the US are needed to assess constructs related to clinical utility within their specific contexts and populations. Research on the utilization of NCATs within different deployment environments would also be beneficial. Further, longitudinal studies that address temporal stability/test-retest reliability over time with different NCATS would also be an asset. Studies that address the psychometric properties and clinical utility of NCATs with other conditions known to adversely affect cognitive functioning among military populations, such as depression, PTSD, sleep deprivation, chronic pain, and others, would be particularly beneficial. This would allow clinicians to better assess cognitive performance and make clinical decisions that could influence the function, productivity, and safety of military members, their units, and those they interact with through their high-stakes occupations. This would also assist clinicians in designing rehabilitation plans that target specific domains of cognition, leveraging cognitive strengths and targeting areas of reduced performance.

Studies with a higher presence of military personnel who have sustained mTBI, or other conditions that affect cognition, would be an asset especially for clarifying recovery trajectories and possibly return to duty decisions (Bryan & Hernandez, 2012). These studies would benefit from consistency in the way mTBI and other conditions are defined and/or diagnosed. As well, if studies are specific to a condition, it is important that other injuries or illnesses that may act as confounding variables are tested and controlled for.

Further research is also needed to better determine if using NCATs for baseline testing is indicated, or if normative-based comparisons are valid for use in a clinical setting. Further, it would be beneficial for standardized NCAT norms to be established among military populations, that represent not only healthy individuals but also those with mTBI and other conditions that affect cognition.

Finally, studies that further address clinical utility, including the feasibility, accessibility, acceptability, usability, appropriateness, specificity, and other pragmatic factors, are needed to contextualize the use of NCATs and assist healthcare professionals with clinical decision making around which NCAT to utilize in practice, what rehabilitation is indicated, and how NCATs may guide with return to duty decisions. Evidence-based literature and best practice guidelines that discuss facilitators, barriers, and recommendations for NCATs and digital health technologies would be an asset to support the healthcare professional working with military personnel experiencing cognitive dysfunction.

3.5.3 Strengths and Limitations

There are a number of notable strengths within this scoping review study. This scoping review was conducted following a planned *a priori* procedure with attention to ensuring quality control and minimizing bias. The detailed search strategy was extensive, including 7 databases, and the inclusion and exclusion criteria were determined before study onset and adhered to throughout. Appropriate calibration and pilot testing, use of at least two independent reviewers for all stages of the process, and group discussion of conflicts improved the quality of this scoping review.

Several limitations of this scoping review also warrant discussion. First, although the review process was calculated and rigorous, it is possible that relevant studies related to military personnel with mTBI and NCATs were overlooked. Second, it is noted that other studies specific to civilian populations exist that were not included in this scoping review and which may include important information. Third, with the rapid rate of research and publishing on this topic, it is plausible that additional research has been published before the release of this scoping review. Finally, there are limits of aggregate data and specific nuanced details may have become generalized during the synthesis process.

3.6 Conclusion

Cognitive functioning is imperative to the day-to-day activities of military personnel in their work, self-care, and leisure activities. Military members must be able to make decisions in precarious and ambiguous situations where risk to self and others is high, and must possess an adequate level of cognitive functioning to communicate, utilize weapons and technological devices, and perform other military duties without error. Assessing cognitive functioning is part of a multidisciplinary best practice protocol for management and treatment of mTBI (McCroy et al., 2017; Arrieux, Cole, & Ahrens, 2017; Radomski, Goo-Yoshino, Hammond, et al., 2015). NCATs are one such tool that can be utilized to assist healthcare professionals with treatment plans and advise on readiness to return to activity.

The results of this study indicated that the published literature regarding NCAT utilization among military personnel who have sustained mTBI is quite heterogeneous in study design, construct being measured, and outcome goals. Based on the five Randolph Criteria, the psychometric properties of the most commonly evaluated NCATs among this population have yet to demonstrate adequate validity, reliability, sensitivity, and, especially, clinical utility among military personnel with mTBI. As well, NCATs do not have the established diagnostic utility to identify which military members have sustained mTBI and which have not. Additional research is needed in order to further validate NCATs within military populations especially those outside of the US and those who experience other conditions known to adversely affect cognitive processing. Further study of psychometric properties, clinical utility, and the utility of baseline and normative testing for NCATs is needed to assist healthcare professionals with improving clinical decision making and services for military personnel experiencing cognitive dysfunction.

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3.8. Appendices

Appendix 3.8.1. Detailed Search Strategy

Databases

1. Medline Ovid
2. Embase Ovid
3. Psycinfo Ovid
4. CINAHL Ebsco
5. Psyc articles Ebsco
6. Scopus
7. Military and Government Collection Ebsco

Search Terms

Military
(Military OR armed-force* OR armed-service* OR servicewomen OR servicemen OR air-personnel OR defense-force* or defence-force* OR service-personnel OR army OR navy OR air-force OR marine* OR sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel).mp.

Computerized Cognitive assessment
((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*)).mp.
(impact and (cogniti* or neuro*)).mp.
(Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA).mp.

Mild traumatic brain injury
1. brain injuries, diffuse/ or brain injuries, traumatic/ or brain concussion/ or brain contusion/ or chronic traumatic encephalopathy/
2. (concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) adj5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*).mp.

Medline
Date searched: April 15, 2020
Results: 56

1. (Military or armed-force* or armed-service* or servicewomen or servicemen or air-personnel or defense-force* or defence-force* or service-personnel or army or navy or air-force or marine* or sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel).mp.
2. ((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*)).mp.
3. (Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA).mp.
4. 2 or 4
5. brain injuries, diffuse/ or brain injuries, traumatic/ or brain concussion/ or brain contusion/ or chronic traumatic encephalopathy/
6. (concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) adj5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*).mp.
7. 6 or 7
8. 1 and 5 and 8

Psycinfo
Date searched: April 15, 2020
Results: 56

1. (Military or armed-force* or armed-service* or servicewomen or servicemen or air-personnel or defense-force* or defence-force* or service-personnel or army or navy or air-force or marine* or sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel).mp.
2. ((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*)).mp.
3. (Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA).mp.
4. (exp Cognitive Assessment/ or neuropsychological assessment/) and exp Computerized Assessment/
5. 2 or 3 or 4
6. exp brain injuries/
7. exp head injuries/
8. brain damage/
9. (concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) adj5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*).mp.
10. 6 or 7 or 8 or 9
11. 1 and 5 and 10

CINAHL Plus with Full Text
Date searched: April 15, 2020
Results: 59

1. (Military or armed-force* or armed-service* or servicewomen or servicemen or air-personnel or defense-force* or defence-force* or service-personnel or army or navy or air-force or marine* or sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel)
2. ((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*))) OR ((Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA))
3. (MH “Brain Damage, Chronic”) OR (MH “Brain Injuryies+”) OR (MH “Head Injuries”)) OR((concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) N5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*))
4. S1 AND S3 AND S3

Embase
Date searched: April 21, 2020
Results: 69

1. (Military or armed-force* or armed-service* or servicewomen or servicemen or air-personnel or defense-force* or defence-force* or service-personnel or army or navy or air-force or marine* or sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel).mp.
2. ((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*)).mp.
3. (Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA).mp.
4. 2 or 3
5. Exp diffuse brain injury/ or traumatic brain injury/ or exp concussion/ or brain contusion/ or chronic traumatic encephalopathy/
6. (concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) adj5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*).mp.
7. 5 or 6
8. 1 and 4 and 7

Scopus
Date searched: April 21, 2020
Results: 57

(TITLE-ABS-KEY (military OR armed-force* OR armed-service* OR servicewomen OR servicemen OR air-personnel OR defense-force* OR defence-force* OR service-personnel OR army OR navy OR air-force OR marine* OR sailor* OR soldier* OR infantryman OR civil-defense OR troops OR ranger* OR "medic" OR coast-guard OR submariner* OR active-duty OR enlisted-personnel OR reserve-personnel)) AND (TITLE-ABS-KEY ((computer* OR online OR internet OR web-based OR ipad OR tablet OR tablets OR smartphone* OR cellphone* OR electronic) W/10 (cogniti* OR neuropsych* OR neurofunction* OR neurobehavio*) W/4 (assess* OR screen* OR measur* OR test*)) OR TITLE-ABS-KEY (automated-neuropsychological-assessment-measure OR anam OR brainfx OR brain-fx OR immediate-post-concussion-assessment-and-cognitive-testing OR defense-automated-neurobehavioral-assessment OR dana)) AND (TITLE-ABS-KEY (concuss* OR postconcuss* OR commotio-cerebri OR coup-contrecoup OR cranio-cerebral-trauma OR ((brain OR cerebral) W/5 contusion) OR closed-head-injur* OR mtbi OR tbi OR brain-damage OR brain-injur* OR head-injur*))

Military and Government Collection
Date searched: April 21, 2020
Results: 36

military OR armed-force* OR armed-service* OR servicewomen OR servicemen OR air-personnel OR defense-force* OR defence-force* OR service-personnel OR army OR navy OR air-force OR marine* OR sailor* OR soldier* OR infantryman OR civil-defense OR troops OR ranger* OR "medic" OR coast-guard OR submariner* OR active-duty OR enlisted-personnel OR reserve-personnel
AND
((computer* OR online OR internet OR web-based OR ipad OR tablet OR tablets OR smartphone* OR cellphone* OR electronic) N10 (cogniti* OR neuropsych* OR neurofunction* OR neurobehavio*) N4 (assess* OR screen* OR measur* OR test*)) OR automated-neuropsychological-assessment-measure OR anam OR brainfx OR brain-fx OR immediate-post-concussion-assessment-and-cognitive-testing OR defense-automated-neurobehavioral-assessment OR dana
AND
concuss* OR postconcuss* OR commotio-cerebri OR coup-contrecoup OR cranio-cerebral-trauma OR ((brain OR cerebral) N5 contusion) OR closed-head-injur* OR mtbi OR tbi OR brain-damage OR brain-injur* OR head-injur*

Psych article
Date searched: April 21, 2020
Results: 39

1. (Military or armed-force* or armed-service* or servicewomen or servicemen or air-personnel or defense-force* or defence-force* or service-personnel or army or navy or air-force or marine* or sailor* or soldier* or infantryman or Civil-defense or Troops or ranger* or "medic" or coast guard or submariner* or active duty or enlisted personnel or reserve personnel).mp.

2. ((computer* or online or internet or web-based or ipad or tablet or tablets or smartphone* or cellphone* or electronic) adj10 (cogniti* or neuropsych* or neurofunction* or neurobehavio*) adj4 (assess* or screen* or measur* or test*)).mp.
3. (Automated Neuropsychological Assessment Measure or ANAM or BrainFX or BrainFX or "Immediate Post-Concussion Assessment and Cognitive Testing" or Defense Automated Neurobehavioral Assessment or DANA).mp.
4. (concuss* or postconcuss* or commotio-cerebri or coup-contrecoup or cranio-cerebral-trauma or ((brain or cerebral) adj5 contusion) or closed-head-injur* or mTBI or TBI or brain damage or brain injur* or head injur*).mp.
5. 2 or 3
6. 1 and 4 and 5

Appendix 3.8.2: Detailed Descriptive Analysis of Studies Included in Scoping Review

Figure 3.8.2.1: Publication years of papers included in this scoping review (n=33)

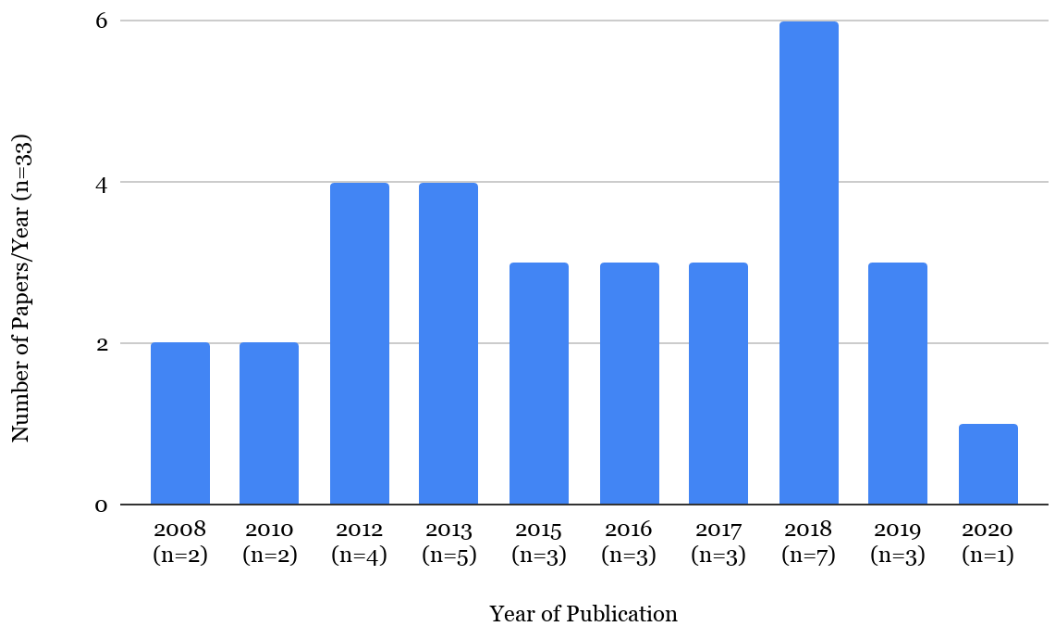


Figure 3.8.2.2: Country of origin of included military participants (n=34)

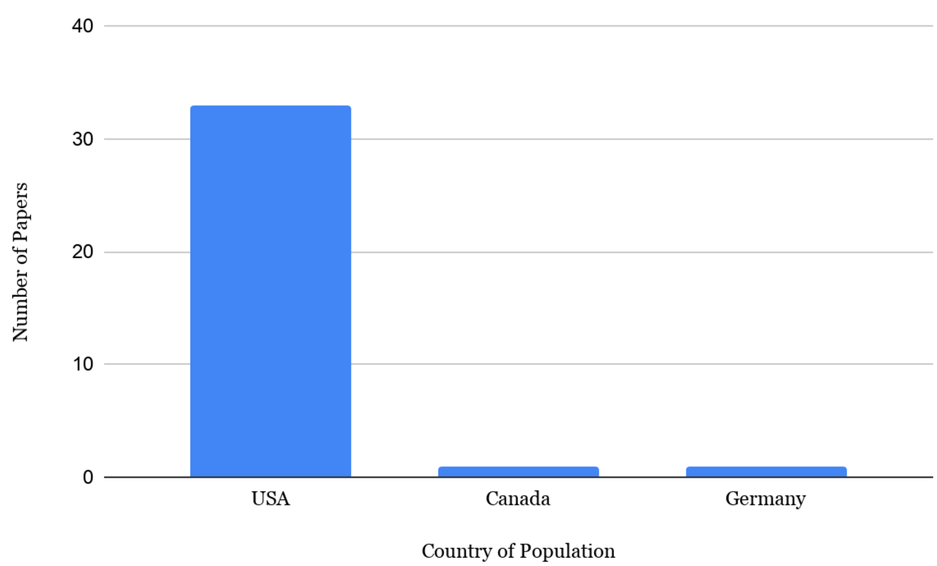


Figure 3.8.2.3: Country of paper publication (n=33)

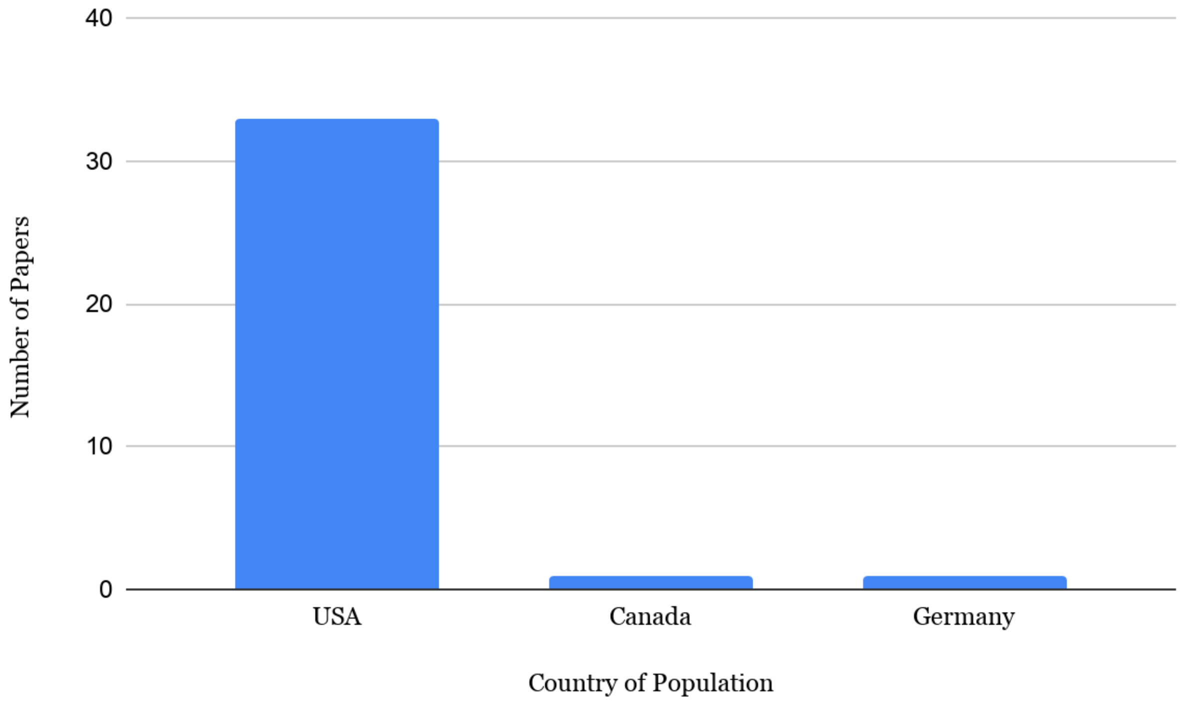


Figure3.8.2.4: Categories of participants included in scoping review by paper (n=34)

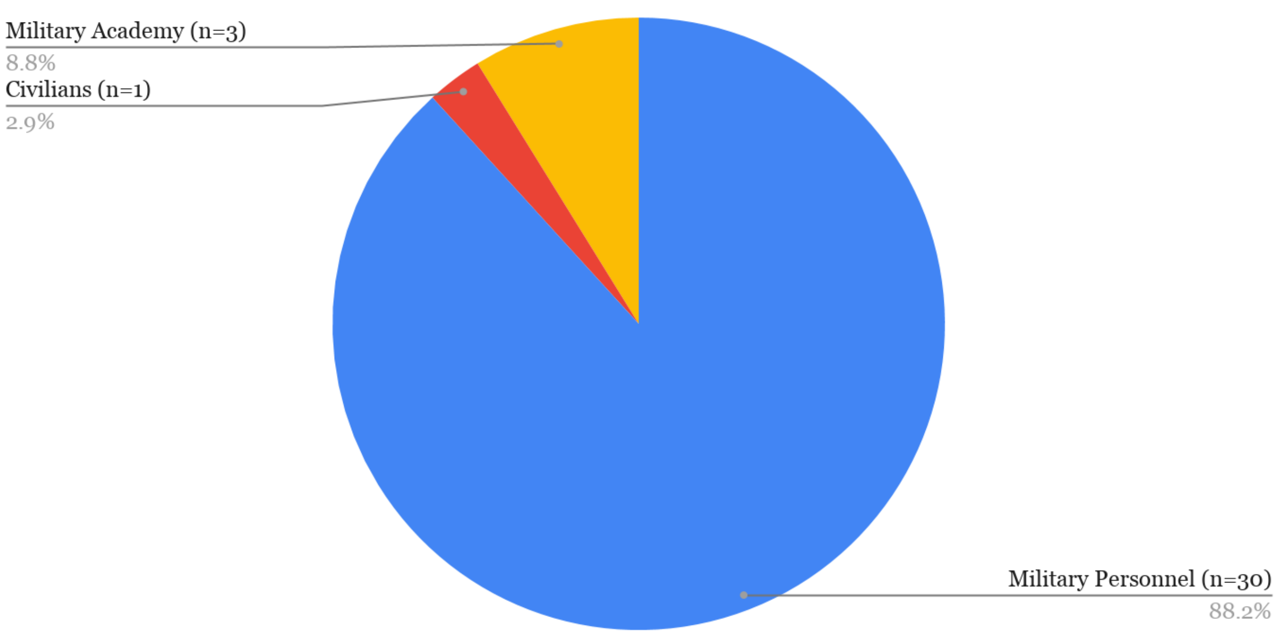


Figure 3.8.2.5: Sex of the participants included in scoping review (n=36,657)

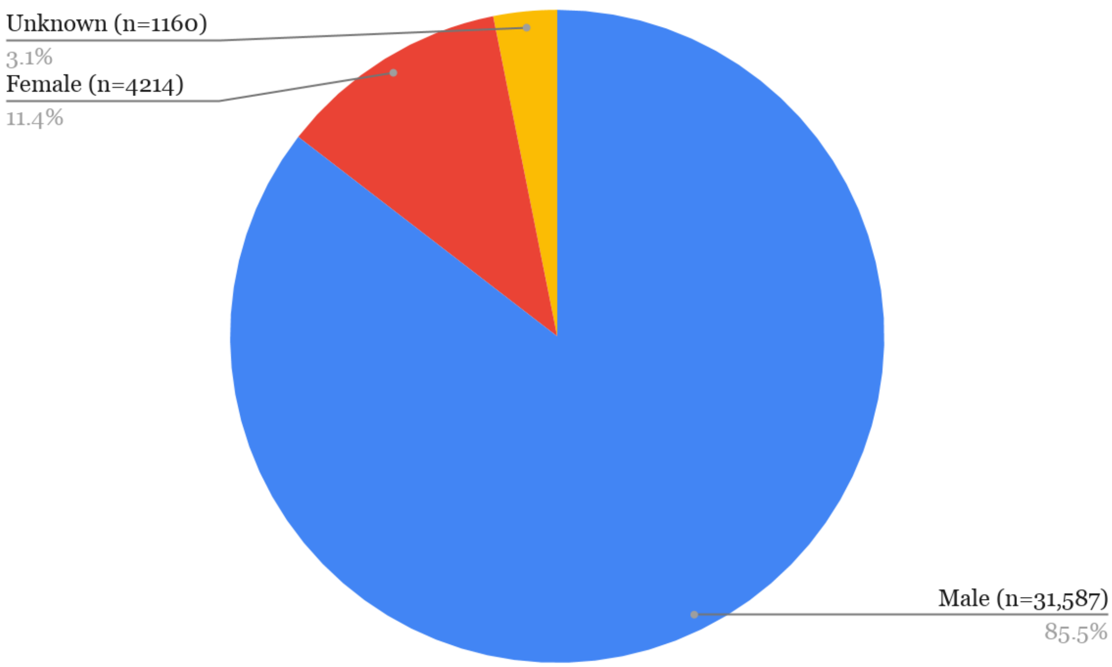


Figure 3.8.2.6: Specific conflicts of papers included in scoping review (n=32)

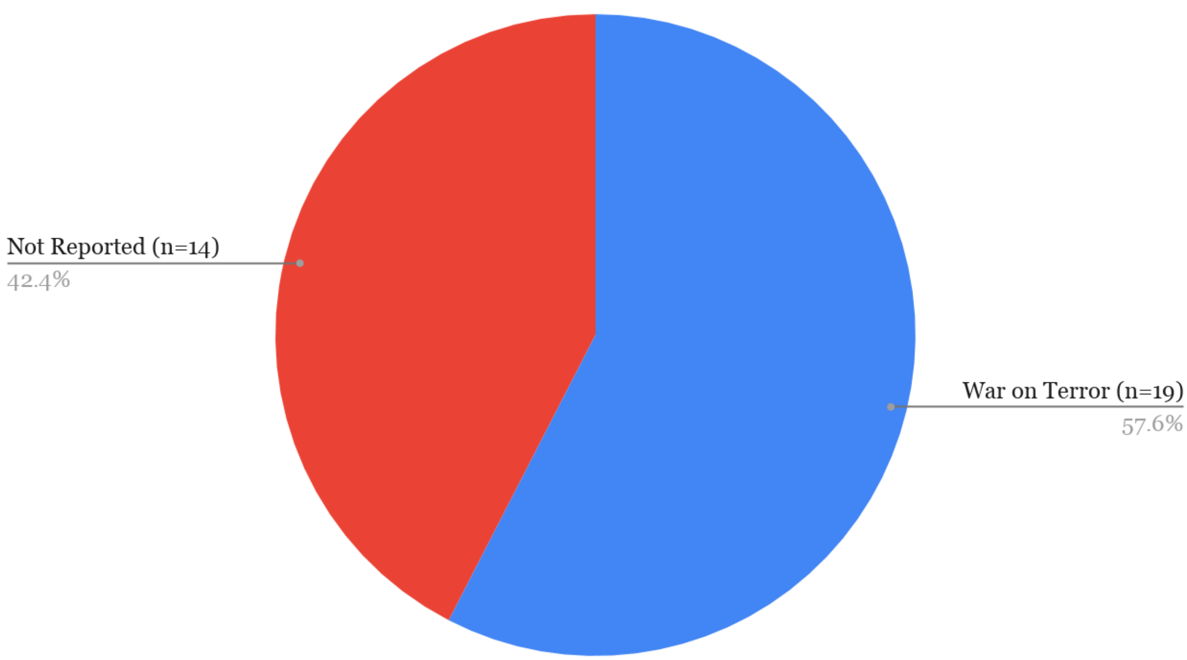


Figure 3.8.2.7: Primary condition of participants included in scoping review (n=36,872)

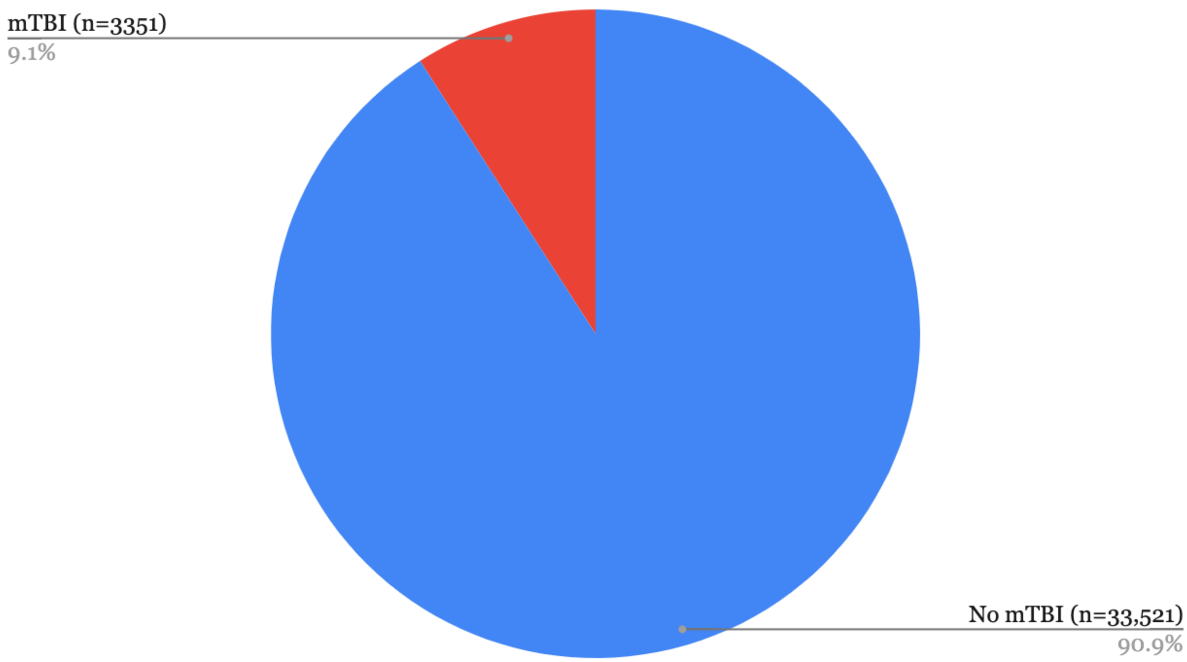


Figure 3.8.2.8: Primary Impairment Category ICD-10 (n=44)

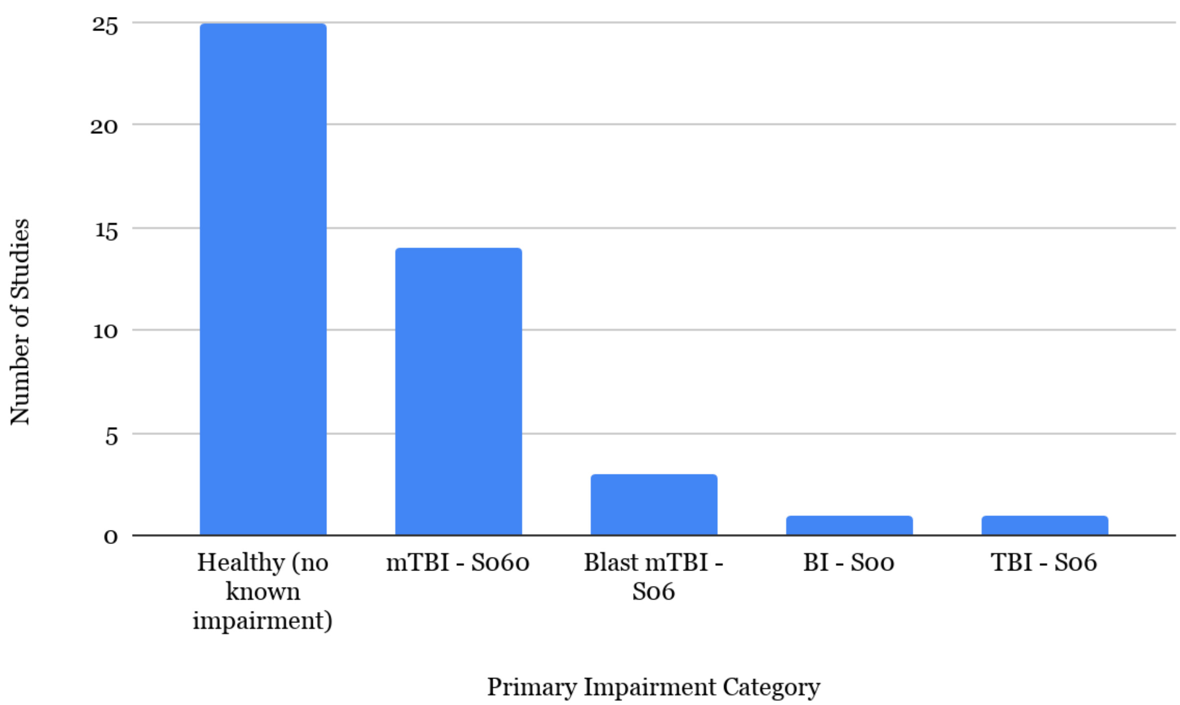


Figure 3.8.2.9: Secondary Impairment Category ICD-10 (n=33)

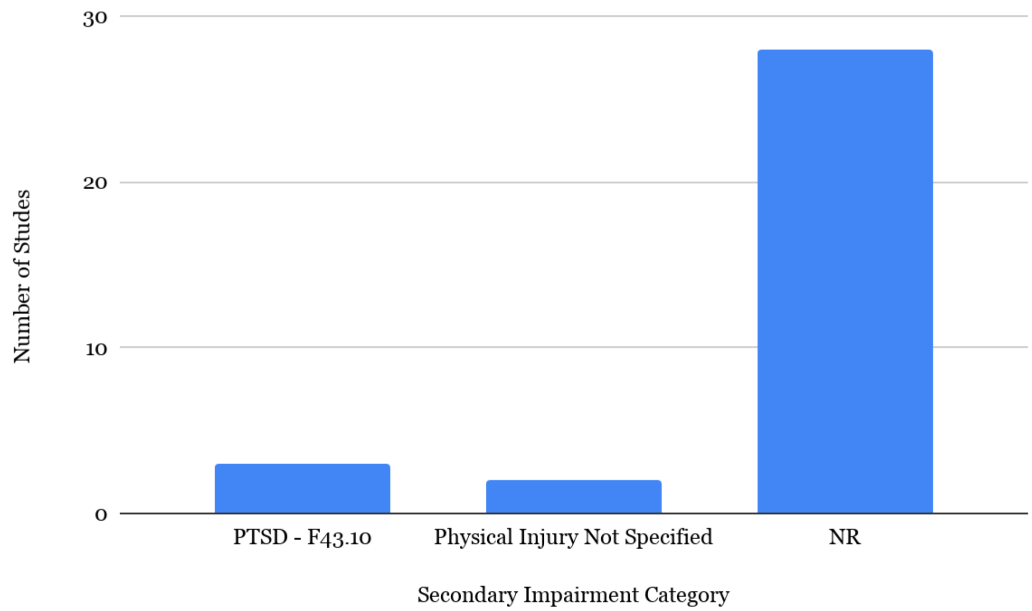
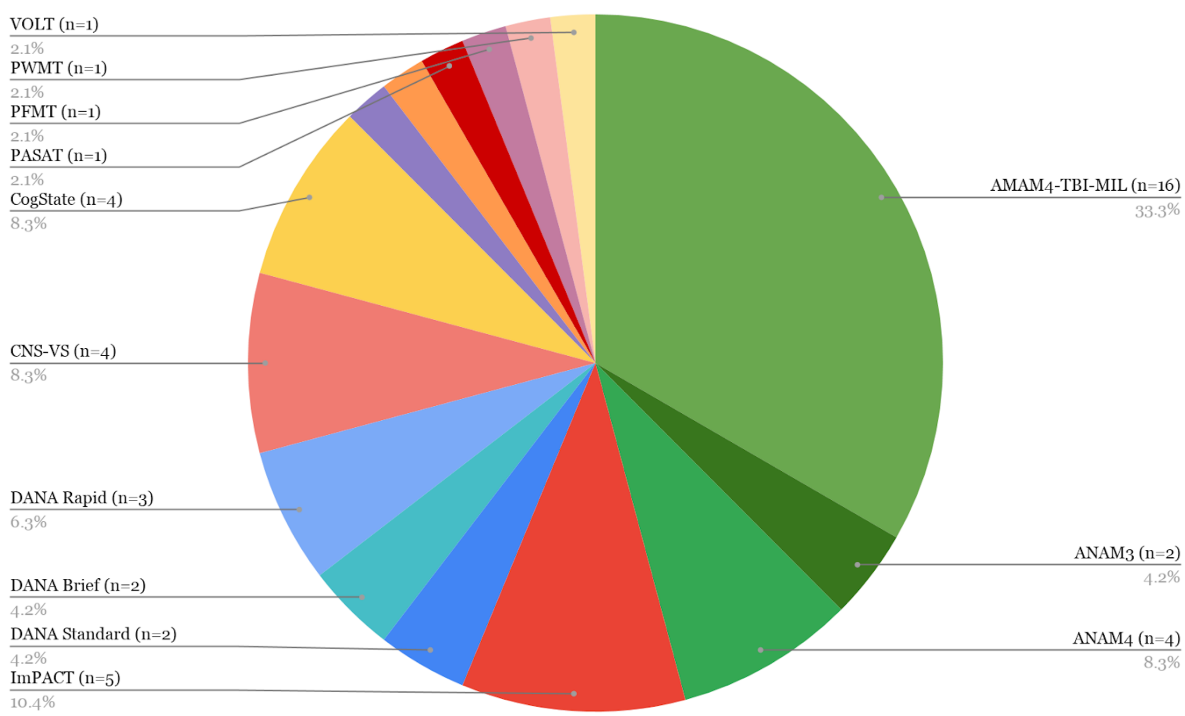
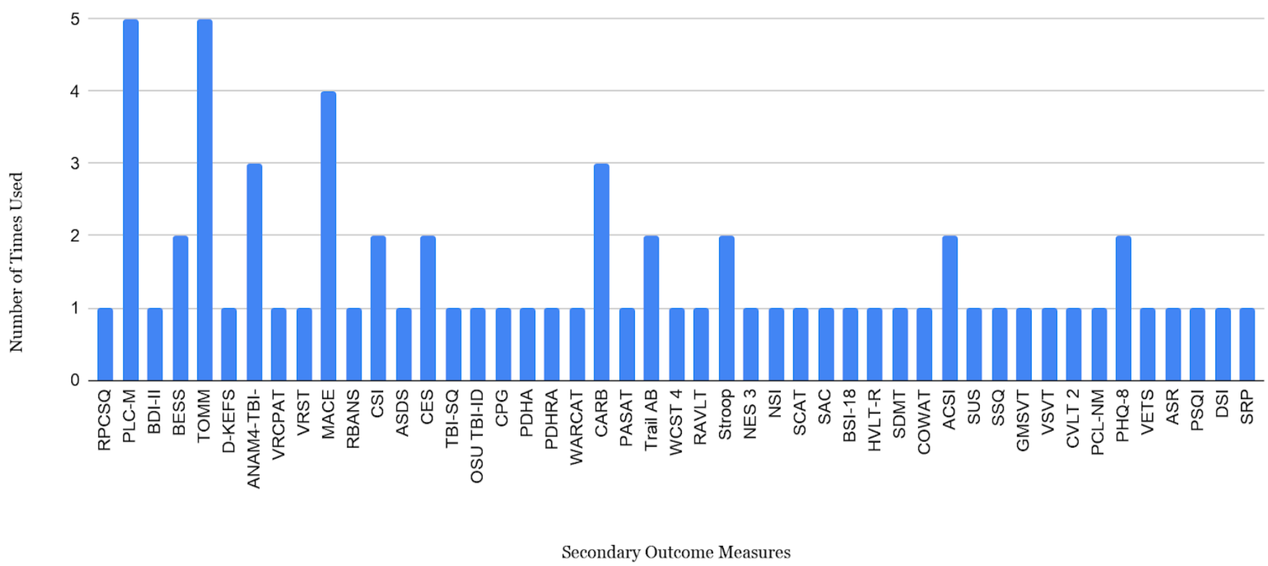


Figure 3.8.2.10: NCAT type by paper (n=46)



ANAM4-TBI- MIL (Automated Neuropsychological Assessment Metrics Version 4 Traumatic Brain Injury Military); ANAM3 (Automated Neuropsychological Assessment Metrics Version 3); ANAM4 (Automated Neuropsychological Assessment Metrics Version 4); ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing); DANA Standard (Defense Automated Neurobehavioral Assessment Standard); DANA Brief (Defense Automated Neurobehavioral Assessment Brief); DANA Rapid (Defense Automated Neurobehavioral Assessment Rapid); CNS-VS (CNS Vital Signs); CogState (Axon Sports' CogState Sport); VRST (Virtual Reality Stroop Test); VRai (Virtual Reality avatar interaction); PASAT (Paced Auditory Serial Addition Test); PFMT (Penn Face Memory Test); PWMT (Penn Word Memory Test); VOLT (Visual Object Learning Test).

Figure 3.8.2.11: Secondary outcome measures (n=46)



RPCSQ (Rivermead Post Concussion Symptom Questionnaire); PCL-M (Posttraumatic Stress Disorder Check List-Military); BDI-II (Beck's Depression Inventory II); TOMM (Test of Memory Malingering); BESS (Balance Error Scoring System); D-KEFS (Delis-Kaplan Executive Function System); ANAM4-TBI- MIL (Automated Neuropsychological Assessment Metrics Version 4 Traumatic Brain Injury Military); VRCPAT (Virtual Reality Cognitive Performance Assessment Test); MACE (Military Acute Concussion Evaluation); RBANS (Repeatable Battery for the Assessment of Neuropsychological Status); CSI (Cognitive Stability Index); ASDS (Acute Stress Disorder Scale); CES (Combat Experience Scale); TBI-SQ (Traumatic Brain Injury Screening Questionnaire); OSU TBI-ID (Ohio State University Traumatic Brain Injury Identification Method); CPG (Chronic Pain Grade); PDHA (post-deployment health assessment); PDHRA (post-deployment health reassessment); WARCAT (Warrior Administered Retrospective Casualty Assessment Too)l; CARB (Computerized Assessment of Response Bias); PASAT (Paced Auditory Serial Addition Test); Trail AB (Trail Marking Test); WCSR4 (Wisconsin Card Sorting Test, Computerized Version 4); RAVLT (Rey Auditory Verbal Learning Test); Stroop Test; NES 3 (Neurobehavioral Evaluation System 3); NSI (Neurobehavioral Symptom Inventory); SCAT (Sport Concussion Assessment Tool); SAC (Standardized Assessment of Concussion); BSI-18 (Brief Symptom Inventory); HVLT-R (Hopkins Verbal Learning Test-Revised) SDMT (Symbol Digit Modalities Test); COWAT (Controlled Oral Word Association Test); ACSI (Abbreviated Concussion Symptom Inventory); SUS (Slater-Usoh-Steed); SSQ (simulator sickness questionnaire); GMSVT (Green's Medical Symptom Validity Test); VSVT (Victoria Symptom Validity Test); CVLT2 (California Verbal Learning Test-Second Edition); PCL-NM (Posttraumatic Stress Disorder Check List – non-military version); PHQ-8 (Patient Health Questionnaire); VETS (Virtual Environment TBI Screening); ASR (Acute Startle Reaction); PSQI (Pittsburgh Sleep Quality Index); DSI (Deployment Stress Inventory); SRP (Soldier Readiness Process).

Figure 3.8.2.12: Categories of constructs being measured by secondary outcome measures (n=48)

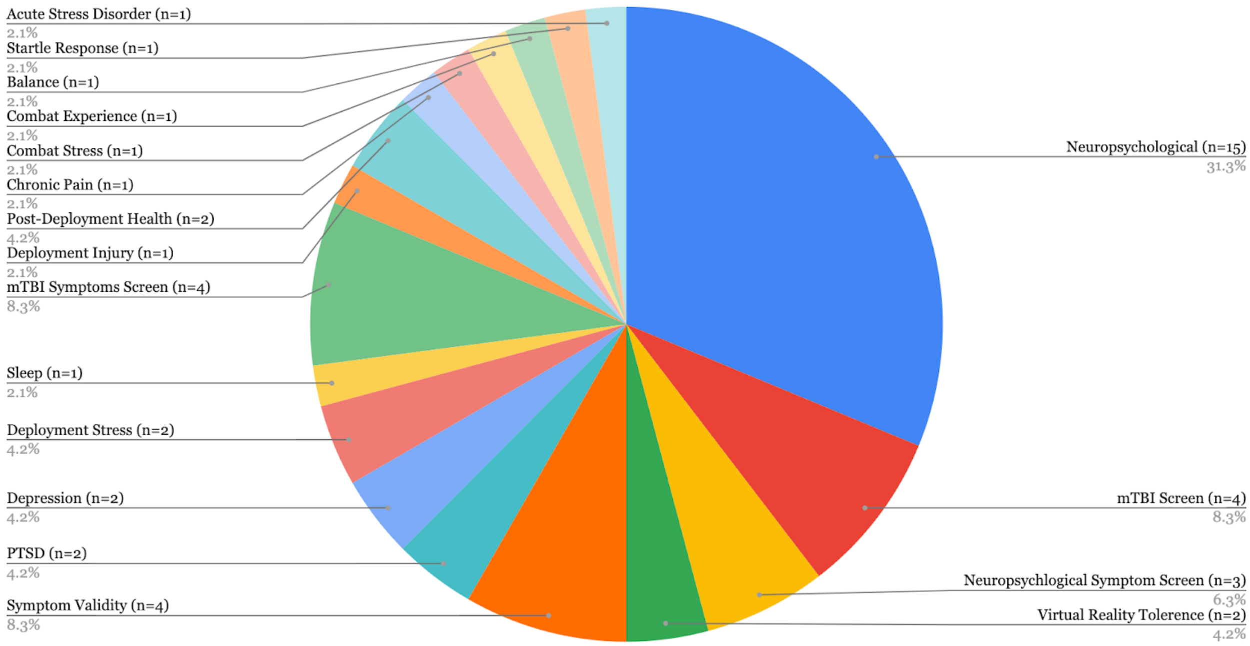


Figure 3.8.2.13: Quantitative study types by papers (n=36)

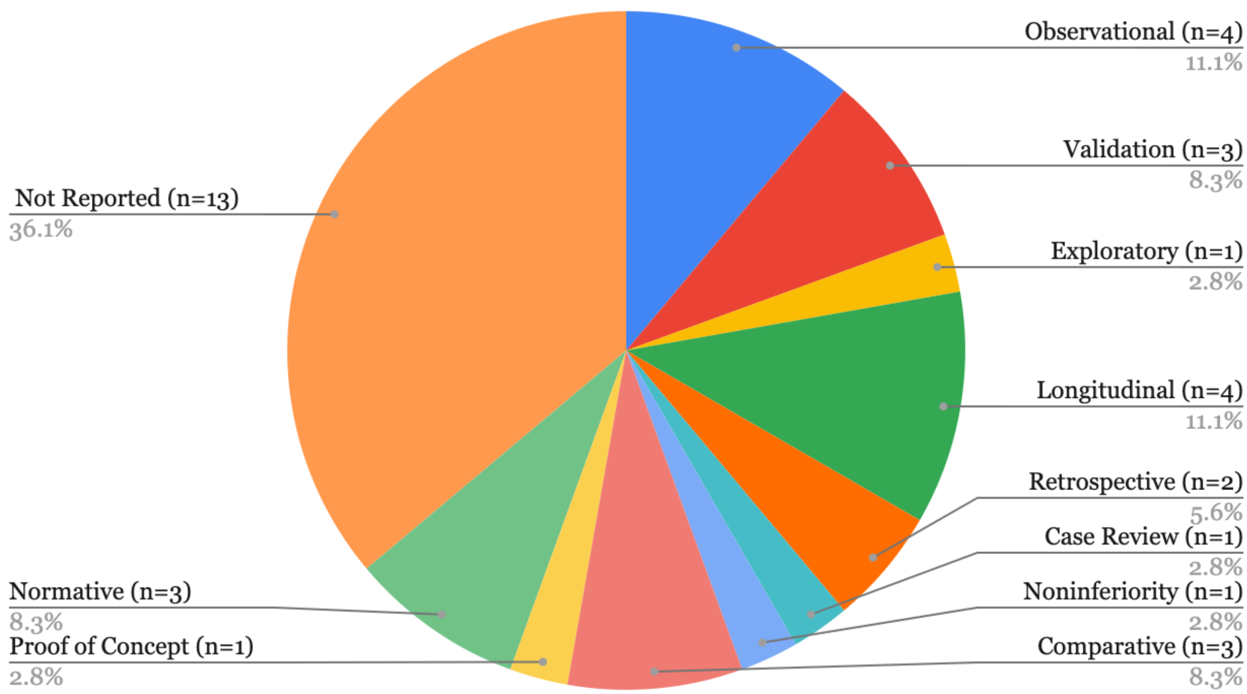


Figure 3.8.2.14: Main constructs being measured by studies included in scoping review (n=41)

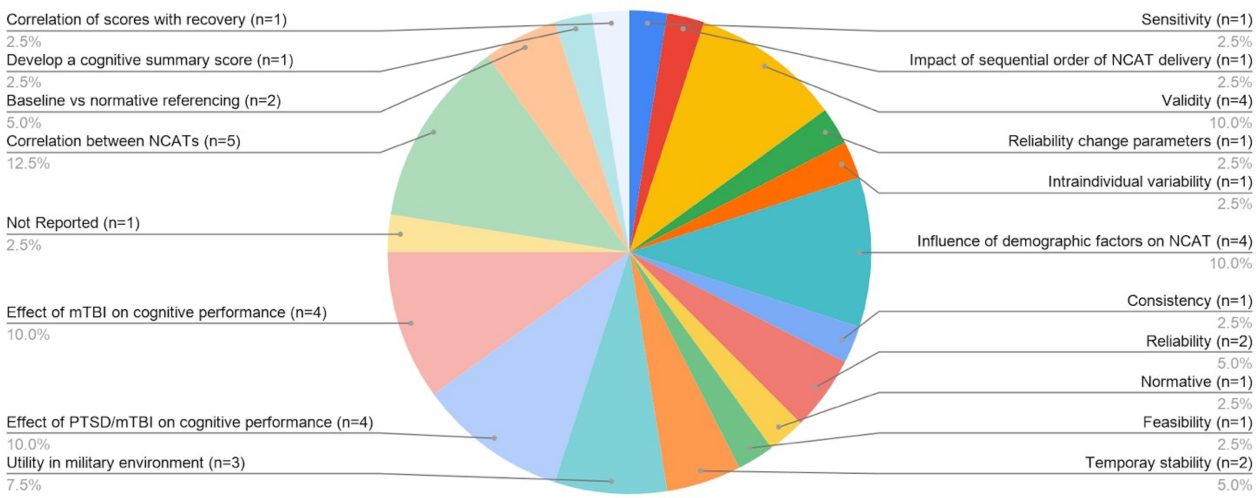
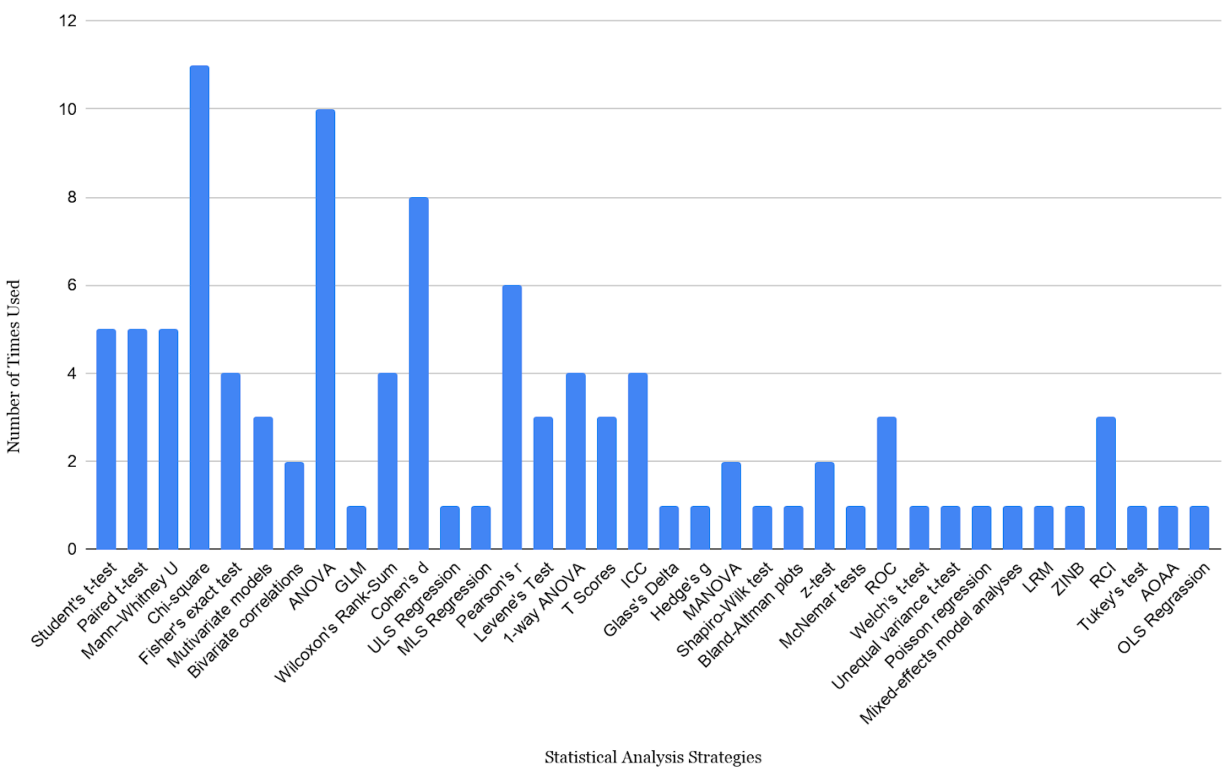


Figure 3.8.2.15: Statistical analysis strategies (n=104)



ANOVA (analysis of variance); GLM (general linear model); ULS Regression (univariate leads square regression); MLS Regression (multivariate least square regression); ICC (intraclass correlation coefficients); MANOVA (multivariate analysis of variance); ROC (receiver operator characteristic); LRM (linear regression model); RCI (reliable change index); AAOA (all others as anchors); OLS Regression (ordinary least squares regression).

Appendix 3.8.3. Description of the most common Neuropsychological Computerized Assessment Tools (NCATs)

3.8.3.1 Automated Neuropsychological Assessment Metrics, Version 4 (ANAM4)

The ANAM4 is a battery of neuropsychological tests originally developed in 1984 to provide a standardized and valid method of testing used for a number of different military applications (Table 3.8.3.1; Reeves, Winter, Bleiberg, & Kane, 2007). This assessment tool is now performed as an NCAT and the ANAM4-TBI-MIL is widely administered to generate baseline cognitive scores prior to deployment of US military personnel (DoDi 6490.13). The ANAM tests 7 domains within three general factors (processing speed/efficiency, retention/memory, and working memory; Vincent et al., 2008; Betthauser et al., 2018). From the data an ANAM Performance Report (APR) is generated, in which an individual’s performance is compared with the normative data (Vincent et al., 2008). The APR includes three summary variables: mean response time for correct responses, percent correct, and a cognitive efficiency throughput the latter being a combination of accuracy and reaction time (Baker et al., 2018). Lower scores indicate greater impairment (Baker et al., 2018; Vincent et al., 2008). Military specific norms exist for the ANAM4 with and without mTBI (Reeves et al., 2006; Vincent et al., 2008).

Table 3.8.3.1: Automated Neuropsychological Assessment Metrics, Version 4 (ANAM4) Description

Test/module	Description
Simple Reaction Time	Provides an index of attention and visuomotor response timing by having the user respond as fast as possible after a snowflake symbol that appears on the monitor.
Code Substitution—Learning	Provides an index of complex scanning, visual tracking, and attention by requiring the user to compare a digit-symbol pair with a predefined set of digit symbol pairs that appear on the monitor.
Procedural Reaction Time	Measures reaction time and processing efficiency by presenting the user with a number on the monitor. The user then has to indicate whether the number is low (2 or 3) or high (4 or 5) by pressing the left or right mouse button, respectively.
Mathematical Processing	Provides an index of basic computational skills, concentration, and working memory by asking to solve a simple arithmetic problem and indicate whether the answer is less than or greater than 5.
Matching to Sample	Provides an index of spatial processing and visuospatial working memory by requiring the user to first view a pattern in a 4 × 4 sample grid and then determining which of the 2 additional grids that appear matches the sample grid.
Code Substitution—Delayed	Provides a measure of learning and delayed visual recognition memory by requiring the user to determine whether a digit-symbol pair matches those presented during the Code Substitution—Learning test presented earlier in the battery.
Simple Reaction Time (Repeated)	This test is identical to the Simple Reaction Time test administered earlier in the battery and is designed to assess fatigue.

Table 1: Betthauser, Brenner, Cole, Scher, Schwab, & Ivins, 2018.

3.8.3.2. Defense Automated Neurobehavioral Assessment (DANA)

The Defense Automated Neurobehavioral Assessment (DANA; Tables 3.8.3.2.1 and 3.8.3.2.2) is a NCAT that includes a library of standardized cognitive and psychological assessments, with three versions that range from a brief 5-minute screen to a 45-minute complete assessment (Lathan, Spira, Bleiberg, Vice, Tsao, 2013). The DANA is written using the Android open-source operating system and is JAVA-based, and can be used on a touch screen (Lathan, Spira, Bleiberg, Vice, Tsao, 2013). The main outcome variable in this study is "throughput," which is defined as a speed-accuracy product that quantifies the number of correct responses per minute (Coffman, Resnick, Drane, & Lathan, 2018). A normative DANA data set for military members has yet to be established (Coffman, Resnick, Drane, & Lathan, 2018).

Table 3.8.3.2.1: Defense Automated Neurobehavioral Assessment (DANA) Test Variations

DANA Rapid (5 Minutes)	DANA Brief (15 Minutes)	DANA Standard (45 Minutes)**
Simple Reaction Time (SRT)	SRT	SRT
Procedural Reaction Time (PRO)	Code Substitution Simultaneous (CDS)	CDS
Go/No-Go (GNG)	PRO	PRO
	Spatial Discrimination (SPD)	SPD
	GNG	GNG
	Code Substitution Delayed (CDD)	CDD
	SRT	Matching to Sample (MSP)
	Patient Health Questionnaire (PHQ)	Sternberg Memory Search (STN)
	Primary Care PTSD Screen (PC-PTSD)	SRT
	Insomnia Screening Index (ISI)	Combat Exposure Scale (CES)
		PHQ
		Pittsburgh Sleep Quality Index (PSQI)
		PTSD Checklist—Military Version (PCL-M)
		Deployment Stress Inventory (DSI)

Table 3.8.3.2.1: Coffman, Resnick, Drane, & Lathan, 2018.

Table 3.8.3.2.2: Overview of the Defense Automated Neurobehavioral Assessment (DANA)

Test Name (Abbreviation)	Task Structure	Task Purpose
Simple Reaction Time (SRT)[a–c]	The subject taps on the location of the yellow asterisk symbol as quickly as possible each time it appears.	This task measures pure RT.
Procedural Reaction Time (PRO)[a–c]	The screen displays one of four numbers for 3 seconds. The subject presses on a left button (“2” or “3”) or right button (“3” or “4”) depending upon the number pressed.	A choice RT measure of accuracy, RT, and impulsivity. This choice RT task targets simple executive functioning with easy decision-making capabilities.
Go/No-Go (GNG)[a–c]	This is a forced choice RT task relevant to warfighters. A house is presented on the screen with several windows. Either a “friend” (green) or “foe” (white) appears in a window. The respondent must push a “fire” button only when a “foe” appears.	A choice RT measure of sustained attention and impulsivity. The test assesses speed and accuracy of targets, omissions, and commissions.
Spatial Discrimination (SPD)[b,c]	Pairs of four-bar histograms are displayed on the screen simultaneously, and the subject is requested to determine whether they are identical. One histogram is always rotated either ±90 degrees with respect to the other histogram.	Assesses visuospatial analytic ability.
Code Substitution Simultaneous (CDS)[b,c]	Subjects refer to a code set of 9 symbol-digit pairs that are shown across the upper portion of the screen. A sequence of single symbol-digit pairs is shown below the key, and the subject indicates whether or not the single pair matches the code by pressing Yes or No.	Assesses visual scanning and attention, learning, and immediate recall.
Code Substitution Delayed (CDD)[b,c]	After a delay of several intervening tests, the same symbol-digit pairs are presented without the code. The subject indicates whether or not the pairing was included in the code that was presented in the earlier code substitution learning section.	Assesses learning and short-term memory.
Sternberg Memory Search (STN)[c]	The subject memorizes a set of five letters, after which letters appear on the screen one at a time, and the subject determines if the letter on the screen is a member of the memory set.	Assesses working memory.
Matching to Sample (MSP)[c]	A single 4 × 4 checkerboard pattern is presented on the screen for brief study period. It then disappears for 5 seconds, after which two patterns are presented side-by-side. The subject indicates which of these two patterns matches the first.	A measure of short-term memory, attention, and visuospatial discrimination.
Insomnia Screening Index (ISI)[b]	A 5-item scale evaluating perceived insomnia severity and sleep habits. Each item is rated on a 5-point scale (0–4).	The total score ranges from 0 to 28 and higher scores indicate more severe insomnia. A cutoff score of 10 has been shown to indicate insomnia.[11]
Primary Care PTSD Screen (PC-PTSD)[b]	Four screening questions designed for use in clinical settings to screen for PTSD, with 3 out of 4 endorsed items suggestive of likely PTSD.	Questions assess hyper-arousal, re-experiencing, and avoidance for PTSD screening. This test is more sensitive than specific, but correlates highly with the PCL.[12,13]
Patient Health Questionnaire (PHQ)[b,c]	A 9-item depression scale assessing symptom severity and diagnostic criteria for major depressive disorder. For research purposes, item no. 9 (concerning suicide) was not included, yet research indicates that the scoring, reliability, and clinical validity are almost identical.	A score of 0–9 is likely to have no depression, 10–14 mild depression, 15–19 moderate depression, and 20+ severe depression.[14]
Pittsburgh Sleep Quality Index (PSQI)[c]	19 self-rated items and 5 partner-rated items, which measure sleep quality during the previous month. This scale differentiates “good” from “poor” sleepers based on seven areas: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction over the last month.	This scale is the most widely utilized sensitive and specific self-report measure for insomnia. A score above 6 indicates a “poor” sleeper, and a score above 12 is associated with “insomnia.”[15]

Test Name (Abbreviation)	Task Structure	Task Purpose
Combat Exposure Scale (CES)[c]	A 7-item self-report measure that assesses wartime stressors experienced by service members. The total CES score (ranging from 0 to 41) is calculated by using a sum of weighted scores, which can be classified into 1 of 5 categories of combat exposure ranging from "light" to "heavy."	This scale rates cumulative combat exposure and is highly predictive of PTSD, pain and injury, TBI, depression, and other behavioral sequellae.[16]
PTSD Checklist—Military Version (PCL-M)[c]	A 17-item scale assessing symptoms in response to stressful military experiences. This scale assesses PTSD, with subscales including re-experiencing, avoidance/numbing, and hyperarousal.	Higher scores indicate increased PTSD symptomatology. In a military population, scores >49 are likely to have PTSD. For greatest specifically, scores >44 with 3 re-experiencing, 1 avoidance/numbing, and 2 Hyperarousal endorsed as at least "most of the time" are more specific for PTSD and correlate very highly (0.92) with the Clinician Administered PTSD Scale (CAPS).[17]
Deployment Stress Inventory (DSI)[c]	Based upon the neurobehavioral symptom inventory with additional items added to assess anger, pain, and sleepiness. Test is a 28-item experimental scale that factors into three domains (cognitive-emotional, somatic, and anger) and five subscales (cognitive, emotional, pain, sleep, and anger).	This experimental measure is intended to be used as a broad psychological screening tool sensitive to combat-related distress, especially reporting of persistent postconcussive symptoms.[18]

[a]DANA Rapid Battery. [b]DANA Brief Battery. [c]DANA Standard Battery.

Table 3.8.3.2.2: Coffman, Resnick, Drane, & Lathan, 2018.

3.8.3.3 Description of Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is a computer administered neuropsychological test battery that consists of six individual test modules that measure aspects of cognitive functioning including attention, memory, reaction time, and processing speed (Iverson, Lovell, & Collins, 2013). Each test module contributes to an overall composite score. Although there is normative data for the general population, there are no norms specific to the military population. The ImPACT is utilized on a desktop or laptop computer, and has been approved by the Food and Drug Administration (FDA; United States Food and Drug Administration, 2016) for mTBI testing.

Table 3.8.3.3: Description of Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

Test*	Cognitive domain measured
Word discrimination	Attention, verbal recognition
Symbol memory	Visual working memory, visual processing speed
Sequential digit tracking	Sustained attention, reaction time
Visual span	Visual attention, immediate memory
Symbol-matching	Visual processing speed, learning and memory
Color track	Concentration, response inhibition, reaction time
Three letters	Working memory, visual-motor response speed

Table 3.8.3.3: Kontos, Collins, & Russo, 2004.

5. Perceptions of Canadian Armed Forces Healthcare Professionals on Cognitive Assessment Processes within Canadian Armed Forces Health Services: A Qualitative Thematic Analysis - Exploration Stage

Accepted: Journal of Military, Veteran and Family Health

4.1 Abstract

Introduction: Canadian Armed Forces (CAF) Service Members (SMs) experience a higher prevalence of mild traumatic brain injuries (mTBI) compared to Canadian civilians. As cognitive dysfunction may be experienced after injury or illness, assessment of cognitive functioning is necessary to ensure CAF-SMs can safely and efficiently perform their duties post-injury. Effective treatment and rehabilitation to address cognitive dysfunction can be prescribed once reliable, valid, specific, and evidence-based cognitive screening/assessment are performed by healthcare professionals. To date, a standardized process that includes cognitive screen/assessment within a mTBI rehabilitation strategy is not widely utilized within Canadian Forces Health Services (CFHS). The objective of this study was to explore the experiences of CFHS healthcare professionals who perform cognitive screens/assessments, identifying specifically: (1) perceptions of facilitators and barriers to cognitive assessment practices, and; (2) recommendations for improving the practice of cognitive assessment for injured CAF-SMs. Methods: A qualitative thematic analysis nested within an implementation science approach was performed. Seventeen CFHS healthcare professionals (HCPs) were interviewed with the data being transcribed, coded, and analyzed. Results: Themes focused around facilitators, barriers, and recommendations associated with: (1) Education and knowledge of clinicians and staff regarding mTBI and cognitive screens/assessments, (2) Multidisciplinary collaboration, (3)

Stigma, awareness, and attitudes of CAF-SMs, (4) Availability of resources, and; (5) Cognitive screen/assessment tools. Conclusion: Development and implementation of cognitive screen/assessment policies and protocols will enable CFHS HCPs to best assess, treat and rehabilitate cognitive dysfunction among CAF-SMs.

4.2 Introduction

Canadian Armed Forces (CAF) Service Members (SMs) experience a higher prevalence of mild traumatic brain injury (mTBI) compared to Canadian civilians both on and off deployment, and at a rate consistent with other global militaries (Besemann, Godsell, Mahoney, & Hawes, 2019). A mTBI, also known as a concussion, is specifically defined as a temporary change in brain functioning caused by an insult to the head with a period of post-traumatic amnesia lasting less than a day where "clinical signs and symptoms cannot be explained by drug...use or other injury" (McCrory et al., 2017). The resulting symptoms of a mTBI can cause a variety of functional issues in the short and long term (Marshall et al., 2018; McCrory et al., 2017; Doneva, 2018). Symptoms of mTBI may include headaches, fatigue, nausea, sensitivity to light and sound, visual disturbances, sleep disturbances, balance or vestibular issues, emotional disturbances, seizures, loss of consciousness, and cognitive dysfunction (Marshall et al., 2018; McCrory et al., 2017). Symptom resolution generally occurs within 2 weeks when no additional physical or mental comorbidities and extenuating factors are present (Marshall et al., 2018; McCrory et al., 2017). If 3 or more symptoms of mTBI persist for longer than 3 months, a diagnosis of postconcussion symptoms (PCS) may be determined (Marshall et al., 2018; McCrory et al., 2017).

mTBI affects 1 in 25 CAF-SMs, with an undetermined number of subclinical cases not being reported or diagnosed (Besemann, Godsell, Mahoney, & Hawes, 2019). Compared to civilians, CAF-SMs who experience a mTBI in military service are at higher risk of their symptoms and scenarios developing into career-limiting medical conditions (Garber, Rusu, Zamorski, & Boulos, 2016). Moreover, as a CAF-SM transitions out of the CAF to civilian life, PCS may continue to contribute to challenges with personal issues, the family unit, civilian employment, leisure activities, and self-care (Rona et al., 2012; Garber, Rusu, Zamorski, & Boulos, 2016; Radomski, Davidson, Voydetich, & Erickson, 2009).

The co-occurrence of mTBI and posttraumatic stress disorder (PTSD) arising from the same or separate traumatic incidents can exacerbate PCS. Determining whether symptoms are related to a mTBI and/or a concurrent mental health diagnosis is difficult as many of these symptoms have similarities (Roberge, Baker, Ely, Bryan, Bryan, & Rozek, 2020; Doneva, 2018; Bryden, Tilghman, & Hinds, 2019). It is globally acknowledged that military members experience PCS at a higher rate than the civilian population in part due to the aforementioned co-morbidities and circumstances (Garber, Rusu, & Zamorski, 2014; Rona et al., 2012; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Armistead-Jehle, Soble, Cooper, & Belanger, 2017). Among CAF-SMs deployed for Operation Enduring Freedom (OEF) between 2009-2012, for example, 5.2% self-reported experiencing a mTBI and 15-21% of these members noted PCS (Garber, Bryan, Rusu, & Zamorski, 2014). Despite differences amongst mechanisms of injury, no significant variations in mTBI symptoms and PCS caused by blast versus blunt force has been identified apart from more severe hearing loss in those who sustained a mTBI due to a blast (Doneva, 2018).

4.2.1 A Multidisciplinary Approach to Mild Traumatic Brain Injury

As mTBI and its symptomatology is multifaceted and complex, assessment, intervention and rehabilitation will vary depending on the needs of the individual (Radomski, Davidson, Voydetich, & Erickson, 2009; Cicerone et al., 2011; Janak et al., 2017; Marshall et al., 2018). As a result, a multidisciplinary approach to mTBI and PCS treatment is considered best practice, including primary care, physical therapy, occupational therapy, psychology, social work, speech-language pathology, ophthalmology and other healthcare professionals for interventions involving cognition, mental health, vestibular systems, visuoperceptual abilities, and sleep function (Janak et al., 2017; Marshall et al., 2018).

Within the Canadian Forces Health Services (CFHS), multiple clinical disciplines have a role in the assessment and management of mTBI including physiotherapists and occupational therapists (OT) in the Physical Rehabilitation Department, psychologists and psychiatrists in the General Mental Health Department, and multiple professions such as nurse practitioners, physicians, and physician assistants within the Primary Care Department (Department of National Defense, 2017). After initial cognitive screening or assessment has been conducted by CFHS Heathcare Professionals (HCPs), it may be deemed necessary to outsource CAF-SMs for a resource-intensive comprehensive neuropsychological assessment outside of CFHS to more specifically determine cognitive deficits and strengths.

4.2.2 Cognition and Cognitive Screening and Assessment

Cognition is a broad construct that refers to information-processing functions carried out by the brain (Diller & Weinberg, 1993), including attention, memory, executive functions, comprehension, speech (Sohlberg & Mateer, 1989), calculation ability (Roux, Boetto, Sacko, Chollet, & Trémoulet, 2003), visual perception (Warren, 1993), and praxis skills (Donkervoort, Dekker, Stehmann-Saris, & Deelman, 2001). Adequate cognition is required to be able to learn, retain, and use new information and is essential to effective performance across the broad range of daily occupations such as work, educational pursuits, home management, and leisure (American Journal of Occupational Therapy, 2013). Cognitive dysfunction, which is defined as functioning below expected normative levels, can manifest as a loss of ability in one or more cognitive domains and functional challenges in daily activities (American Journal of Occupational Therapy, 2013). Cognitive dysfunction is most commonly recognized as associated with conditions such as mTBI and organic brain conditions (e.g., tumors or cerebrovascular events, neurological disorders, and mental illnesses). Within the military context, cognitive dysfunction can potentially result in decreased efficiency and effectiveness and increased risk of harm to self, the unit, and a CAF mission (Jones, Pike, & Brémault-Phillips, 2019).

Cognitive screen/assessment protocols typically utilize standardized and validated tools that address multiple domains of cognition. These tools are administered by HCPs with varying levels of training, registration, and qualification. While the goal and use of test results may vary across healthcare disciplines (e.g., diagnosis, rehabilitation, and determination of treatment pathways), they are all dependent on the foundational administration of a reliable, valid, specific, and function-based cognitive screen/assessment (Larner, 2017). As cognitive dysfunction is a symptom often experienced with mTBI and PCS, screening and assessment of cognitive functioning is important to ensure that CAF-SMs can safely perform their military roles (Jones, Pike, & Brémault-Phillips, 2019).

As the evidence-based literature on mTBI and cognitive assessment practices and protocols rapidly evolves, many questions remain regarding best-practice for cognitive screening and assessment tools as well as the role HCPs play in addressing cognition in the military context. Further, although assessment of functional cognition is necessary to identify cognitive impairments that challenge a patient's ability to accomplish real world tasks, the extent to which these cognitive assessments predict and transfer to functional performance is still widely unknown (Malloy, et al., 1997). Evidence-based literature on individual assessment batteries is often lacking and further complicated by poor reporting on the appropriateness, timing, validity, reliability, effectiveness, specificity, fidelity, sensitivity, and feasibility of these tools to specific populations. This lack of clarity frequently results in HCPs having difficulty deciding on the appropriate cognitive assessment to perform, and how to interpret and report results. Engaging with the primary stakeholders, such as CFHS HCPs, in the development of a usable innovation or practice process for cognitive screening/assessment would be a key component of an implementation science-based approach to improve the access, effectiveness, feasibility, and utility of this clinical service.

4.2.3 Purpose and Objectives

To date, a protocol and policy that includes cognitive assessment as part of an mTBI rehabilitation strategy has not been established within CFHS. Assessing the experiences, knowledge, and opinions of CFHS staff regarding cognitive screen/assessment is essential to implementation of cognitive screen/assessment practices for CAF-SMs who experience mTBI and subsequent mental health disorders. The purpose of this study is to answer the research question: “What is the experience of CFHS HCPs with cognitive assessment utilization with CAF-SMs who have sustained mTBI?”

The objective of this study is to explore the experiences of CFHS HCPs who perform cognitive screens/assessments, specifically identifying: (1) perceptions of facilitators and barriers to cognitive assessment practices, and (2) recommendations for improving cognitive assessment for injured CAF-SMs.

4.3 Methodology

4.3.1 Study Design

This study utilized a thematic analysis as a component of a wider implementation science framework guided by the Active Implementation Frameworks (AIFs; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). This thematic analysis of responses from CAF HCPs fits within the Exploration Stage (Figure 11), as it explores a usable intervention (i.e., cognitive assessments) and provides a situational assessment of primary intended users' context when administering cognitive assessments (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Figure 11: Stages Framework of the Active Implementation Frameworks by the National Implementation Research Network (NIRN)

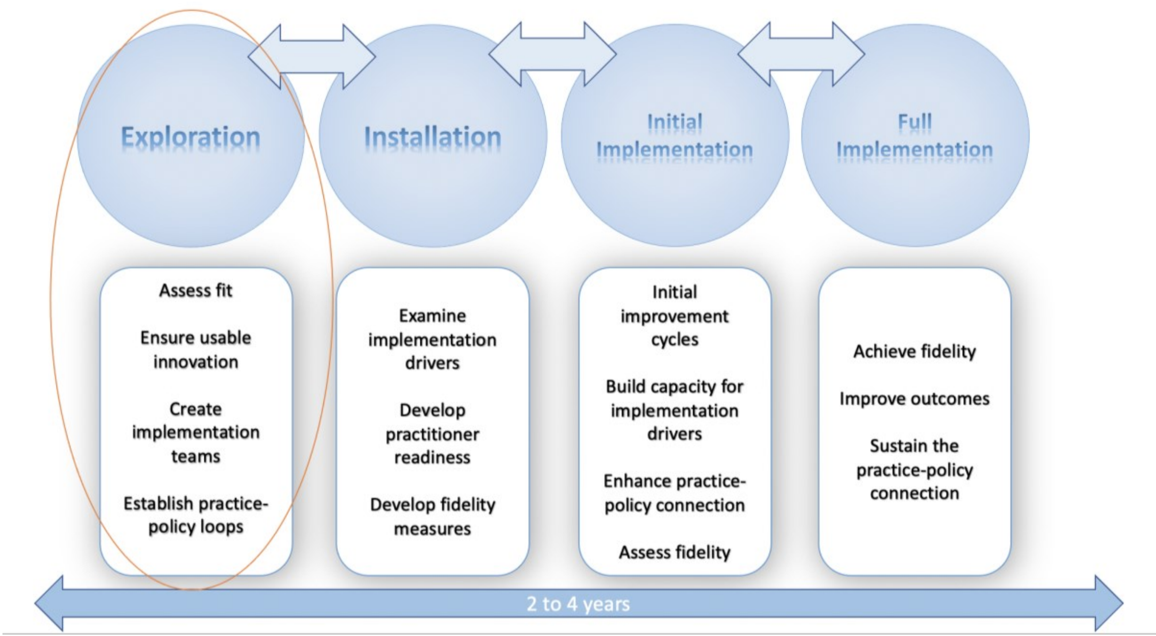


Figure 11: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

4.3.2 Recruitment and Sampling

Recruitment was initiated via an email with study information circulated by key stakeholders within CFHS. Recruitment emails were forwarded to physiotherapists, occupational therapists, psychiatrists, and psychologists within CFHS across the 4 regions: Western, Ontario, Quebec, and Atlantic. HCPs who were interested in participating in the study were instructed to email the researcher to indicate consent to be contacted. HCPs meeting the inclusion criteria were forwarded an online Consent Form over email via a secure server (RedCap) and an interview time was scheduled. Potential participants were informed that engagement in the study was voluntary. A sample size of 15 participants, estimated based on the fact that there are few CAF HCPs across Canada who offer cognitive assessment, was determined to be sufficient for gathering rich qualitative data. This study has received endorsement from the Surgeon General Health Research Program and ethical approval from the Research Ethics Board at the University of Alberta.

4.3.3 Inclusion Criteria

Participants included in this study were current or previous CAF HCPs including physiotherapists, occupational therapists, psychologists, psychiatrists, and primary care clinicians who engage(d) in the assessment and treatment of CAF-SMs with cognitive dysfunction due to mTBI or mental health conditions. The employment status of the HCPs could include regular or reserve force CAF-SMs, public service employees, or contractors. All participants were required to verbally communicate in English.

4.3.4 Measurements and Instruments

A multiple-choice Demographic Questionnaire was provided via email to participants through RedCap. Variables collected included the participant's profession, years in profession, years working with CAF-SMs, years working with populations with cognitive dysfunction due to mental health diagnosis or mTBI, and employment status. A semi-structured interview guide was developed to assist the researcher with the deductive qualitative interview questions while leaving space for the inductive nature of the thematic analysis.

4.3.5 Data Collection

The researcher conducted individual 20-to-60-minute telephone interviews for all participants guided by the semi-structured interview guide. All interviews were audio-recorded via a handheld recorder and AudioNote software. In order to reach data saturation, the interview questions evolved as themes emerged throughout subsequent interviews (Creswell, 1997). The interviews were transcribed by a designated transcriptionist prior to analysis.

4.3.6 Data Analysis

Qualitative interview data was subjected to thematic analysis. Thematic analysis is a method for identifying, analyzing and reporting patterns (themes) in rich detail, and allowing the researcher to interpret various aspects of the topic (Braun & Clarke, 2006). Practically, thematic analysis involves examining the text in detail to identify recurring patterns (open coding) which are refined into 'themes' through both inductive and deductive reasoning, that is, themes that arise directly from the data and those which relate to theory and previous findings, respectively (Braun & Clarke, 2006). The framework by Braun and Clarke (2006) guided the inductive analysis such that no pre-existing coding frame was imposed on the interviews. The deductive analysis was guided by the research questions regarding perceived barriers, facilitators, and recommendations associated with cognitive assessment practices within CFHS. Thematic analysis is a useful method for (1) participatory research paradigm with participants as collaborators; (2) allowing for social as well as psychological interpretations of data; and (3) producing qualitative analyses suited to informing policy development (Clarke & Braun, 2017). NVivo 12 Software was used to facilitate thematic analysis and coding. The open coding process yielded an initial 35 codes, which were further refined during the thematic analysis. Open codes were subsequently combined into preliminary patterns focusing on similarities and differences within and between the interviews. The 35 open codes were collapsed into 5 primary cross-cutting themes after being reviewed and organized via their patterning. Analysis of the 5 cross-cutting themes using deductive codes of barrier, facilitators, and recommendations followed. To ensure the validity, reliability (dependability), and conformability of the analysis, the data was re-coded by the researcher, researcher bias was clarified and bracketed, and an external audit of the analysis was made by other members of the research team (Morse, 2015; Lincoln and Guba, 1985). Differences of opinion between members of the research team regarding themes were resolved through discussion. Following review of the data and completion of the secondary level of analysis, the themes were narratively summarized with the aim of organizing, describing, exploring, interpreting, and telling the story of the analysis.

4.4 Results

4.4.1 Demographic Information

Seventeen participants were interviewed; demographic information on the participants is shown in Table 3. The sample covered multiple professions, regions, and levels of experience within the respective profession as well as with cognitive screening/assessment.

Table 3: Characteristics of study participants

Participant Characteristics	**Percentage of Participants (n=17)**
Gender (n=17)	
Male	29
Female	71
Profession (n=19)	
Physiotherapist	42
Occupational Therapist	32
Primary Care Clinician	11
Psychiatrist	16
Psychologist	0
Employment Status (n=19)	
Enlisted Reg Force Member	32
Public Service	37
Contractor	32
Geographical Region (n=17)	
Western	35
Ontario	47
Quebec	12
Atlantic	6
Years in Profession (n=17)	
Less than 5 Years	0
5 to 10 years	6
10 to 15 years	41
15 to 20 years	12
20+ Years	41
Education (n=17)	
Bachelor's Degree	29

Graduate Degree	71
Experience with Cognitive Screen Administration	
Less than 1 Year	0
1 to 3 years	6
3 to 5 Years	24
More than 5 Years	70
Experience with Cognitive Assessment Administration	
Less than 1 Year	29
1 to 3 years	6
3 to 5 Years	18
More than 5 Years	53

4.4.2 Thematic Analysis Results

The thematic analysis yielded a number of crucial topic areas regarding cognitive screen/assessment for CAF-SMs with mTBI. These included: (1) Education and knowledge of clinicians and staff regarding mTBI and cognitive screens/assessment (Table 4), (2) Multidisciplinary collaboration (Table 5), (3) Stigma, awareness, and attitudes of CAF personnel (Table 6), (4) Availability of resources (Table 7), and; (5) Cognitive screen/assessment tools (Table 8). Associated themes related to facilitators, barriers and clinical recommendations emerged from the interview data. These are expanded upon in the following section, accompanied by supporting quotes from the interview data.

4.4.2.1. Education and Knowledge of Clinicians and staff regarding mTBI and cognitive screens/assessment

The education and knowledge of clinicians and staff (Table 4) referred to the familiarity of the HCPs and their support staff with the evidence-based literature, practices, policies, and protocols as it pertains to mTBI cognitive screen/assessment and management in the CAF context. While education and knowledge were identified as an asset, breakdowns in care pathways for CAF-SMs and complications with attaining services or interpreting cognitive screen/assessment results were noted if HCPs' knowledge in the area of cognition was not up-to-date. Widespread, regular, multidisciplinary education for HCPs regarding mTBI management as well as cognitive screen/assessment best practices, specifically around interpretation and utilization of results and transfer to functional outcomes, were the main recommendations put forth by the participants.

Table 4: Education and Knowledge of Clinicians and staff regarding mTBI and cognitive screens/assessment

	Themes and Supporting Quotes
Facilitators	**Units and Chain of Command are supportive of training and education.** *"Where I am now, I am 100% supported and I don't feel that I'm lacking in anything. Whether its support from the unit, whether its patient buy in, or tools. I think I'm very well surrounded." p2*
Barriers	**Interpretation of results from cognitive screen/assessment are challenging.** *"The question is what they do with that data? Like how you interpret that and how you sort of decide whether additional assessment is required? So then what's the next stage and are those particular professionals able to make that next step judgment?" p7* **The appropriateness of cognitive assessment referrals from primary care providers is variable.** *"Some of its even having the physicians and the PCNs (primary care nurse) and mental health recognize that they're (CAF-SMs) struggling with their ability to remember things, have difficulty with pacing, or they're struggling with motivation, to know that they can refer to OT to provide more of an occupational focussed assessment." p7* **There is a lack of prompt identification of those who have sustained an mTBI and**

	need for cognitive screen/assessment. *"I feel there is probably a lot of mTBI that has become chronic that we don't necessarily catch and gets thrown under the label of a mental health disorder when it is in-fact an organic disorder. So I don't know how primary care is necessarily screening for that but I feel they could be doing a better job." P17*
Recommendations	**Implement CFHS-facilitated education for clinicians and staff regarding assessment of acute mTBI in primary care through to post-concussion in rehabilitation.** *"Education for all the team members. Physicians to physical rehab to mental health so everyone is on board with the same process." p1* **Facilitate education regarding the purpose and desired outcome of cognitive screen/assessments by organization**. *"Mental health and physicians need to have a better idea of what type of assessments we have available and what are the dimensions of that assessment. And then the practical, the link to the practical aspects and how that can impact the day-to-day of the clients." p7*

4.4.2.2. Multidisciplinary collaboration

The practice of HCPs from different disciplines working together in the healthcare and management of mTBI among CAF-SMs including cognitive screen/assessment practices (Table 5) was commonly discussed by study participants. Identified as the most prominent facilitator, participants from all represented disciplines expressed the desire for enhanced multidisciplinary collaboration in mTBI and cognitive screen/assessment processes and recommended action to improve this within clinics, regions, and departments.

Table 5: Multidisciplinary Collaboration

	Themes and Supporting Quotes
Facilitators	**Evidence-based policies and procedures are emerging from Headquarters.** *"I think policies and the communiques are starting to gradually come out...I think it's getting there but still a lot to go but we are still a lot further than we were 5 years ago." p3* **The collaborative relationship between physiotherapy and occupational therapy supports cognitive assessments.** *"Within our (physio) office we have OT right here so that's fantastic because we talk to them one on one and it's very collaborative." p14*

	Recent expansion of the Occupational Therapy program has made cognitive assessments more accessible. *"if I need a cognitive assessment and, like I said we've only gone short periods of time where we didn't have an OT, I can get that fairly quickly." p11* *"The new OT program and having it and having the OTs there getting involved in the multidisciplinary between the OTs and physios and OTs pushing it." p3*
Barriers	**A lack of standardization in policy, protocol, and practice for mTBI and cognitive screen/assessment impacts treatment**. *"I just don't think there has been a direction from Ottawa with how to deal with a patient presenting to Primary care with concerns about cognitive impairment so I think we need to ...we need more national direction and more protocols on … at the primary care level on how to manage those patients." p17* **There is a lack of clarity of the clinical roles and scope pertaining to cognitive screens/assessment.** *"I'm not exactly sure if it's something psychologists or social work are administering frequently. Or even nurses or physicians or physician's assistants." p5* *"what should we be doing with it as a physio? How much can we do with it and when is the tipping point that when we should be sending to OT? Or should it be automatically OT? The question is a grey area, I'm not sure what the right answer is." p3* *"I don't know if the psych(ology) on base do any of this stuff or not." p9* **Communication among healthcare disciplines can impede cognitive assessments.** *"we don't have good communication with mental health. And sometimes trying to get the doctors on board too is difficult. So I find that's lacking. I find there's not a great multidisciplinary approach for treating concussions and that can be worked on. I know it's a policy here, I cannot look in "patients' mental health (record). So if the patient has had a neuro-psych assessment and its filed under mental health, I can't look at it...I think that's part of concussion patients. When you have that neuro-psych (assessment report) you can at least have a better understanding of how to treat the patient." p11*
Recommendations	**Standardize policies, protocols, and practices for mTBI and cognitive screens/assessments across CFHS.** *"it should be the same for every region and it also should be the same for taking the concussion patient and you know, bringing him in a clinic, a medical clinic. The approach should be the same, not just on the physio part, but on the mental health and the primary care part. So, it should be among the professionals and also among the region." p10* **Create standard guidance documents, cheat sheets, or summation of the evidence-base for clinicians of each discipline.** *"...a diagnostic and treatment algorithm based on evidence because I am sort of searching for it myself. If we had a synopsis of literature saying within our population given this presentation these are the things that are shown to work and evidence- based. And given this presentation here, other dx. routes should be followed. So again it comes back to having good protocols." p17 "if we knew what the policies and procedures were I think that might help.. I don't know if there are any other policies and procedures or anything that I should be looking at as to when I should be using such a screen or not." p11*

	"Well inherent in your question is for me to know what best practices are and to be quite frank, I can't tell you what they are." p15

4.4.2.3. Stigma, awareness, and attitudes of CAF personnel regarding mTBI

Although overall awareness and acceptance of mTBI in society is at an all-time high, reducing the stigma associated with mTBI and enabling others to recognize the injury is essential. Participants felt that CAF-SMs continued to underreport mTBI and cognitive challenges due to fear of career repercussions or a lack of education about mTBI management and recovery. Recommendations involved forms of education for CAF-SMs at the clinical and unit levels to improve overall knowledge of mTBI and de-stigmatize engaging with healthcare when appropriate (Table 6).

Table 6: Stigma, awareness, and attitudes of CAF personnel regarding mTBI

	Themes and Supporting Quotes
Facilitators	**Increased awareness of mTBI in society and media has had an impact on stigma and attitudes toward mTBI.** *"I think there's more education there in general about concussions that's kind of getting out in different avenues. Be it the media or be it just through our athletic population...So it's not so much of a stigma to get, to go get help if you got whacked in the head any more than it used to be." p14*
Barriers	**CAF-SMs fear mTBI diagnosis or recognition of cognitive impairment will have a negative impact on military career.** *"Some patients' units are quite supportive and some are still very, if you don't mind the term, old school. In that you just got knocked in the head, you know what suck it up, keep going, push through your course and push through the exercise you're on. So until that old school mentality gets removed or gets put in check there still are, I think are some people who, units are not supportive of them seeking medical care...they (the patient) don't want to get taken off of course or off an exercise or put on a TCAT or something because they want to deploy. So the patient themselves might be a barrier for that." p14* **Patient reaction to cognitive screen/assessment can impede assessment and treatment for mTBI.** **a) Patients can lack engagement.**

	"I find with some of the assessments they're not based in function enough for people to buy into. They're like, why am I doing this? This is silly." p15 *"it's a longer assessment it can be very anxiety provoking for the member. So the emotional distress rises, they have a harder time focusing." p7* **b) Patients can have a lack of insight into their cognitive issues.** *"might be challenging for some people to identify that they do maybe have some type of cognitive dysfunction." p2* *" their rationalization is I'm getting old, I'm distracted, my kids are running my ragged, you know, it's those kinds of things." p16*
Recommendations	**Implement education campaigns for all CAF-SMs on mTBI.** *"I've had many, when I was there having difficult conversations with members who were in with concussions saying that, 'well you can't be on the computer.' Well, my job requires me to. I'm like, 'Well, then your job has to be modified.' Well, it can't. Well then it's, 'how do we get you better?' How do you minimize these cognitive symptoms if you can't actually do the things you have to do? And I think there needs to be understanding and it comes right back to that unit level. You need huge buy in there and it's hard, especially when you have, not to sound gruff, but these crusty old people." p13*

4.4.2.4. Availability of Resources

Availability of equipment, personnel, training, finances, time, and other factors were noted by participants to be both barriers and facilitators to the effectiveness and efficiency of healthcare services, which varied widely depending on geographic location (Table 7). As well, HCPs noted that a multidisciplinary team was needed in the cognitive screen/assessment processes which includes disciplines such as OTs and neuropsychologists. Further, it was acknowledged that even within the profession, the "right" HCP was required as not all HCPs have the same training, experience, and knowledge regarding mTBI and cognitive screening/assessment. Recommendations from the HCPs centred around improving access to IT so cognitive screen/assessment processes could be updated and the most current evidence-based tools could be utilized.

Table 7: Availability of Resources

	Themes and Supporting Quotes
Facilitators	**Convenient, timely access to healthcare services is available through CFHS.** *"Easy to engage with health services to talk about symptoms. They have access to the health system." p4* **CAF-SMs have full financial coverage for healthcare.** *"because it (CAF) supports, financially supports the assessment. Facilitates it. They're not cheap." p12*
Barriers	**Challenges exist with IT limiting access to more current and computerized assessments.** *"The assessment is made in the early 2000s. It's now 2020 and we don't use any electronic or any computer because of the computer security issue and everything but I really feel that we are 10 to 15 years behind because of this." p6* **Finding outsourced HCPs in the community with adequate training and experience with cognitive assessment and the military context is challenging.** *"When we don't have an (in-house) OT, then it's a question of outsourcing and then we're, you know, reliant on the availability of the outsourced occupational therapy. So I think it's mostly the availability of resources." p11* **Cost of neuropsychological assessments is high.** *"several thousand dollars for full on neuro psychiatric assessments done by psychologists who often conclude there's a little bit of impairment but probably because of mental illness. In treating the mental illness it might go away." p16* **Small and remote CAF sites may have less resources or unique resource requirements.** *"A lot of neuro psych isn't that easy to do remotely...there's pen and paper testing, there's scoring, there's feedback, there's sometimes there's tiles to work with and all this stuff. So I don't think that translates that well virtually. So the person in the isolated places, sadly will probably not get access to the quality of care that they would in the major centres or would have to wait an inordinate amount of time for it or may have to travel for it." p16* **Time constraints impede assessment preparation and execution.** *"I feel that I'm not up to date, even if I'm trying to read. Trying to get up to date by myself but I don't feel like with a clinical caseload that I don't have the time to do all that I want." p6* *"...the guys don't have much time, so when they come that needs to be up and ready and needs to work, right." p10* *"I think once they're in the system, it's to ensure that you have consistent time with them. In my unit the operational tempo is so incredibly fast that sometimes it's hard to have consistent time with somebody." p2*

Recommendations	**Modernize IT and security to accommodate newer screening/assessment demands.** *"I think we could be better. I think there's room for improvement, for more modern, using like...a tablet-based type of assessment. I mean there's definite options to grow and improve." p5* **Employ the right profession for the job.** **a) Occupational Therapy** *"You need an OT. To treat concussion patients or even mental health or chronic pain, you need an OT. It has to be multidisciplinary. " p11* **b) Neuropsychology** *"It would be nice if we had our own in-house neuro psych capability. We don't have a position for one and even if we had psychologists who have neuropsychology training we can't use them as such." p12*

4.4.2.5. Cognitive screen/assessment tools

The tools and kits used for cognitive screen/assessment were also consistently noted by participants to be both barriers and facilitators (Table 8). The availability of cognitive screen/assessment was identified as a facilitator, while sensitivity, specificity to the population, functionality, and up-to-datedness were identified as barriers. This is consistent with many of the issues noted in the evidence-based literature regarding cognitive screen/assessment in military and civilian healthcare contexts. Recommendations largely centred around considerations unique to the CAF, including the need for the translation and validation of bilingual tools, updating IT capacity, and research specific to CAF personnel in their context.

Table 8: Cognitive Screen/Assessment Tools

	Themes and Supporting Quotes
Facilitators	**Adequate access to cognitive assessment tools and kits enables administration of cognitive assessments.** *Multiple cognitive screening and assessment tools were reported by study participants.*

Barriers	**Current tools lack sensitivity.** *"The testing that we do have is not sensitive enough for our members. They are showing symptoms but it's not coming through in our data. I think there needs to be more, better sensitivity and specificity for more advanced, not advanced, but higher functioning soldiers because that's been the common concern." p3* **There is a lack of evidence for assessment tools specific to military personnel.** *"in terms of limitations, it'd be great to have the normative data for our members versus the sports population. A lot of the data is for younger athletes. Our guys, you know, are more experienced but their level, like what they have to do is very different than an athlete." p10* **Tasks included in assessment tools are not functionally relevant to military environments.** *"I have to work from my home for adapting (the assessment) to the military population because what we've seen for cognitive assessment is more for older people...so I had to work on my own for adaptive and found specific assessments that fit with my population." p6* **Outdated assessment tools are used.** *"paper and pencil tests that have been developed for the general population might not be appropriate for our population, for the military members." p5*
Recommendations	**Assessment tools need to be translated and validated in French and English.** *"If we're testing primary language as French, first language as French, and we are doing the test in English, is that really going to give you a right, the proper results that we're looking for?" p3* **Research initiatives are needed specific to the CAF population.** *"There needs to be more research and development done for the specific military population." p3* *"Research. And it could be through affiliation with a university, researchers like you, but also like in house mini research and projects." p5* **Baseline cognitive testing ought to be conducted for all CAF-SMs.** *"Basically anyone that is coming back from exercise, anyone who is enrolling, anyone who has a change in their status needs to be screened for mTBIs. We should have a baseline ax. for patients when they come into the CAF...a lot of sports teams do it too." p17*

4.5 Discussion

This study aimed to gain the HCP's perspectives on cognitive screen/assessment practices within CFHS to inform future efforts at providing this service to CAF-SMs with mTBIs. Thematic analysis of interviews with HCPs offered valuable insights regarding the administration of cognitive screen/assessment on the front lines of CFHS. Categorization of key topics by facilitators, barriers, and recommendations (Tables 4 to 8) offered a window into the current cognitive screen/assessment practices and may provide a starting point to construct a best-practice approach and implementation strategy that is appropriate within the CAF context. Doing so, however, will require policy, practice, and system change. Each topic identified by study participants has distinct facilitators and barriers, though the extent to which each affects practices and participants varied between geographical regions and clinics. Ideally, facilitators need to be maximized, barriers overcome, and recommendations implemented to ensure that cognitive assessment practices are best used in practice; doing so will require policy, practice, and system change.

Some of the themes can be generalized to other military and civilian mTBI and cognitive screen/assessment practices, while others are unique to the CAF context. For example, themes that emerged regarding multidisciplinary collaboration and cognitive screen/assessment tools demonstrated consistency with evidence-based practices and recommendations for mTBI management. The concerns of the participants addressed many of the widespread issues with cognitive screen/assessment tools in multiple healthcare contexts including validity, reliability, feasibility, functionality, sensitivity and appropriateness to the population. Conversely, the availability of resources is unique to the CAF context, including vast geographical regions and military operations. This has less generalizability to other healthcare systems. Themes also consistently cascaded throughout the health disciplines with commonality opposed to each having unique facilitators, barriers, and recommendations. These observations and conclusions could be helpful in paving a path forward to design and trial best-practice cognitive screen/assessment protocols and procedures within an implementation science approach.

4.5.1 Active Implementation Frameworks

Implementation science is the study of variables and conditions that impact changes at practice, organization and systems levels; changes that are required to promote the systematic uptake, sustainability, and effectiveness of evidence-based programs and practices in typical service and social settings (Eccles & Mittman, 2006). The field of implementation science has developed to facilitate the spread of evidence-based practice and research, including both psychosocial and medical interventions with the use of theoretical approaches to provide better understanding and explanation of how and why implementation succeeds or fails (Bauer, Damschroder, Hagedorn, Smith, & Kilbourne, 2016; Nilson, 2015). The AIFs (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005) are a common set of evidence-based frameworks used in implementation research and science that can assist with the planning and execution of such an undertaking that will promise to be resource intensive (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). A well-mapped implementation plan can assist with filling the gap from research to practice through evidence-based guidance in knowledge exchange, transfer, integration, and utilization (Nilson, 2015).

This thematic analysis may act as a step in the Exploration Stage in a process of developing a cognitive screen/assessment protocol, or the "usable innovation" (Figure 12). Further research and investigation within the Exploration Stage, including assessing fit, ensuring a usable innovation (cognitive assessment best practice process), enhancing competencies of HCPs to administer evidence-based cognitive screens, and creating implementation teams to facilitate sustainable cognitive assessments across CFHS, and establishing practice policy loops. Consideration of participant recommendations from this study may set the stage for development and implementation of a widespread and multidisciplinary cognitive screen/assessment process embedded within mTBI protocols and policies.

Figure 12: The Exploration Stage and the Usable Innovations AIF

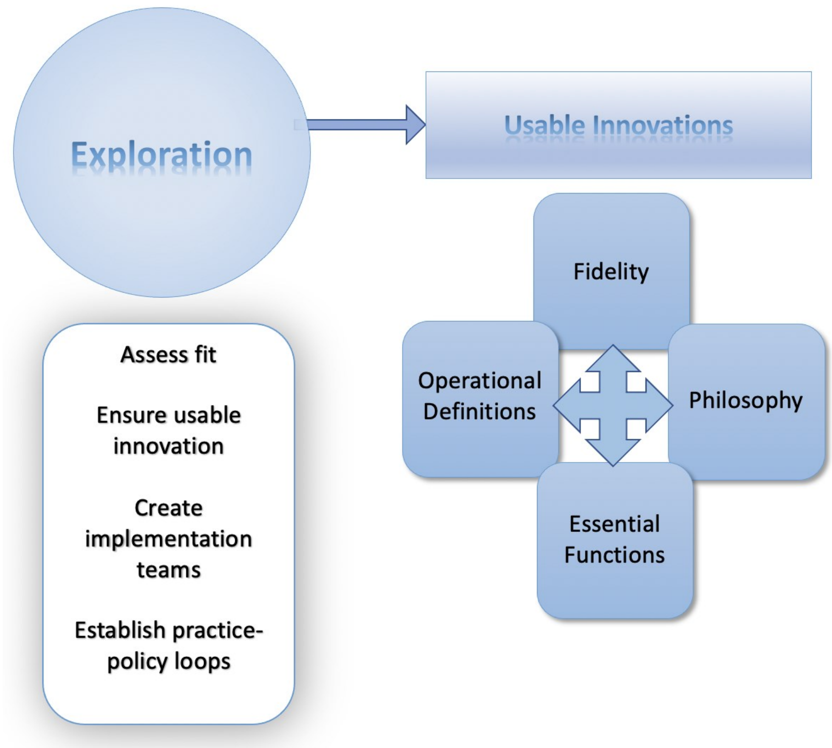


Figure 12: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

4.5.2 Future Implications

Looking forward, the next stage of implementation shown in the AIFs (Figure 11) is the Installation of cognitive screen/assessment policies and protocols which would include a plan for ongoing evaluation of effectiveness, efficiency, fidelity, and sustainability of the cognitive screen/assessment policy and protocol. Once the Initial Implementation stage is initiated, the ongoing evaluation and review process would enable modifications and improvements to be made before full implementation. Evaluations and communication with decision-makers can be guided by ongoing Plan, Study, Do, Act (PDSA) Cycles (Figure 13) and Practice-Policy

Communication Cycles (Figure 14) which engage stakeholders and the primary intended users (i.e., HCPs and CAF-SMs) at a micro, meso, and macro level. Full Implementation would see the cognitive screen/assessment policy and protocols implemented on a wider scale with the primary goals of continued improvement, efficiency, effectiveness, fidelity, and sustainability. Throughout the full implementation, the PDSA and Practice-Policy Communication Cycles would remain ongoing as well as other components of the previous stages to ensure that the evidence-base is monitored and new research and findings are incorporated for maximum effectiveness.

Figure 13: Plan, Do, Study, Act (PDSA) Cycle AIF

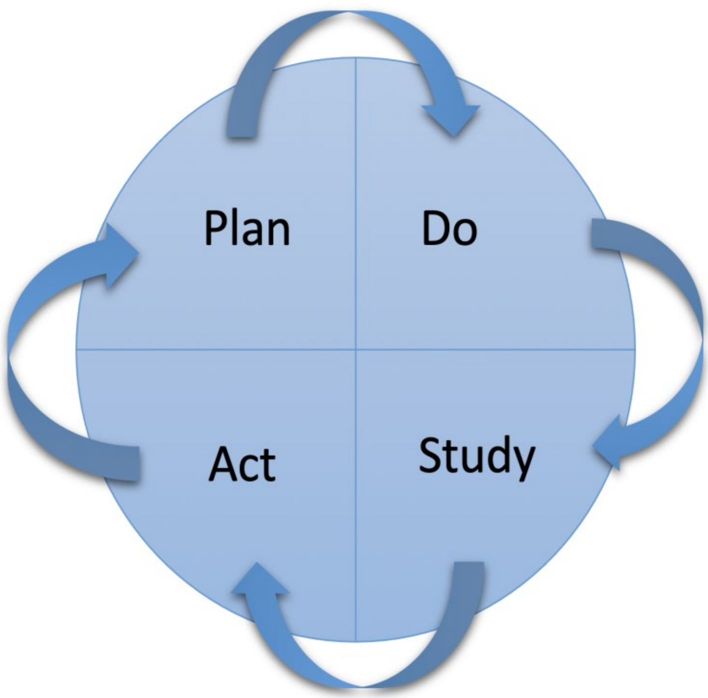


Figure 13: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Figure 14: Practice-Policy Communication Cycle AIF

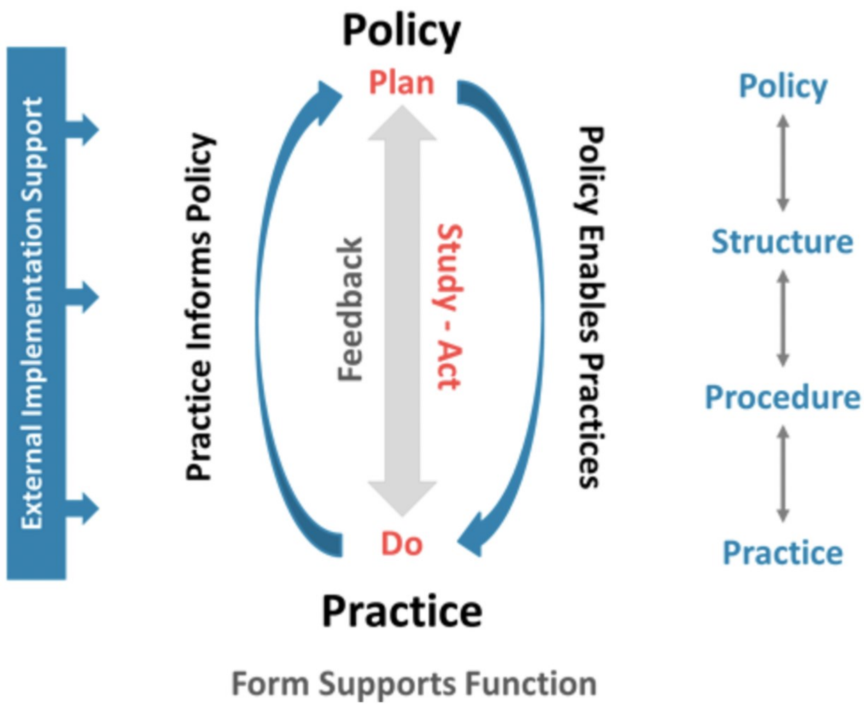


Figure 14: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Notably, addressing barriers regarding IT accessibility is crucial in the wake of healthcare scenarios, such as global pandemics, that warrant increased utilization of digital health and other healthcare technologies. Cognitive screen/assessment policies, protocols and tools should be feasible from a privacy, security, confidentiality, accessibility, and equipment perspective with educated and qualified clinicians performing this role. Concerns around availability and security of networks, Wi-Fi, computer access, etc. are evident when the additional factor of national security is of foremost importance. With the use of technology-based and remote digital assessment tools, it is important to note that significant gaps in research and clinical knowledge remain and further research and investigation as part of a planned implementation approach is warranted. Generalizable to other healthcare systems, issues surrounding the need and possibilities of virtual screen and assessment of cognition will warrant research.

4.5.3 Study Limitations

There were a number of limitations associated with this study. Firstly, although attempts were made to recruit a variety of HCPs, none of the CFHS psychologists volunteered to participate. This leaves a component of the multidisciplinary perspective absent. Secondly, although many similarities in themes were observed across disciplines, the extent of how they affected the participants in their clinical practice showed variation at the national, regional, and unit levels. Lastly, although attempts were made to maximize the confidentiality and privacy of participants, in organizations with traditional hierarchical dynamics it is always possible that data collection may be influenced by distrust, fears, or pressures that are directly attributed to the organizational hierarchy. This could be a threat to the dependability of the data which is a common concern with qualitative research among military personnel (Bernthal, 2015).

4.6 Conclusion

mTBI, cognitive dysfunction, and cognitive screening and assessment practices are complex and require additional in-context consideration, research, and knowledge translation to assist with creating a best practice approach within CFHS. The mobile nature of the CAF necessitates cognitive screen/assessment practices that can be performed across Canada whether CAF-SMs are engaged in military training, natural disaster recovery, or other military duties. Further, cognitive screening/assessment is necessary in deployment areas around the globe, especially where mTBI and other injuries are likely to be prevalent at a higher rate. It is incumbent upon members of multidisciplinary healthcare teams to identify cognitive deficits and develop healthcare plans addressing them to maximize functioning (Radomski et al., 2009). By using a guided implementation science approach to the development, operationalization and implementation of an evidence-based, standardized, and sustainable system that optimizes cognitive screening and assessment practices, CFHS will be supported to best assess, treat, and rehabilitate cognitive dysfunction facilitating a more productive, safe, and healthy fighting force.

4.7 References

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6. Technology Acceptance and Usability of the BrainFX® SCREEN in Canadian Military Members and Veterans with Posttraumatic Stress Disorder and Mild Traumatic Brain Injury: A Mixed Methods UTAUT Study

Submitted to: Journal of Medical Internet Research: Rehabilitation and Assistive Technologies

5.1. Abstract

Introduction: Canadian Armed Forces (CAF) service members (SMs) and veterans exhibit higher rates of injuries and illnesses such as posttraumatic stress disorder (PTSD) and traumatic brain injury (TBI), which can cause and exacerbate cognitive dysfunction. Computerized neurocognitive assessment tools (NCATs) have demonstrated increased reliability and efficiency compared to traditional cognitive assessment tools. Without assessing the degree of technology acceptance and perception of usability to the end users, it is difficult to know if a technology-based assessment will be used successfully in wider clinical practice. The Unified Theory of Acceptance and Use of Technology (UTAUT) model is commonly utilized to address technology acceptance and usability of applications in 5 domains. Purpose: To determine the technology acceptance and usability of a NCAT, titled the BrainFX® SCREEN, by CAF-SMs and veterans with PTSD utilizing the UTAUT model. Methods: This mixed-methods embedded pilot study had CAF-SMs and veterans (n=21) 18-60 years of age with a diagnosis of PTSD complete pre/post questionnaires on the same day the BrainFX® SCREEN was utilized. A partial least square structural equation model was utilized to analyze questionnaire results. Qualitative data was assessed via thematic analysis. Results: Facilitating conditions, which was the most notable

predictor of behavioural intention, increased after using the BrainFX® SCREEN, while effort expectancy decreased. Performance expectancy, effort expectancy, and social interaction were not factors in predicting behavioural intention. Conclusion: The BrainFX® SCREEN appears to be a feasible, usable, and accepted assessment tool for CAF-SMs and veterans who experience PTSD.

5.2. Introduction

Canadian Armed Forces (CAF) service members (SMs) and veterans exhibit higher rates of injuries and illnesses, such as posttraumatic stress disorder (PTSD), depression, anxiety, sleep disorders, and mild traumatic brain injury (mTBI) which can cause and exacerbate cognitive dysfunction (Department of National Defense, 2016; Jones, Pike, & Brémault-Phillips, 2019). Numerous studies conducted in Canada, the United States, and United Kingdom demonstrate a high prevalence of mTBI and PTSD as comorbidities specific to deployments during the War on Terror (2001 to 2013; Armistead-Jehle, Soble, Cooper, & Belanger, 2017; Hodge, McGurk, Thomas, Cox, Castro, & Engel, 2008; Rona, et al., 2012). The co-occurrence of traumatic brain injuries (TBI) and PTSD can arise from the same or separate traumatic incidents (Armistead-Jehle, Soble, Cooper, & Belanger, 2017).

When mTBI symptoms persist for longer than 3 months, they may be referred to as post-concussive symptoms (PCS: McCrory, Meeuwisse, Dvořák, Aubry, Bailes, Vos, et al., 2017). In a study assessing CAF-SMs with mTBI from deployments in Iraq and Afghanistan during the War on Terror, PCS was present in 21% of those with less severe forms of mTBI and in 27% of those with more severe forms of mTBI (Garber, Rusu, & Zamorski, 2014). Rates of PTSD amongst Canadian veterans has been estimated at 16% (van Til L, Sweet, & Poirier, 2017). Interestingly, after adjustment for confounding variables, mTBI were found to have no significant association with PCS relative to non-TBI injury (Garber, Rusu, & Zamorski, 2014; Roberge, Baker, Ely, Bryan, Bryan & Rozek, 2020). Mental health conditions, such as combat related (cr) PTSD, had a strong association with reporting 3 or more PCS (Garber, Rusu, & Zamorski, 2014; Roberge, Baker, Ely, Bryan, Bryan & Rozek, 2020). Identifying if symptoms are related to mTBI and/or a concurrent mental health diagnosis is difficult as many of the symptoms attributed to these conditions overlap. Symptoms often described as PCS in patients with mTBI may be better explained from a psychological standpoint and may be more likely to be caused by PTSD (Roberge, Baker, Ely, Bryan, Bryan & Rozek, 2020). One such symptom that may present as a result of mTBI and/or PTSD is cognitive dysfunction.

5.2.1. Cognitive Dysfunction and Assessment

Cognition is a broad construct that refers to information-processing functions carried out by the brain (Diller & Weinberg, 1993). Such functions include attention, memory, executive functions, comprehension, speech (Sohlberg & Mateer, 1989), calculation ability (Roux, Boetto, Sacko, Chollet, & Trémoulet, 2003), visual perception (Warren, 1993), and praxis skills (Donkervoort, Dekker, Stehmann-Saris, & Deelman, 2001; American Journal of Occupational Therapy, 2013). Cognition is instrumental in human development and the ability to learn, retain, and use new information in response to everyday life, and is integral to effective performance across the broad range of daily occupations such as work, educational pursuits, home management, and leisure, (American Journal of Occupational Therapy, 2013). Reduced cognitive functioning can detrimentally affect a person's relationships and cause mental and emotional distress (Radomski, Davidson, Voydetich, & Erickson, 2009; American Journal of Occupational Therapy, 2013). Within the military context, cognitive dysfunction can potentially result in decreased efficiency and effectiveness and increased risk of harm to self, the unit, and a CAF mission (Jones, Pike, Brémault-Phillips, 2019).

Due to the cognitive challenges and dysregulation that can be caused by PTSD, cognitive assessment and screening is important to enable clinicians to recommend treatment, referrals, and advise on a CAF-SM's or veteran's safety in activities of daily living which may include military activities (Radomski, Davidson, Voydetich, & Erickson, 2009; Soble, Critchfield, &

O'Rourke, 2016). Reliable, valid, specific, and function-based cognitive screening and assessment practices are essential to determination of effective interventions to improve cognitive functioning (Soble, Critchfield, & O'Rourke, 2016). Computerized neurocognitive Assessment Tools (NCATs) are widely utilized in other global militaries and have multiple benefits including increased inter- and intra-rater reliability, ease of administration, reduced time to administer, and ease of calculating and analysing results (Cernich, Brennana, Barker, & Bleiberg, 2007). One such tool that is being trialed within the Canadian Forces Health Services (CFHS) is the BrainFX® SCREEN.

5.2.2. BrainFX® SCREEN

The BrainFX® SCREEN is a function focused, Canadian made tool that addresses neurofunction through a digital interface on a tablet (Milner & Condello, 2017). Based on its more comprehensive predecessor the BrainFX® 360, the BrainFX® SCREEN has a 10-15-minute duration and is administered by a healthcare professional trained as a Certified BrainFX® Administrator (CBA) via a touch tablet to set a baseline or to determine if a further assessment or test is needed (Milner & Condello, 2017). The BrainFX® SCREEN has 15 tasks within 7 domains of cognition which include: (1) Overall Skill Performance, (2) Sensory and Physical Skill Performance, (3) Social and Behavioral Skills Performance, (4) Foundational Skills Performance, (5) Intermediate Skills Performance, (6) Complex Skills Performance, and; (7) Universal Skills. The BrainFX® SCREEN is a condensed and more recent version of the BrainFX® 360 assessment; as such, it has not been researched for validity and reliability as its predecessor has. The BrainFX® SCREEN also collects a variety of demographic and health information including level of education, presence of other comorbidities including mTBI, chronic pain, and other mental health diagnoses, current level of fatigue, presence of sleep difficulties, and presence of self-perceived neurofunctional deficits. The BrainFX® 360 assessment has been subjected to reliability and validity testing and current evidence demonstrates that this comprehensive assessment has promising validity, reliability, and sensitivity, with a focus on neurofunction (Searles, 2015; Sergio, & Gage, 2014). The BrainFX® SCREEN has undergone widespread uptake within Canada and the US but has yet to be subjected to testing based on evidence-based models or frameworks for technology acceptance.

5.2.3. Technology Acceptance and Usability in Healthcare and Military Contexts

Technology offers healthcare professionals a variety of benefits from improving effectiveness, efficiency, and potentially engagement in record keeping, assessments and interventions. As such, the acceptance of such technologies by healthcare professionals is an important topic of interest to both practitioners and researchers (Ifinedo, 2012). Without technology acceptance and acceptable usability for the user, technological assessments and interventions may not be adopted into clinical practice despite effectiveness. Evaluation of acceptance and usability of emerging technology is integral to advancing best practice in healthcare (Liu, Miguel-Cruz, Rios-Rincon, 2020).

Due to some of the fundamental differences in military culture, environment, and contexts, the relationship between the users and technologies, and the variables influencing this, may need to be considered separately from civilian relationships with technology. Many military organization's approach to technology is to measure and maximize the operator performance in order to increase system efficiency that translates to success in military missions (Smsek, 2008). It is unknown if current models and frameworks of technology acceptance and usability have applicability with military populations, as the relationship of the military personnel and organization is not consumer based. It may also be presumed that performance and functionality of technology is prioritized over comfort and aesthetics (Smsek, 2008).

Regardless of the potential differences in the relationship between the user and technology in a military context, the use of digital and mobile (m)health innovations is becoming widespread within military and veteran populations (Jones, O'Toole, Jones, & Brémault-Phillips, 2020; Tam-Seto, Wood, Linden, & Stuart, 2018). This has been amplified by the recent COVID-19 pandemic when virtual health solutions have become increasingly common in all healthcare practices, including those in military environments. Although the majority of studies addressing technology attitudes, beliefs, acceptance, and usability within military and veteran populations are US based, current evidence suggests that the military population is willing to utilize digital and mHealth technologies (Jones et al, 2020; Tam-Seto, Wood, Linden, & Stuart, 2018; Armstrong et al., 2017). Regardless of the context for a technological innovation, adequate technology acceptance and usability is key to its uptake within that environment and culture. Before addressing the facilitators and barriers to the usability of a technological innovation, it is helpful to directly or indirectly assess the technology acceptance within the different user groups within their context using a framework or model.

5.2.4. The Unified Theory of Acceptance and Use of Technology Model

The Unified Theory of Acceptance and Use of Technology (UTAUT) model was developed based on previous theories and models for acceptance and adoption of technologies and consumer products that addresses the perceived technology acceptance of a user group with the goal of predicting usage behaviour (Figure 15; Venkatesh, Morris, Davis, Davis, 2003). The UTAUT has been demonstrated to explain as much as 70% of the variance in intention to use technology compared to its predecessors (Venkatesh, Morris, Davis, Davis, 2003).

Figure 15: The Unified Theory of Acceptance and Use of Technology (UTAUT) Model

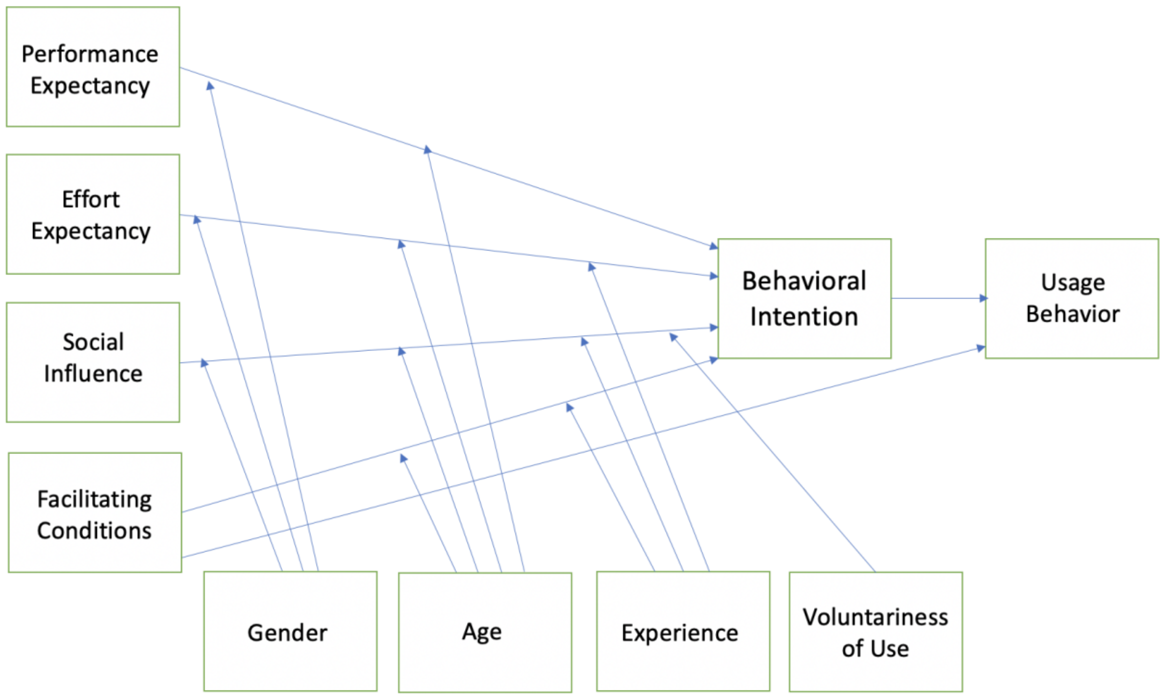

Figure 15: (Venkatesh, Morris, Davis, Davis, 2003).

The UTAUT model addresses the perceived expectations of technological acceptance of new technology in five constructs: performance expectancy (PE), effort expectancy (EE), social influence (SI; direct determinants on behavioral intention) as well as facilitating conditions (FC) and behavioural intentions (BI) which is the direct impact upon use behavior (Venkatesh, Morris, Davis, Davis, 2003). This model was developed from the point of view of the implementation of new technologies in practice within organizations, on individuals rather than technology for mass consumer consumption (Rondan-Cataluña, Arenas-Gaitán, & Ramírez-Correa, 2015; Williams, Rana, & Dwivedi, 2015). The UTAUT is a model that is commonly tested by using partial least square (PLS) structural equation modelling (SEM) and is an example of a reflexive PLS path model (Venkatesh, Morris, Davis, Davis, 2003). The exogenous latent variables (PE, EE, SI, and

FC) are affected by the endogenous latent variable (BI) which affects the construct of use (U; (Venkatesh, Morris, Davis, Davis, 2003). As well, FC can also have a direct effect on U (Venkatesh, Morris, Davis, Davis, 2003). Moderator variables, which include age, gender, experience, and voluntariness of use, also affect the interaction between the indicators and constructs (Venkatesh, Morris, Davis, Davis, 2003; Williams, Rana, & Dwivedi, 2015).

BI is defined as the intention to utilize technology and U is defined as the actual use (Venkatesh, Morris, Davis, Davis, 2003). BI predicts if the technology in question will be adopted by the user in reality. The three direct determinants of BI to use technologies are PE, EE, and SI. PE has been defined as the degree to which an individual believes that using the system will help the person to attain gains in task performance (Venkatesh, Morris, Davis, Davis, 2003). The EE construct was defined as the degree of ease associated with the use of the system and SI is the degree to which an individual perceives that important others believe he or she should use the new system (Venkatesh, Morris, Davis, Davis, 2003). FC have been defined as the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system (Venkatesh, Morris, Davis, Davis, 2003). FC, PE, and EE are considered beliefs, or the information the person has about an object, and SI is considered the subjective norm (Venkatesh, Morris, Davis, Davis, 2003). The UTAUT has well established construct and content validity. Validity is more likely to be influenced by bias and other factors including those unique to research with military populations.

The UTAUT model has most commonly been utilized with civilian populations. As military contexts necessitate unique and varying relationships between the user groups and the technology, it is unknown if the UTAUT model could be an accurate representation of technology acceptance and usability amongst military members and other secondary or tertiary users. The perspective of the end and primary user, the military member, is not always measured or even considered since global effectiveness is prioritized over individual preferences (Smsek, 2008). As the UTAUT was originally developed for an individualistic approach to measuring technology acceptance and usability, it may not be applicable to military contexts (Smsek, 2008; Venkatesh, Morris, Davis, Davis, 2003). Literature utilizing the UTAUT model amongst military populations is scarce and the model has not been utilized in the CAF context. The results of existing studies utilizing the UTAUT amongst military populations demonstrate varying results making it challenging to form a hypothesis for future studies.

The UTAUT has been utilized in more recent years as a model and framework for addressing technology utilization and acceptance in healthcare (Liu, Miguel-Cruz, Rios-Rincon, 2020). To date, the majority of research in health technology utilizing the UTAUT has involved exploration of computerized medical records where the primary intended user is the healthcare professional (Liu, Miguel Cruz, Rios Rincon, Buttar, Ranso, & Goertzen, 2015). Studies that focus on the patient as the primary intended user are beginning to emerge in the literature with specific demographics, such as older adults, youth, and cardiac populations. These studies have evaluated the technology acceptance and usability of a multitude of digital and mHealth technologies including health apps, wearable measurement technology, and virtual access to medical records. Hypotheses regarding the effect of the latent variables on BI and U have been formed regarding the healthcare professional as the primary intended user. Studies focusing on the patient as the primary intended user have demonstrated variable results making the formation of a directional hypothesis challenging.

The technology acceptance and usability of NCATs from the perspective of the patient within a healthcare setting, warrants evaluation as questions of feasibility must be addressed before clinical investigations regarding specificity, reliability, validity, and sensitivity can take place. Without addressing acceptance and usability, technological innovations may not be adopted or sustained. Although technology acceptance and usability testing is emerging in healthcare technologies, the combination of a military context and its effects at multiple user levels warrants further exploration. The adoption of the BrainFX® SCREEN within Canadian Forces Health Services (CFHS) provides an opportunity to investigate technology acceptance and usability at the primary user level of the patient.

5.2.5. Purpose

The purpose of this mixed-methods pilot study is to determine the technology acceptance and usability of a computer-based cognitive BrainFX® SCREEN, by CAF-SMs and veterans with crPTSD utilizing the UTAUT model. This study acknowledges the CAF-SMs and veterans with crPTSD and/or mTBI as the primary intended users. Potential rejection of the BrainFX® SCREEN by the CAF-SMs would provide important information and direction to CFHS on the way forward in addressing cognitive assessment with the BrainFX® SCREEN as a tool. It is hypothesized that PE and FC will be the most influential variables on BI and U respectively. As well, it is hypothesized that SI will be the least influential on BI.

5.2.6. Research Model

Figure 16 demonstrates the research model utilized for this study. The moderator variables of “Experience" were removed since the BrainFX® SCREEN is not meant to be utilized continuously or practiced with the goal of improving performance when used as an assessment tool. Since the user is asked to complete the assessment by their clinician, and is not a tool designed for regular use, the moderator of “Voluntariness of Use” was removed for the research model. Age and Gender are the two moderator variables that remained in the original research model utilized for this study.

Figure 16: The UTAUT Model with Age and Gender as the Moderator Variables

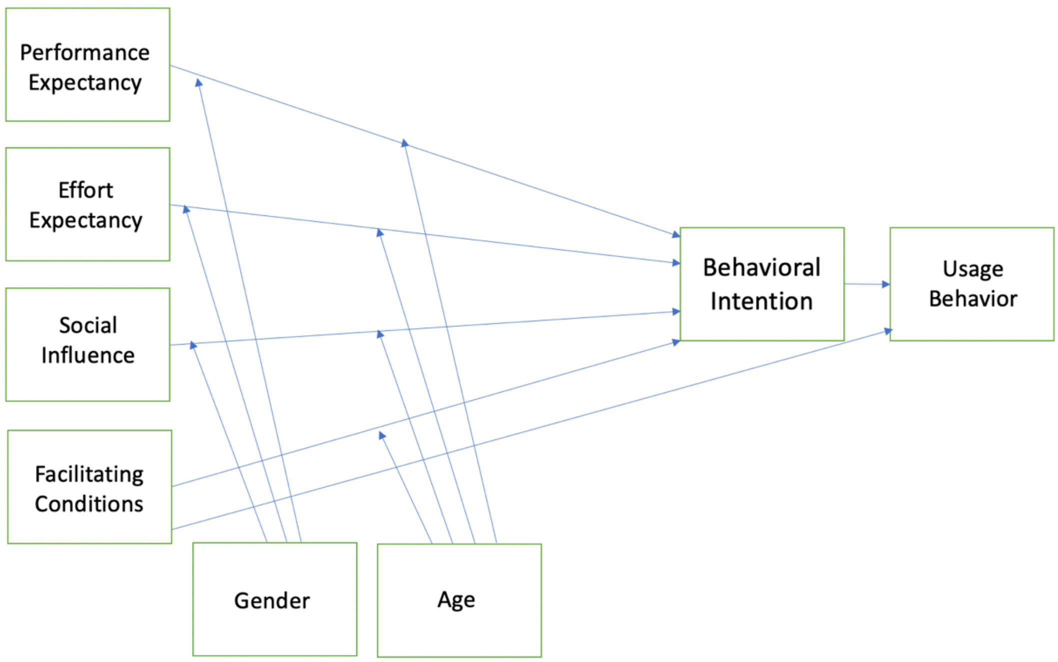

Figure 16: (Venkatesh, Morris, Davis, Davis, 2003).

5.3 Methodology

5.3.1. Study design

This study of the technology acceptance of the BrainFX® SCREEN was a mixed-methods embedded study design with a quantitative pre/post quasi-experimental approach as the primary method of data collection and a qualitative thematic analysis secondary to this. This study was embedded in a larger clinical trial, which undertook a mixed-methods staggered entry randomized control trial.

5.3.2. Sample size

The target sample size was set at a minimum of 32 CAF-SMs and/or veterans with crPTSD that would participate in the study to account for a 10 percent dropout rate which would still allow for power at 24 participants. With 4 latent variables, for 80% significance at a 5% significance level, the sample size required for this study is 18 (R^2 = 0.50; Cohen, 1992).

5.3.3. Recruitment and Sampling

Recruitment of regular and reserve CAF-SMs and veterans, was conducted by word of mouth among potential participants, and mental health service providers as convenience and snowball sampling. Service providers supporting CAF-SMs and veterans, after being informed of the study via word of mouth and institutional email, informed those patients who met the study inclusion and exclusion criteria. These potential participants who showed interest in participation were provided with a “Permission to Share Contact Information with the Research Team” form by their service provider. Completed forms were forwarded to the research team. The researchers then contacted the potential participants via phone or email with a request for them to meet with the research team to learn more about the study and be evaluated to confirm eligibility to participate. Voluntary verbal and written informed consent were obtained from all CAF-SMs and veterans participating in the study. As well, the BrainFX® SCREEN has an additional digital informed consent forms that are required signature before partaking in the screen.

5.3.4. Inclusion and Exclusion Criteria

Participants included regular and reserve CAF-SMs and veterans aged 18-60 years under the care of a mental health clinician or service provider working at or associated with Canadian Forces

Base Edmonton, an Operational Stress Injury (OSI) Clinic in Edmonton and Calgary, Alberta, or Veterans Affairs Canada (VAC). All participants met the Diagnostic and Statistical Manual 5th Edition (DSM5; American Psychological Association, 2013), criteria for PTSD diagnosis and had a score of 30 or higher on the Clinician-Administered PTSD Scale for DSM-5 (CAPS5) Worst Month version. Participants were classified as having treatment resistant crPTSD which indicated they had previously not responded to at least two types of evidence-based treatments, at least one of which must have been a psychotherapeutic intervention. Participants were stable on their current psychotropic medication for a period of at least 4 weeks before entering the study. Individuals with co-morbidity (i.e., mTBI) were included if they satisfied the other inclusion/exclusion criteria. Participants were English speaking and able to provide informed written consent.

5.3.5. Measurements and Instruments

Two UTAUT questionnaires specific to the patient population were developed specifically for this study. Version 1 (T0) includes questions in the future tense while Version 2 (T1) includes the same questions but modified to reflect the past tense. The 12 questions outcome measures are based on a Likert Scale with a score of 1 -7 assigned to each question with 1 being “strongly disagree” and 7 being “strongly agree”. A Likert scale with 7 points was utilized as the original UTAUT questionnaires by Venkatesh, Morris, Davis, & Davis (2003) utilized a 7-point scale. The maximum score is 84 and minimum score is 12. The 12 included questions addressed the 5 different constructs of the UTAUT (2 PE, 3 EE, 3 SI, 3 FC, and 1 BI) that influence the use (U) of a technological innovation. Gender and age demographic information was also collected via the UTAUT questionnaire as they are modifier variables within the UTAUT model.

2 additional open-ended questions were asked as part of both of the questionnaires:

1. What did you like most about the BrainFX® SCREEN?
2. What did you like the least about the BrainFX® SCREEN?

5.3.6. Data Collection

The BrainFX® SCREEN and both UTAUT questionnaires were completed on the same day all within 30 minutes. The BrainFX® SCREEN and UTAUT questionnaires were administered by the CBA. First, the participant was provided with an explanation of the purpose of the BrainFX® SCREEN by the CBA. Secondly, the participant was presented with the BrainFX® SCREEN tablet and asked to read the introduction screen and acknowledge they understood the purpose of the assessment. They were then presented with a paper version of the first UTAUT Questionnaire (Version 1; future tense, intended to measure expectations of the technology). After completing this questionnaire, the full BrainFX® SCREEN was executed on the tablet. On completion of this, the second paper-based UTAUT questionnaire (Version 2; past tense, intended to measure actual intention to use technology) was completed by the participant.

5.3.7. Data Analysis

Partial least square (PLS) structural equation modeling (SEM) was utilized for this study based on the UTAUT which utilizes a reflexive path model. The expectations from T0 and the actual experience from T1 was statistically analyzed utilizing the PLS-SEM with both a within-sample path model as well as a pre/post analysis (multi-group analysis [MGA]).

SEM is considered a second-generation technique of multivariate analysis which allows researchers to incorporate unobservable variables measured indirectly by indicator variables (Hair, Hult, Ringle, & Sarstedt, 2017). PLS-SEM is variance-based, as it accounts for the total variance and uses this to estimate parameters (Hair, Hult, Ringle, & Sarstedt, 2017). In this method of analysis, the algorithm computes partial regression relationships in the measurement and structural models by using ordinary least squares regression (Hair, Hult, Ringle, & Sarstedt, 2017; Hair, Risher, Sarstedt, Ringle, 2019). In an exploratory study such as this, data analysis is concerned with testing a theoretical framework from a prediction perspective making the PLS-SEM an ideal method for analysis (Hair, Risher, Sarstedt, Ringle, 2019).

The path model must be analyzed through measurement and structural model assessments (Hair, Hult, Ringle, & Sarstedt, 2017; Hair, Risher, Sarstedt, Ringle, 2019). Reflexive measurement models are evaluated based on internal consistency (Cronbach's alpha), convergent validity (average variance extracted [AVE]), and discriminant validity (cross-loading analysis, Fornell-Lacker Criterion Analysis, and Heterotrait-Monotrait Ratio (HTMT; Hair, Hult, Ringle, & Sarstedt, 2017). Evaluation of the structural model included an analysis of collinearity, significance, the coefficients of determination (R^2), size and significance of the path coefficients, effect size (f^2), and predictive relevance (q^2). Goodness of fit will not be assessed as this is an exploratory PLS path model with both reflexive (measurement model) and formative (structural model) components rendering current model fit measurements unnecessary and inappropriate.

As PLS-SEM does not assume data is normally distributed, it relies on a nonparametric bootstrap procedure to test the significance of estimated path coefficients in PLS-SEM. In bootstrapping, subsamples are created with randomly drawn observations from the original set of data (with replacement) then used to estimate the PLS path model (Davison & Hinkley, 1997).

SmartPLS® was utilized for PLS analysis. The maximum iterations were set at 300 with +1 for the initial value for all outer loadings and the path weighting scheme and the stop criterion at $1*10^7$. A minimal number of bootstrap repetitions needed depends on the desired level of accuracy, the confidence level, the distribution of the data, and the type of bootstrap confidence interval constructed (Streukens & Leroi-Werelds, 2016). It is commonly accepted that 5000 bootstrap repetitions meet this minimum threshold (Preacher & Hayes, 2008). As such, basic bias-corrected (Bca) bootstrapping was utilized with 5000 samples at a significance level of $p < 0.05$. (Hair, Hult, Ringle, & Sarstedt, 2017). SPSS® was utilized for analysis of descriptive statistics (mean and standard deviation), frequency counts, Pearson's Chi-square test, and the Harman Single Factor Test (Podsakoff, MacKenzie, & Podsakoff, 2012; Kock, 2017). Webpower® was utilized to verify non-normality of the data prior to analysis. Qualitative data from the questionnaires was assessed with NVivo® software to identify key themes. A concurrent parallel approach following a data transformation model will be utilized in the data analysis process to converge the data to compare and contrast quantitative statistical results with qualitative findings (Creswell &Plano Clark, 2011; Schoonenboom & Johnson, 2017).

5.4 Results

The demographic information of the sample ($n = 21$) is displayed in Table 9. The sample was largely male ($n = 20$), which prevented the use of Gender as a moderator variable in the research model. As well, the age of the participant (young or middle-aged) did not demonstrate to have an effect in the research model and was therefore removed for the final PLS model. The psychometric properties for the raw data of the survey items utilized to measure the latent variables are shown in Table 10 and 11. The difference between the means of the pre/post scores is a 2.6% increase (Table 11). When pre/post scores indicate a less than 5% difference in change, this is indicative that the expectations of the participants regarding the technological innovation were met within the constructs used (Venkatesh, Morris, Davis, Davis, 2003).

Additionally, a Pearson's Chi-square test was utilized to measure if participants who reported experiencing a mTBI were more likely to report ongoing cognitive symptoms. Participants who reported a previous mTBI were significantly more likely to report currently experiencing symptoms of cognitive impairment (p = 0.000).

Table 9: Sample Demographic Information

Characteristics	n (%)
Total Sample	21 (100)
Gender	
Male	20 (95)
Female	1 (5)
Age	
18 – 34 (young)	10 (48)
35 – 60 (middle age)	11 (52)
Military Employment Status	21 (100)
Regular Force Member	8 (38)
Veteran	13 (62)
Education	
High School Diploma	21 (100)
Diploma	6 (29)
Degree	1 (5)
Graduate Degree	1 (5)
Missing	4 (19)
Previous mTBI/TBI	14 (67)
Current Cognitive Dysfunction	18 (86)

Table 9: Characteristics of sample by Age, Gender, Employment Status, and Education, Previous mTBI/TBI, and report of Current Cognitive Dysfunction (N = 21).

Table 10: Psychometric Values of Indicator Variables

Exogenous Latent Variables (Indicators)	Mean[1]	Median[2]	SD[3]
Performance Expectancy (PE; 2 indicators)			
1. PE-PU1: Using the BrainFX® SCREEN would improve my medical condition.	4.143	4	1.424

5. PE-JF2: Using the BrainFX® SCREEN would have a positive effect on my medical condition.	4.524	4	1.292
Effort Expectancy (EE; 3 indicators)			
3. EE-EU2: I believe my interaction with the BrainFX® SCREEN will be clear and understandable.	5.5	6	1.383
8. EE-OU1: Interaction with the BrainFX® SCREEN will be easy for me.	5.452	5	1.301
12. EE-EU2: I believe that it is easy to get the BrainFX® SCREEN to do what I want it to do.	5.119	6	1.382
Social Influence (SI; 3 indicators)			
2. SI-SF2: I would use the BrainFX® SCREEN because my colleagues will use it too, to improve their medical condition.	4.5	4	1.502
4. SI-SN1: People who are important to me think that I should be involved in using the BrainFX® SCREEN.	4.667	4	1.14
6. SI-SF1: In general, my organization has supported my involvement in utilizing the BrainFX® SCREEN.	4.833	4	1.057
Facilitating Conditions (FC; 3 indicators)			
11. FC-PB2: I believe specialized instruction concerning the interaction with the BrainFX® SCREEN will be available to me.	5.81	6	1.063
7. FC-FC2: I believe guidance will be available to me during my utilization of the BrainFX® SCREEN.	6.119	6	1.234
9. FC-FC1: I have the necessary resources to use the BrainFX® SCREEN.	5.881	6.5	1.108
Behavioral Intention (BI; 1 indicator)*			
10. BI-1: I am willing to use the BrainFX® SCREEN in the future.	6.333	7	0.845

Table 10: Psychometric properties of indicators utilized to measure latent variables. [1]Raw mean scores of items within scale where each item is measured on a 7-point Likert scale; 1 = strongly disagree, 7 = strongly agree. The higher the indicator score, the more agreement with the statement. 2median scores of each question. [3]Standard deviation (SD) of raw scores. *Single indicator.

Table 11: Descriptive Analysis of Total Pre/Post Scores

Total Score	Mean[1]	Median[2]	SD[3]	Min[4]	Max[5]
Pre (T0)	62.05	60	8.87	48	76
Post (T1)	63.71	64	9.71	42	84

Table 11: 1Mean total of T0 and T1 raw scores. [2]Median of the means of T0 and T1 raw scores. [3]Standard deviation of total T0 and T1 total scores. [4]Minimum mean T0 and T1 score. [5]Maximum mean T0 and T1 score.

The results of the measurement model evaluation, including the factor analysis, internal consistency (Cronbach's alpha; α), convergent validity (AVE), and composite reliability are shown in Table 12. The factor indicators, known as the outer loadings or reflexive indicator loadings, should be ≥ 0.5 to demonstrate the indicator variable is a good measurement of the latent variable (Hulland, 1999). Only one outer loading for SI was below this threshold indicating good indicator reliability (Table 12). All the latent variables, with the exception of SI, demonstrated values above 0.70 for both Cronbach's alpha and AVE which would indicate good validity and reliability of the latent variables (Hair, Hult, Ringle, & Sarstedt, 2017). A single item construct, such as BI, is not represented by a multi-item measurement model and thus the relationship between the single indicator and latent variable is 1 (Table 10, 12, and 13). As there are no established criterion variables to correlate with the BI indicator, criterion validity and reliability cannot be determined for this construct (Hair, Hult, Ringle, & Sarstedt, 2017). Composite reliability is displayed in Table 10 with all values, with the exception of SI, ≥ 0.7 which is acceptable.

Table 12: Measurement Model

Latent Variables	Indicator Variables	Outer Loadings[1]	α[2]	AVE[3]	CR[4]
Behavioral Intention (BI)*			1.000	1.000	1.000
	10. BI-1*	1.000			
Effort Expectancy (EE)			0.857	0.776	0.912
	12. EE-EU2	0.866			
	3. EE-EU2	0.926			

	8. EE-OU1	0.849			
Facilitating Conditions (FC)			0.874	0.798	0.922
	11. FC-PB2	0.885			
	7. FC-FC2	0.928			
	9. FC-FC1	0.866			
Performance Expectancy (PE)			0.885	0.875	0.933
	1. PE-PU1	0.881			
	5. PE-JF2	0.987			
Social Influence (SI)			0.446	0.402	0.559
	2. SI-SF2	-0.011			
	4. SI-SN1	0.601			
	6. SI-SF1	0.919			

Table 12: Results of the validity and reliability evaluation of the measurement model (N = 21). [1]Outer loadings ≥ 0.5 indicate indicator reliability. With a reflective model, internal consistency is measured by [2]Cronbach's alpha; α ≥ 0.7 indicates good indicator reliability. [3]Average Variance Extracted AVE ≥ 0.5 indicates convergent validity. [4]Composite reliability (CR) ≥ 0.5 indicates good internal consistency. *Single indicator.

For evaluation of discriminant validity, cross-loading, Fornell-Larcker Criterion (Table 11), and HTMT (Table 13) were utilized. These measures demonstrated good discriminant reliability for all latent variables except SI. FC demonstrated the highest correlation with BI based on this analysis. Potential common method bias was assessed with the Harman Single Factor Test yielding cumulative and variance loadings under 50% (34.427%).

Table 13: Discriminant Validity

Measure						
	Latent Variables	**BI***	**EE**	**FC**	**PE**	**SI**
FLC						
	Behavioral Intention (BI)*	1.000				
	Effort Expectancy (EE)	0.467	**0.881**			
	Facilitating Conditions (FC)	0.736	0.564	**0.893**		
	Performance Expectancy (PE)	0.052	0.343	0.025	**0.935**	
	Social Influence (SI)	0.340	0.173	0.393	0.325	**0.634**
HTMT						
	Behavioral Intention (BI)*					
	Effort Expectancy (EE)	0.495				
	Facilitating Conditions (FC)	0.776	0.654			

Performance Expectancy (PE)	0.045	0.339	0.122		
Social Influence (SI)	0.336	0.403	0.438	0.985	

Table 13: Intercorrelations between study variables measured by the Fornell-Larcker Criterion (FLC) and Heterotrait-Monotrait Ratio (HTMT). Diagonals are the square root of the AVE of the latent variables and indicates the highest in any column or row. *Single indicator.

Measure of lateral collinearity of the structural model demonstrated inner variance inflation factor (VIF) values below 5 for all latent variables. The coefficient of determination (R^2) measures the proportion of variance in a latent endogenous variable that is explained by other exogenous variables expressed as a percentage. The explained variance (R^2) of the structural model was 0.549 indicating over 50% of BI is explained by this model and moderate predictive accuracy. The effect size (f^2) for each of the latent variables is displayed in Table 14. Based on this analysis of the structural model, the largest path coefficient and effect size was for FC indicating it was the strongest predictor of BI (Table 14 and Figure 17).

Table 14: Structural Model Evaluation and Hypothesis Testing

Relationship	**Std Beta**	**Std error**	**t-value**	f^2	q^2	**CI 2.5%**	**CI 97.5%**
Effort Expectancy (EE) -> Behavioral Intention (BI)	0.108	0.153	0.598	0.010	-0.001	-0.179	0.409
Facilitating Conditions (FC) -> Behavioral Intention (BI)	0.643	0.166	3.950*	0.492*	0.443*	0.285	0.950
Performance Expectancy (PE) -> Behavioral Intention (BI)	0.013	0.110	0.176	0.001	-0.040	-0.215	0.212
Social Influence (SI) -> Behavioral Intention (BI)	0.075	0.108	0.669	0.008	-0.030	-0.152	0.277

Table 14: Prediction of Behavioral Intention (BI). Effect size (f^2) and predictive relevance (q^2) values under 0.02 denote small effect size/predictive relevance while values over 0.35 indicate large effect size/predictive relevance (Cohen, 1988). *significant at $p \leq 0.05$.

Figure 17: PLS Path Model

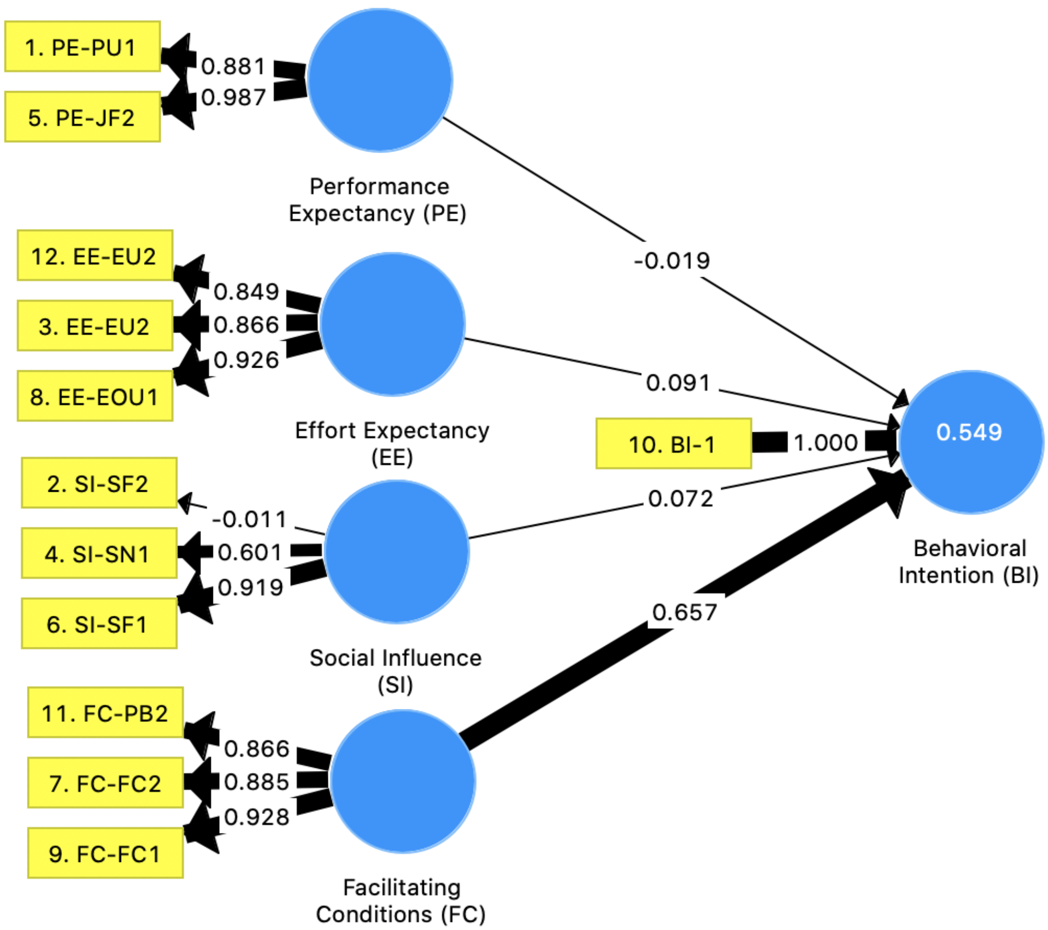

Figure 17: Path analysis model of UTAUT predicting BI. FC is the largest predictor of BI (path coefficient = 0.657). $R^2 = 0.549$.

Based on the MGA, there was a statistically significant increase ($p = 0.007$) in the scores for FC in the Version 2 UTAUT questionnaire (post: T1) data compared to the Version 1 UTAUT questionnaire (pre: T0). A statistically significant decrease in EE was noted in the in the Version 2 UTAUT questionnaire (post: T1) data compared to the Version 1 UTAUT questionnaire (pre: T0) where the latent variable EE was a significant predictor of BI within the pre-group, but not the post-group (Table 15; $p = 0.029$). Combined, this rendered EE to not be statistically significant in predicting BI. There was no statistically significant change in pre/post groups for PE or SI (Table 15).

Table 15: Pre/Post Multi-Group Analysis (MGA)

Latent Variable	t-Value	p-Value
Effort Expectancy (EE)	2.355	0.029*
Facilitating Conditions (FC)	2.997	0.007*
Performance Expectancy (PE)	0.008	0.994
Social Influence (SI)	0.173	0.864

Table 15: Results of pre versus post MGA. *significant at $p \leq 0.05$

Finally, a brief thematic analysis took place analysing the responses on the open-ended from the UTAUT questionnaires (pre and post). The first 2 themes, likes and dislikes, were imposed on the data, while the third theme, the Unclear Purpose of Cognitive Assessments, arose inductively Table 16). The qualitative results will be triangulated with the quantitative data and discussed further.

Table 16: Thematic Analysis

1. Likes	
1.1. Challenges the brain	*"challenged myself to multitask, test my short-term memory."*
1.2 Fun, engaging, and interactive	*"Interaction with tablet. No writing. Fun."*
1.3 Easy to use	*"Ease of use."*
1.4 Quick to complete	*"Quick."*
1.5 Clear Instructions	*"Clear Instructions."*
2. Dislikes	
2.1 Math questions not enjoyable	*"I hate math."*
2.2 Fear of the unknown	*"(I have) anxiety about what it will be like."*
2.3 Screen sensitivity	*"Touch screen delay, would rather use paper."*
2.4 Clarity of Instructions	*"Instructions not clear."*
2.5 Difficult to predict what stimuli can be a "trigger."	*"Disturbing images"*
3. Unclear Purpose of Cognitive Assessments	
	"Alternative treatment, mood alteration." *"Help(ed) me to get rid of my anger."*

Table 16: Thematic Analysis Results of qualitative questions from UTAUT questionnaire.

5.5 Discussion

The UTAUT model was utilized as the theoretical foundation for understanding the behavioral intention of CAF-SMs and veterans with crPTSD to use the BrainFX® SCREEN. Facilitating conditions was the most notable predictor of behavioural intention and increased after using the BrainFX® SCREEN, while effort expectancy decreased. Performance expectancy, effort expectancy, and social interaction were not factors in predicting behavioural intention. Based on study results, the BrainFX® SCREEN appears to be a feasible, usable, and accepted assessment tool for CAF-SMs and veterans who experience PTSD.

A number of notable findings from this mixed-methods pilot study warrant consideration. Demographically, 67% (n = 14) of participants reported a previous mTBI/TBI as comorbid with their PTSD, and those who reported a previous mTBI/TBI were significantly more likely to report currently experiencing symptoms of cognitive impairment. The relationship between PTSD and mTBI, as well as the effect on cognition, is complex and continues to be a topic of research that is being explored among military and veteran populations. The most recent literature points to symptoms of PCS being largely attributed to PTSD as opposed to mTBI pathologies. If PCS are mostly attributable to mental health conditions in those with co-occurring mTBI, it would be assumed that those with and without past mTBI/TBI would both report subjective cognitive impairment at the same rate.

The analysis of the open-ended questions revealed a number of themes that can be attributed to the latent variables of the UTAUT as well as BI as a construct. To understand the results of the PLS-SEM and qualitative data, triangulation can assist with providing a clearer explanation of why the relationships in the path model exist (Schoonenboom & Johnson, 2017).

As previously mentioned, PE refers to the degree an individual believes that using the system will help the person to attain gains in performance (Venkatesh, Morris, Davis, Davis, 2003). In the context of the BrainFX® SCREEN, the performance being measured is cognitive functioning in different neurofunctional domains (Milner & Condello, 2017). It is integral to the validity of the BrainFX® SCREEN that the participant does not receive any feedback on their performance from either the CBA or the software and platform. The participant is limited to their intrinsic subjective insight to speculate their performance which may be a logical explanation as to what PE did not register as an important factor in BI and did not demonstrate a significant pre/post change

SI is the degree to which an individual perceives that important others believe he or she should use the new system (Venkatesh, Morris, Davis, Davis, 2003). As the BrainFX® SCREEN was performed within a research study with only a CBA present and confidentiality maintained, it is unlikely that the participants perceived SI specifically to the technology. This demonstrated to be an accurate hypothesis as SI was the least influential latent variable in prediction of BI.

EE is the degree of ease associated with the use of the system (Venkatesh, Morris, Davis, Davis, 2003). Many of the “likes” of the participants fell into the category of EE including that the BrainFX® SCREEN was, “quick,” and, “easy to do”. Comments obtained from our participants written in answer to the open-ended questions in the UTAUT post-questionnaire corroborate with why perceptions of EE decreased after the assessment. There was some frustration for some participants with the touch screen sensitivity, or “touch screen delay”. Some felt the instructions were “clear” while others felt they were not. The report of unclear instructions did not apply to the overall BrainFX® SCREEN instructions, but to certain instructions for specific tasks.

FC is the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system (Venkatesh, Morris, Davis, Davis, 2003). This was the variable that had the largest effect on BI. Prior to use of the BrainFX® SCREEN, some participants subjectively reported they had reservations about the unknown, “anxiety about what it will be like,” and uncertainty of what to expect. It is reasonable that the participants felt supported by the CBA, organization, and other facilitators in the immediate environment during the assessment which resulted in their “fear of the unknown” to be reduced. This could be an explanation for the statistically significant improvement in FC in the pre/post MGA.

The thematic analysis also revealed some unexpected findings that could not be categorized into the variables of the UTAUT model. Some of the participants reported that the BrainFX® SCREEN was “fun,” and “engaging.” These experiences may fit better within the update to the UTAUT model; the UTAUT 2 (Figure 18: Venkatesh, Thong, & Xu, 2012). This model aims to provide a more consumer-based explanation of BI and U for technology by incorporating a number of additional latent variables including Price, Habit, and Hedonic Motivation. Although the model is geared towards the consumer context, the UTAUT 2 has been utilized in studies addressing technology in the healthcare context and is emerging in the technology acceptance literature (Murugesh-Warren, Dubb, Sudbury, Nnajiuba, Abdel-Gadir, S., & Caris, 2015).

Figure 18: The UTAUT 2 Model

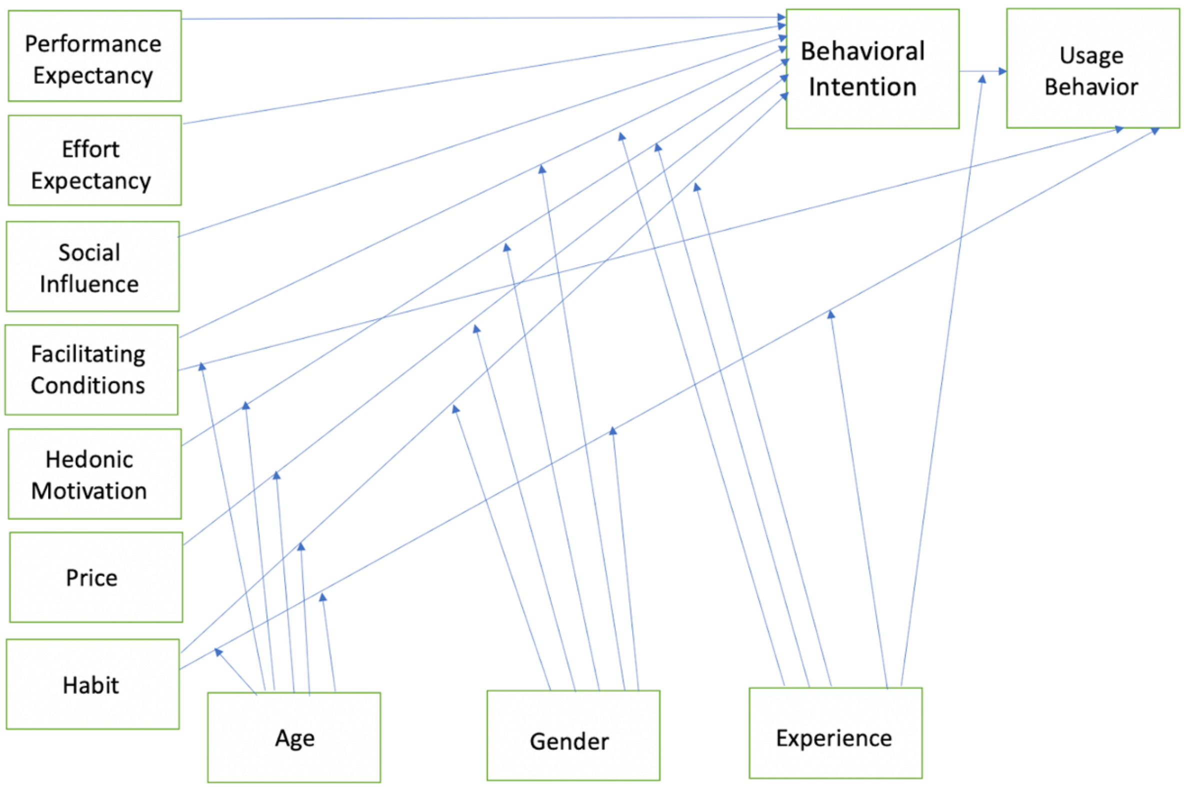

Figure 18: (Venkatesh, Thong, & Xu, 2012).

As the BrainFX® SCREEN does not cost the participants, price would not be a factor that affects BI for this user group. Since the screen is not intended to be utilized by the patient routinely, Habit is also not an appropriate variable to include in the research model. Based on the thematic analysis responses, Hedonic Motivation may be a variable that may influence BI in this study. Hedonic Motivation is defined as, "the fun or pleasure derived from using technology, and it has been shown to play an important role in determining technology acceptance and use" (Brown & Venkatesh 2005). The perceived enjoyment of technological innovation has been found to influence technology acceptance and use directly for the consumer (Brown & Venkatesh 2005). Statements within the qualitative data analysis involving one's enjoyment of the BrainFX® SCREEN fit better within the definition of Hedonic Motivation than the other latent variable definitions which suggests this may have been an unaccounted factor that unexpectedly influenced BI. Hedonic Motivation may be a variable that warrants further consideration when considering technology acceptance and usability in healthcare and, potentially, military contexts. Another unexpected observation that emerged was that participants may not have understood the purpose of cognitive assessments in general. Even with written and verbal explanations of the purpose of and reason for the BrainFX® SCREEN that was similar to, or more, comprehensive than is provided in a typical clinical environment, it was observed during data analysis that some participants did not fully understand these explanations. Some of the qualitative responses indicated that participants felt this tool was for the purpose of improving their cognition, or a “Brain Game.” This may be due to the myriad of tablet and smartphone-based applications currently on the market being advertised as mHealth tools despite limited evidence of their efficacy for improving cognitive status (Jones, O’Toole, Jones, & Brémault-Phillips, 2020). As well, it is possible that some participants were experiencing cognitive impairment due to their comorbidities that hindered their ability to fully comprehend the instructions and explanation. Although the indicators for PE showed to have good reliability and validity, it is possible that a misunderstanding of the purpose of the BrainFX® SCREEN could negatively affect this. This serves as a reminder that as researchers and healthcare professionals alike that the purpose of assessment and screening tools must be explained explicitly especially with populations who may be experiencing cognitive impairment.

Of note, one participant reported feeling disturbed by the images in the BrainFX® SCREEN. Although the imagery within the assessment is generic and positive (i.e., candy, animals, plants, etc.) it is an important reminder that items within any assessment can potentially act as a trigger for a person experiencing PTSD and may increase levels of distress in participants.

5.5.1. Limitations of Study

Although the PLS-SEM is ideal for exploratory research, and is flexible with its non-parametric lack of assumptions regarding data distribution, a number of limitations need to be considered. First, measurement error will always exist to some degree and is challenging to accurately quantify. The PLS-SEM bias refers to the tendency of the path model relationships to be frequently underestimated while the parameters of the measurement model, such as the outer loadings, are overestimated when compared to covariance-based (CB) SEM. Measurement error can also be introduced by variables such as the understanding of the questionnaire items by the participants. As discussed, the level of understanding around the purpose of cognitive assessments may have been an issue, which raises questions about the understanding of other aspects by the participants. As well, the administrative burden of the study when combined with other outcome measures attributed to the RCT with which this study was affiliated may have caused some participants to rush through final questionnaires or experience fatigue and a reduced level of engagement. Second, the lack of global goodness-of-fit measures are considered a drawback of the PLS-SEM that is unavoidable. Third, in the measurement model, BI only had one indicator variable so it could not be evaluated like the other latent variables which had multiple indicators. In the future, this could be resolved by adding additional items (indicators) to the UTAUT questionnaires related to BI. Finally, due to the study being affected by a COVID-19 related shut down, the original statistical power was not reached at 1% significance. The needed sample size of a minimum 24 participants was not attained, so significance was at 5% ($n = 21$; $R^2 = 50\%$; Cohen, 1992). The small sample size made it not possible to incorporate the moderator variables of Age and Gender as was originally planned in the research model.

5.5.2 Future Research

A range of future research endeavours would enhance an understanding of the relationship of the patient, whether military or civilians, with technological innovations. The technology acceptance and usability of the BrainFX® SCREEN, as well as other assessments utilizing digital healthcare technology, warrant evaluation within military and civilian healthcare and at multiple, user levels including the patient, healthcare professional, and organization. This also extends to the use of virtual healthcare technologies where the patient is at a separate location from the healthcare professionals – a practice that is becoming increasingly widespread since the onset of the COVID-19 pandemic. It is important that healthcare professionals also become stakeholders in the process of adopting new healthcare technology. Studies with larger sample sizes may also allow for a research model with the ability to incorporate moderator variables, such as Age, Gender, Voluntariness of Use, and Experience, as well as investigate the effect of Hedonic Motivation as a latent variable.

The utility of the UTAUT as a model for healthcare technology and for patient user groups warrants continued investigation in both civilian and military settings. Further, the appropriateness of the UTAUT, and possibly other technology acceptance models, within military contexts remains an area where research is scarce.

The limitation of the existing technology adoption models is, the lack of task focus (fit) between user, technology and organization which contributes to the mixed results in information technology evaluation studies (Dishaw & Strong, 1999). Notably within the military context, the environment and culture will have an effect on this at multiple user levels. The organization itself is considered as a key factor in the effective use of information technology. To fully evaluate user acceptance of technology, the fit between the user, the technology, and the organization needs to be evaluated together. (Hu, Chau, Sheng, & Tam, 1999; Mohamadali & Azizah, 2013). "Fit" needs to be integrated with existing technology models to better understand issues surrounding implementation of new technology (Mohamadali & Azizah, 2013). Multiple models and frameworks addressing technology acceptance and usability as well as fit exist, including the Task-Technology Fit (TTF) Model (Goodhue & Thompson, 1995), Fit between Individuals, Task and Technology" framework (FITT; Ammenwerth, Iller, & Mahler, 2006), and Design-Reality Gap Model (Heeks, 2006).

Information security has not been incorporated within technology adoption models or frameworks related to user acceptance which may have important implications in a military as well as a clinical context. when the users of the technology perceive that a particular technology provides features which prevent unauthorised access to the clinical related database, they are more likely to trust and accept it (Mohamadali & Azizah, 2013). The incorporation of information security and its involvement in technology acceptance and usability could be an interesting and relevant direction of research in military organizations.

5.6. Conclusion

mTBI was labelled the "signature injury" of military conflicts during the War on Terror, in which National Atlantic Treaty Organization (NATO) forces, including Canada, participated (Armistead-Jehle, Soble, Cooper, & Belanger, 2017; Goverment of Canada, 2019). As well, numerous military personnel and veterans from around the globe who have returned from deployments to this conflict continue to struggle with symptoms of PTSD either in isolation, or comorbid with mTBI/TBI. Despite the plethora of research, publications, and attention that mTBI and PTSD has received in recent years, both in the military and sport contexts, many questions remain regarding the complexities of assessing and treating neurological symptomatology attributed to these diagnoses including cognitive dysfunction. The BrainFX® SCREEN appears to be a promising NCAT that had good acceptability by the CAF-SMs and veterans with crPTSD in this study. Future research is needed to address other factors of the BrainFX® SCREEN including its validity, reliability, effectiveness, feasibility, and sensitivity. As civilian and military healthcare systems increasingly integrate technological innovations to improve the services and care provided to their patients, research must continue to address the use of these novel assessments and interventions at micro, meso, and macro levels.

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6. Discussion

The overall aim of this research project was to investigate evidence-based and best practice approaches for conducting cognitive assessments of CAF-SMs who have sustained mTBI with resulting cognitive dysfunction. This project was guided by the principles of implementation science through the AIFs (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005; Appendix 10.1) and UFE model (Patton, 2013; Appendix 10.2). Ideally, the information compiled in this project will assist with advancing cognitive assessment policies, protocols, and practices within CFHS as it pertains to mTBI as well other conditions that may contribute to reduced cognitive functioning. This information may assist with the informed and evidence-based decision-making processes at the micro (CAF-SM), meso (HCP and clinic), and macro (organizational) levels of CFHS. The results and implications of this project within the CAF setting will be further discussed within the contexts of the AIFs and UFE model.

The Exploration Stage (Figure 1 and 11) requires the building of foundational knowledge about a topic and context to ensure an informed assessment of fit of the innovation in question (Figure 11). The CMCS (Figure 9) is the underlying model that guides the Brain FX® assessments. Chapter 2 introduced the CMCS as a tool in guiding understanding, education, assessment, and rehabilitation of cognitive skills. Given that the CMCS underlies the Brain FX® SCREEN, 360 assessment, and VCA, knowledge of this model could assist HCPs utilizing these tools within different healthcare systems. Knowledge translation of the CMCS could assist with the first 2 stages of the UFE model which include (1) assess and build program and organizational readiness for UFE, and; (2) assess and enhance evaluator readiness and competence (Patton, 2013). Understanding of this model at the patient, HCPs, management, and policy maker levels could assist with the interpretation of patient reports, the designing of cognitive rehabilitation plans, and implementing a multi-disciplinary, functional, and holistic approach as cognitive dysfunction can adversely affect the individual, family, organization, and community. Understanding, acceptance, and adoption of the model by CFHS HCPs may indicate that there is readiness among primary intended users to utilize the Brain FX® assessments to their full potential.

The purpose of the scoping review in Chapter 3 was to, (1) systematically evaluate the quality of the existing peer-reviewed literature on NCATs utilized amongst military personnel with mTBI, and; (2) synthesize the knowledge of barriers, facilitators, and recommendations for NCATs based on the existing literature. This also fits within the Exploration Stage of the AIFs as it continues assessing fit of the usable innovation; NCATs in this instance. The results of this study revealed prominent issues with the current evidence-base for the use of NCATs within military populations. Notably, there is an absence of published evidence regarding NCATs in the Canadian military context. The results of this scoping review could assist with informing the direction of future research to address current needs and research questions at the organizational level. These results may also inform future decisions within CFHS with choosing the NCAT, or usable innovation, to continue through the stages of implementation of the Brain FX® assessments into the Installation Stage. Within the UFE model, and similar to the CMCS, knowledge translation of this information would assist with steps 1 and 2 by building evaluator readiness. As the scoping review aimed to look at the landscape of research on a specific topic, it may also be considered as the beginnings of stage 4 which is an ongoing situational analysis (Patton, 2013).

The purpose of the qualitative study in Chapter 4 was to better understand the experience of HCPs who utilize cognitive assessments with CAF-SMs with mTBI. This study remains within the Exploration Stage of the AIFs as it continues to gather information and assess the potential fit of NCATs. Additionally, the involvement of CFHS HCPs is also consistent with step 3 of the UFE. Since one of the primary intended user groups, the CFHS HCPs, is now identified, organized, and engaged in the process, the UFE can continue to move fluidly through other steps. Continuing through the situational analysis (stage 4) with the involvement of the primary intended users is when the data collection of the UFE begins. As the purpose of the study and evaluation is defined with the CHFS HCPs, the evaluation's priority purposes are communicated and established (stage 5).

Although the CFHS HCPs were identified as a primary intended user group, the patient is also important to engage in the process, especially when healthcare technology is being implemented. Ideally, technology acceptance and usability is established by patient groups before the installation of the usable innovations. Within CFHS, the Brain FX® SCREENwas installed prior to evaluation of this factor. The purpose of the mixed-methods pilot study in Chapter 5 was to determine the technology acceptance and usability of a computer-based cognitive Brain FX® SCREEN, by CAF-SMs and veterans with crPTSD utilizing the UTAUT model. This study acknowledges the CAF-SMs and veterans with crPTSD and/or mTBI as the primary intended users. Although this process would ideally take place in the Installation Stage, the investigation of technology acceptance and usability *ad hoc* during the Initial Implementation Stage can still provide valuable insight that can lead to improvements in processes, policies, and practice through the PDSA Cycles (Figure 8) and Practice-Policy Communication Cycles (Figure 13; Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). Within the UFE, this study rapidly implemented steps 2 through 5 with the patient as the primary intended user. Overall, the results of this study indicated that a NCAT delivered via tablet was acceptable and usable for the population in question. The results of the study could be communicated to CFHS as well as to the creators of the Brain FX® SCREEN resulting in an improved usable innovation, and enhanced facilitating conditions supporting cognitive assessment of CAF-SMs experiencing mTBI and/or mental health challenges.

Combined, the results of this project could assist with which decisions, policies, and NCATs CFHS chooses in the future. The next steps may be to continue with the expansion of the Initial Implementation Stage of Brain FX® assessments, the usable innovation, within the CFHS with the training of additional clinicians as well as providing IT infrastructure and test kits to multiple geographic regions. Within the UFE, CFHS may continue with the remaining steps of the model, which would assure multidisciplinary stakeholder involvement including the primary intended user. The resulting plan of evaluation through stage 6 to 13 of the UFE model would correspond well within the PDSA cycles AIF. Ideally this would result in ongoing use of the useable innovation in practice, investigation of the outcomes of this practice, and evidence-based improvement of the use leading back to improved practice. Alternatively, CFHS may decide the Brain FX® assessments do not fit the needs or context of the CAF, reset the implementation process back to the Usable Innovation AIF (Figure 11; Appendix 10.1), identify an alternative NCAT to be investigated, and focus on implementation of a newly determined usable innovation. In the latter case, the information provided by this project can still inform the Exploration Stage for alternative NCATs in the future and is not necessarily specific to the Brain FX® assessments.

Regardless of the path forward chosen by CFHS, educated and trained personnel are required to execute continued PDSA Cycles and Practice-Policy Communication Cycles in an ongoing implementation and evaluation process, which will be required to improve services and remain up to date with best clinical practices. The designation of Implementation Teams, who do the work of implementation (Stages, Drivers, and PDSA, and Practice-Policy Communication Cycles) with the usable innovation, as well as Implementation Drivers, will be required in order to maximize the chances of sustainable implementation (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). Ideally, the Implementation Team is assigned Full-Time Equivalent (FTE) for this purpose and is actively involved on a daily basis with implementation efforts devoted to assuring the full and effective uses of innovations (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). This team could include administrative leaders within CFHS and the Department of Medical Policy. Implementation Drivers (Figure 18) are the components of infrastructure needed to develop, improve and sustain the ability of staff to implement an innovation as intended as well as create an enabling context for the new ways of work (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). Implementation Drivers are categorized as either (1) Competency, (2) Organization, and/or (3) Leadership all playing their part to contribute to enhancing the fidelity of the usable innovation in the specific context.

Figure 19: Implementation Drivers AIF

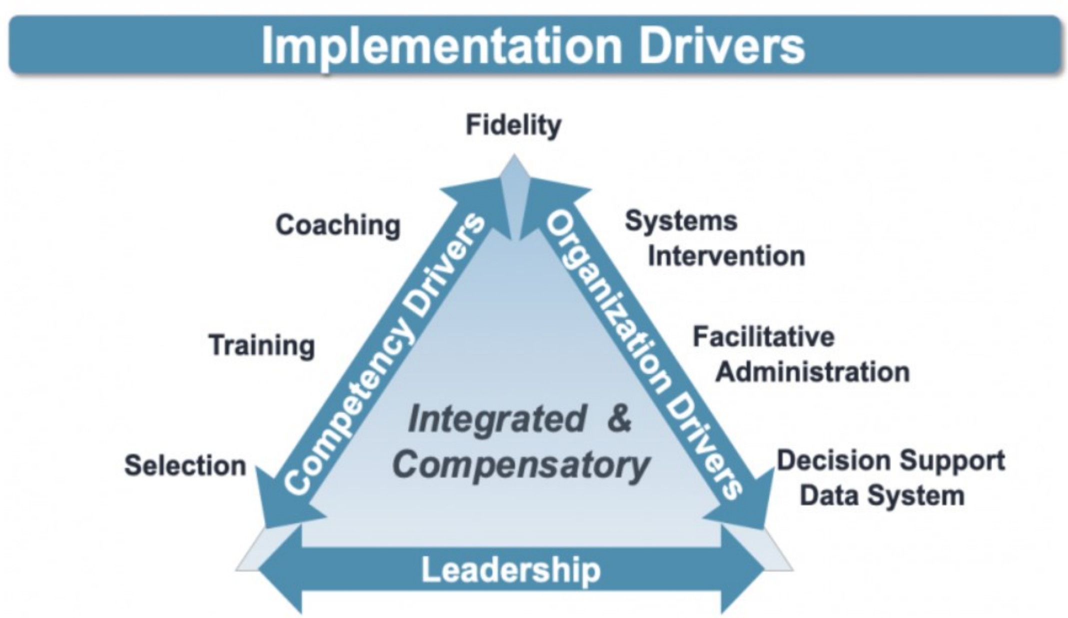

Figure 19: (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005).

Fidelity is defined as the use of the innovation or instructional practices as intended. To ultimately determine if the usable innovation is feasible, was used, and provided the desired outcome consistently across multiple users, planned fidelity assessment methods must be determined and executed. Competency Drivers are the mechanisms to develop, improve and sustain one's ability to implement an innovation as intended. These include the selection of the right personnel, training and educating of personnel, and continued coaching and support for those utilizing the usable innovation. Competency Drivers may be Practice Leaders or designated CFHS HCPs at multiple sites within one or more geographical regions that support the implementation of the usable innovation and act as the site or regional subject matter expert. This may also include the training and support from the NCAT vendor. Competency Drivers would collaborate and communicate with Leadership, and together would make needed changes and improvements to the Organizational Drivers. Organizational Drivers may include the environment and clinical infrastructure and management, the electronic medical record system, such as the Canadian Forces Health Information System (CFHIS), mTBI management guidelines, and other systems, policies, or practices that are implemented in support of the primary intended users utilizing the usable innovation.

Failure to plan and execute ongoing evaluation including policy makers and primary intended users, such as CFHS HCPs and CAF-SMs, will make the implementation of an NCAT less likely to be sustainable and spreadable while maintaining fidelity, validity, and reliability. Keeping up to date with the rapidly evolving evidence base on cognitive assessment, mental health, and mTBI in the military context is also important for informing practice but can be a challenge for HCP and healthcare organizations. In addition to being aware of new research, participation in research and evaluation processes by CFHS at the micro, meso, and macro level is also key to creating emerging evidence that is specific to the CAF context.

Finally, within both the implementation science process guided by the AIFs as well as the UFE, knowledge translation is key to the success, spread, and sustainability of healthcare innovations. Knowledge translation is crucial throughout the AIFs at the end of each stage and within the PDSA and Practice-Policy Communication Cycles. Within the UFE, step 14 refers to organizing and presenting the data for use by the primary intended users. Step 15 involves preparing an evaluation report to facilitate use and disseminating significant findings to expand influence. By providing CFHS with a report of these findings, publishing manuscripts, and presenting at academic conferences, these steps will be fulfilled. It will be up to CFHS as an organization to utilize and/or develop their PDSA Practice-Policy Communication Cycles to translate this information further within their internal structure.

6.1 Future Research

This project serves as a starting point for investigation of NCATs in the CAF context and there are many more research questions to be investigated regarding this topic. Future research regarding the CMCS could focus on its applicability and uptake within a military healthcare setting as a next step in its implementation and as the foundation to the Brain FX® assessments. Further research and evaluation of current cognitive assessment practices within the CFHS may assist with the Exploration and Installation Stages and lead to pragmatic solutions to identified barriers in practice. Technology acceptance and usability of the Brain FX® assessments aside from the Screen, amongst both patients and CFHS HCPs would also be topics of interest that would provide insight into the potential for spread and sustainability. Use of the Brain FX®

assessments and/or other NCATs in other environments in the CAF context outside of clinical settings, such as on exercise and deployment, is also important to investigate as factors such as exposure to the elements and IT access could greatly affect feasibility. Finally, with all NCATs mentioned in this project, including the Brain FX® assessments, more research is needed to determine reliability, validity, sensitivity, and specificity for various populations including military members with conditions and comorbidities that can cause or exacerbate cognitive dysfunction. It is problematic that the majority of the research conducted on NCATs to date is almost solely in the context of the US military and specific to mTBI. NCAT evaluation amongst other global military contexts and amongst those with other conditions experienced at a higher rate amongst this population, such as sleep dysfunction, mental health challenges, chronic pain, etc., is critical to facilitating rehabilitation and recovery plans for ill and injured military personnel with cognitive dysfunction.

7. Conclusion

Cognitive dysfunction is a symptom that has the potential to decrease efficiency and effectiveness in the military context, along with increasing the risk of harm to self, the unit, and mission (Radomski, Davidson, Voydetich, & Erickson, 2009). Military healthcare has been keenly aware of this symptom, and its subsequent functional implications, for centuries. The cognitive dysfunction that was once referred to as a component of “shell-shock” (Shively & Perl, 2012). is now recognized as a consequence of physical and/or mental health injury. Despite the collective experience with cognitive impairment amongst military personnel, the state of the evidence regarding cognitive assessment practices remains inadequate leaving HCPs questioning the best way to assist CAF-SMs experiencing cognitive dysfunction.

NCATs have been embraced by other global militaries; however, the CAF continues to utilize outdated cognitive assessment with questionable psychometric properties and functional relevance to CAF-SMs. Although research and evidence-based publications are ideally translated to clinical practice, other factors such as cost, IT capabilities, languages, human resources, and security, are critical to informing practices around the implementation of NCATs. Further research is required in the CAF context to assess feasibility, usability, accessibility, acceptability, validity, reliability, specificity, sensitivity, functionality, and appropriateness of cognitive assessment practices, protocols, policies. The CAF as a whole will benefit from CFHS's continued exploration of NCATs and commitment to better address cognitive functioning in CAF-SMs who have sustained mTBI and other conditions which adversely affect cognition.

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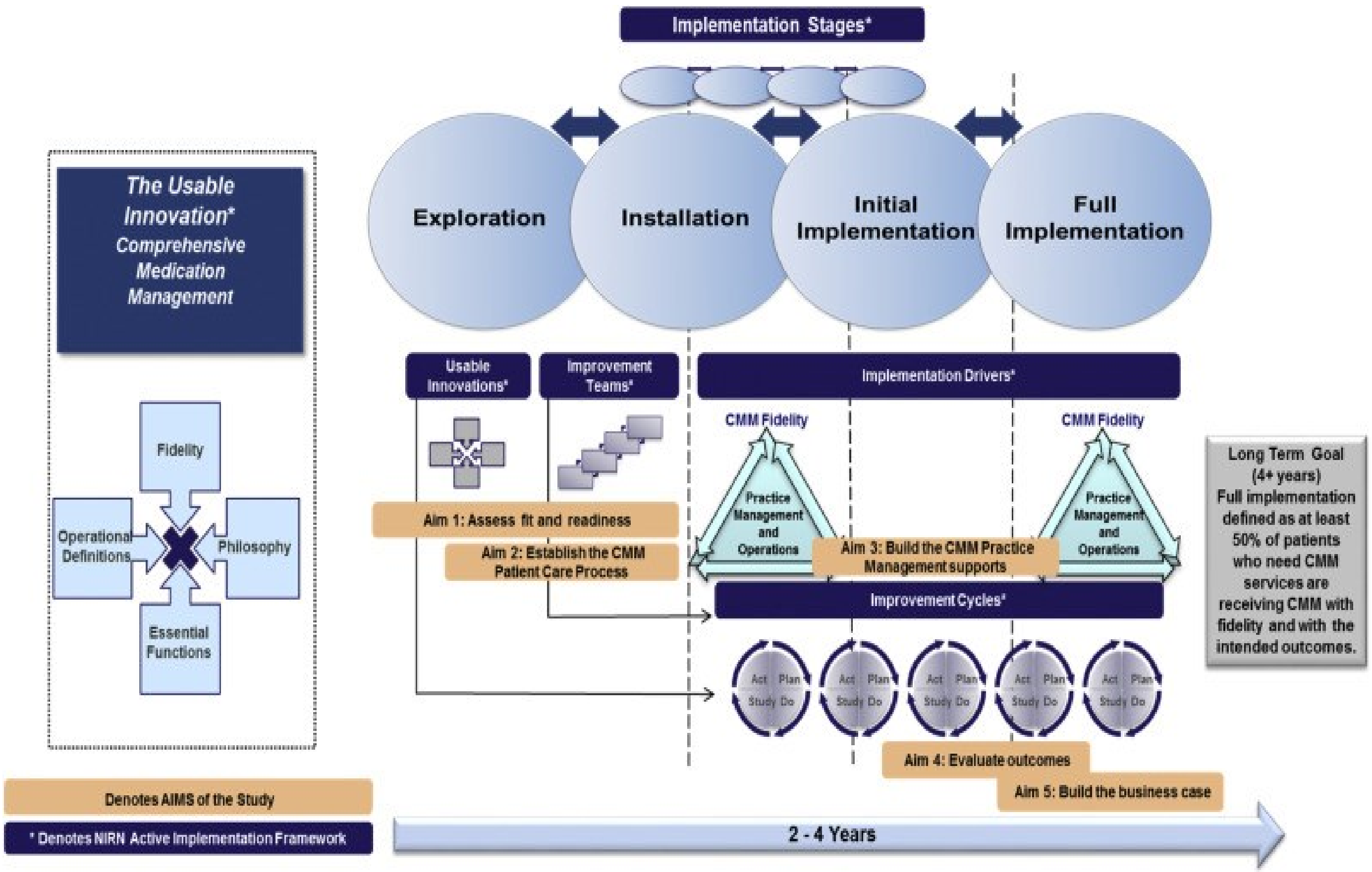
9. Appendices

9.1 Active Implementation Frameworks

Figure 20: Active Implementation Frameworks



9.2 Utilization Focused Evaluation

Utilization-Focused Evaluation begins with the premise that evaluations should be judged by their utility and actual use; therefore, evaluators should facilitate the evaluation process and design any evaluation with careful consideration of how everything that is done, from beginning to end, will affect use. Use concerns how real people in the real world apply evaluation findings and experience and learn from the evaluation process.

Step 1	Assess and build program and organizational readiness for utilization-focused evaluation.
Step 2	Assess and enhance evaluator readiness and competence to undertake a utilization- focused evaluation.
Step 3	Identify, organize, and engage primary intended users.
Step 4	Conduct situation analysis with primary intended users
Step 5	Identify primary intended uses by establishing the evaluation's priority purposes.
Step 6	Consider and build in process uses if appropriate.
Step 7	Focus priority evaluation questions.
Step 8	Check that fundamental areas for evaluation inquiry are being adequately addressed.
Step 9	Determine what intervention model or theory of change is being evaluated.
Step 10	Negotiate appropriate methods to generate credible findings and support intended use by intended users.
Step 11	Make sure intended users understand potential controversies about methods and their implications.
Step 12	Simulate use of findings.
Step 13	Gather data with ongoing attention to use.
Step 14	Organize and present the data for use by primary intended users.
Step 15	Prepare an evaluation report to facilitate use and disseminate significant findings to expand influence.
Step 16	Follow up with primary intended users to facilitate and enhance use.
Step 17	Metaevaluation of use: Be accountable, learn, and improve

Figure 21: Utilization Focused Evaluation Model