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Psychometric Analyses of a Comprehensive Neuropsychological Battery for Retired NFL Players

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Psychometric Analyses of a Comprehensive Neuropsychological Battery for Retired NFL Players

by

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DISSERTATION APPROVAL SHEET

This dissertation was submitted by Kimberly Fitzgibbon under the direction of the Chairperson of the dissertation committed listed below. It was submitted to the School of Psychology and approved in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Clinical Psychology at Nova Southeastern University.

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TABLE OF CONTENTS

LIST OF TABLES

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ABSTRACT

This study examined psychometric properties of the NFL Concussion Battery used to examine neuropsychological functioning in retired NFL players who were part of the NFL's concussion settlement. This battery assesses multiple areas of cognitive functioning; executive functioning, language, processing speed, attention and memory. The study included 117 participants who were male with at least 16 years of education. The sample was 75.9% African-American and average age was 47. All participants completed the entire battery and passed the majority of effort measures. Those that did not pass the majority of effort measures or complete the entire battery were excluded.

T-test analyses were used to test the hypothesis that normative player performance on individual measures within the NFL battery would be poorer than the standardization sample's performance. Results from the analysis demonstrated that most of the measures yielded significantly lower performance in the retired player sample. An exploratory factor analysis was used to study the factor structure of the NFL battery when used in the retired player population. It was hypothesized that the factor analysis would yield a five-factor structure; executive functioning, language, processing speed, attention and memory. The analysis did not support this, suggesting that a six-factor model may be a better fit for the data with subtests loading onto factors identified as visual spatial manipulation and

learning, speeded language fluency, rote verbal learning and memory, contextual verbal learning and memory, abstract reasoning and a Category test factor.

Hypothesis one was largely supported by the study, while hypothesis two was not supported. The results of this study provided novel psychometric information on this NFL battery given that very few studies have been conducted on retired NFL players using a standard neuropsychological battery and no formal psychometric studies have been conducted on this battery. Further examination of psychometrics is needed, especially when looking at ethnicity as a potential moderating factor in performance. Samples should be more diverse and utilize both current and former NFL players to assess performance across the playing lifespan. Future work should utilize a larger sample and provide more specific concussion information to increase clinical utility of the findings.

CHAPTER I : STATEMENT OF THE PROBLEM

This study examined the psychometric properties of a comprehensive neuropsychological battery administered to retired National Football League (NFL) players. Participants were retired NFL players undergoing a day-long neuropsychological evaluation as part of the NFL's concussion settlement program, with the standard battery being the NFL Concussion Settlement Baseline Assessment Program (BAP). The BAP is the official battery that retired players are required to complete as part of the National Football League Players' Concussion Injury Litigation (NFL Players' Concussion Injury Litigation., 307 F.R.D 407-11, 2017). Individuals who did not complete the full battery or who failed the majority of effort and motivation measures were excluded from the analyses. This allowed for a more accurate analysis of psychometric data for valid performances, as opposed to the potential for data contamination if invalid results were included.

Statistical analysis were used to evaluate the average or normative performance on each neuropsychological measure in the battery administered to the retired NFL participants. Subsequently, these data were compared to existing normative data of the measures. Differences between players' scores and standardized sample scores were also analyzed to assess for clinically significant differences. Following an analysis of the normative scores on measures, an exploratory factor analysis was conducted to provide information regarding the factor structure of the existing battery.

The purpose of this study was to provide initial psychometric data on this established NFL battery, given its widespread use and dissemination in the field at the point in time. Comparison of test performance in a retired NFL population compared to existing sample norms for measures is an important component when considering future revisions or interpretations of data from this battery. By conducting this study, the researcher hoped to provide more data and support for the importance of appropriate normative data in unique populations, specifically for retired NFL players. In general, neuropsychological research for retired NFL players has focused on cognitive and psychosocial impacts. Very few studies have looked at this NFL battery in the concussion settlement and the current existing psychometric research centers on current players and short baseline neuropsychological assessment. Additionally, an exploratory factor analysis (EFA) had not been conducted on this existing neuropsychological battery. This is necessary in order to explore or confirm its labeled factor structure within this population of retired players on the NFL battery. While the individual tests within the NFL battery have been extensively studied through general standardization analyses, there have been no studies done in a sample exclusively made up of retired NFL players. A formal EFA will provide increased insight into the factor structure of the battery, an important piece of information for clinicians, patients and researchers that can help better explain and interpret test scores, as well as individual strengths and weaknesses in various cognitive and emotional domains. Additionally, an EFA with this data will provide more specific insight with regard to the retired NFL sample and will aim to determine if the existing factor structure of the NFL battery is maintained in this unique NFL sample. Psychometric analyses, both in regard to test performance and an EFA will provide important information with clinical, and potentially legal, implications as having a better understanding of the underlying foundations of the NFL battery and how retired players perform on the battery, will help inform clinicians as to the nature and severity of any cognitive impairment that is determined from the battery itself.

CHAPTER II : REVIEW OF THE LITERATURE

Traumatic Brain Injury (TBI)

TBI has been classified into ranges based off severity of the injury and resulting sequelae and is formally defined as "an alteration in brain function, or other evidence of brain pathology, caused by an external force" by the Demographics and Clinical Assessment Working Group of the International and Interagency Initiative toward Common Data Elements for Research on Traumatic Brain Injury and Psychological Health (Menon, Schwab, Wright & Maas, 2010). The Center for Disease Control and Prevention(CDC) defines traumatic brain injury as "craniocerebral trauma, arising from blunt or penetrating trauma or from acceleration-deceleration forces" that is then associated with a number of negative symptoms including loss of consciousness, skull fracture, intracranial lesions, bleeds, neuropsychological deficits, and even death (CDC, Thurman, Sniezek, Johnson, et al., 1995). Epidemiological research indicates that over 200,000 Americans are hospitalized for nonfatal TBI each year, with millions of individuals living with long-term consequences of TBI, suggesting a significant healthcare and societal cost to these injuries (Corrigan, Selassie & Orman, 2010).

TBI ratings can differ depending on setting and population, but popular screening measures include the Glasgow Coma Scale (GCS) and the Abbreviated Injury Severity Scale (AIS), both of which are administered by trained clinicians or other trained individuals (Corrigan, Selassie & Orman, 2010). Commonly used ranges of severity include mild, moderate and severe, with mild traumatic brain injury becoming synonymous with the term concussion.

Sports-Related Concussion

Concussion is a mild traumatic brain injury that is considered to be any type of short-term neurological and neurocognitive dysfunction as a result of the impact of mechanical force on the brain (Giza & Hovda, 2001). It can result in a wide range of symptoms that include headaches, loss of consciousness, anterograde and/or retrograde amnesia, disorientation, dizziness, fogginess, fatigue, sleep disruptions, sensitivity to noise and/or light, vision problems, and irritability, among others (Giza & Hovda, 2001). When a concussion is sustained, the brain is not only impacted by the physical force exerted on it, but also by the neurobiological and neurometabolic disruptions that occur, including changes in potassium and sodium levels extracellularly (Takahashi, Manaka & Sano, 1981). Additionally, significant force can result in metabolic hemorrhage within the parenchymal layers of the brain, resulting in excess potassium outside of cells (Hubschmann & Kornhauser, 1983). It has been suggested that the metabolic and neurochemical changes that are induced in the brain when it experiences an impact force result in increased need for glucose in those regions that are disrupted. However, the increased metabolic (glucose) need is typically matched with increased blood perfusion under normal circumstances and concussed brains are thought to not follow this trend, leading to increased glucose need without the perfusion levels to match this need. This imbalance creates relative ischemia in regard to the metabolic demand of the injured cerebral tissue (Bergsneider, et al., 1997).

With significant biological disruption comes impaired neurocognitive and emotional functioning as well. Concussions have been well-documented to result in a number of cognitive deficits including attentional problems, memory difficulties, executive functioning deficits and slowed processing speed (Karr, Areshenkoff & Garcia-Barrera, 2014). Additionally, emotional sequelae can include irritability, impulsivity, anger, psychosis, and depression (Karr, Areshenkoff & Garcia-Barrera, 2014).

In sports, concussions are the most common type of head injury sustained by participants (Poirier & Wadsworth, 2000). Furthermore, it has been estimated that over 300,000 concussions occur each year in the United States in sports, across varying ability levels (Sosin, Sniezek & Thurman, 1996). More recent epidemiological research has indicated that a substantial amount of college athletes across multiple sports are sustaining concussions, with 24-25% of male athletes and 21-29% of female athletes reporting experiencing a sports-related concussion (Bell, Paskus & Hainline, 2014). More recent epidemiological studies have also suggested that the incidence of concussion in professional football is 6.61/1000 (i.e. 6.61 concussions per 1000 athlete exposures to hits across all football positions) (Nathanson, J., Connolly, J., Yuk, F., Gometz, A., Rasouli, J., Lovell, M., & Choudhri, T., 2016) while North American and Canadian hockey leagues were shown to have a concussion percentage rate ranging from 5.3-18.6% (Ruhe, A., Gansslen, A., & Klein, W, 2014). Furthermore, it has been estimated that over the past six football seasons, there have been 250-260 diagnosed concussions within the NFL (Pelechrinis, K., Yurko, R., & Ventura, S, 2019). While concussion rating criteria has changed over the years, the overall level of awareness of concussions, or mild traumatic brain injury, has increased in the past decades.

Past research has suggested a link between numerous concussions or brain injuries from contact sports such as boxing and football, and the neurocognitive decline exhibited by many of these athletes. The discussion regarding the potential impact of repeated sports-related head impact began with boxers and the concept of "Dementia Pugilistica" or the idea of being "punch drunk" where individuals were impulsive, incoherent at times, had significant difficulty with memory, motor difficulties and other emotional and cognitive decline, has been present for almost a century (Martland, 1928). Discussion of the "punch drunk" phenomenon has continued for several decades, with researchers struggling to name and identify the disease, progression and etiology in individuals engaged with contact martial arts (Sercl &Jaros, 1962; Lampert & Hardman, 1984; Jordan, 1993). However, more recent research has contradicted the longstanding idea of multiple hits to the head leading to cognitive decline over time. Bruce and colleagues found that no cognitive differences were observed in a cohort of male collegiate athletes, when those with and without a self-reported history of concussion were compared on a computerized neuropsychological battery (Bruce & Echemendia, 2009). Of note, the implementation of a computerized neuropsychological battery may have impacted results, as computerized batteries often fail to show significant relationships between cognitive ability and self-reported concussion history when used with athletes (Bruce & Echemendia, 2009). Regardless, further work to determine what decline, if any, occurs in retired former athletes is warranted, as there is limited information within this sample.

Few other sports-related controversies have garnered as much attention in the media as has the concussion debate in the NFL. With the discovery of a possible neurodegenerative brain disease, chronic traumatic encephalopathy (CTE) by Dr. Omalu in 2005, the onslaught of media attention has failed to let up (Omalu et al., 2005). Researchers at Boston University in Massachusetts have now taken part in the CTE research, studying brains of deceased NFL players and looking for evidence of the progressive deterioration of brain structures and presence of structural and biochemical abnormalities (McKee et al., 2009). While CTE has yet to be confirmed as the cause of many of the behavioral, emotional and cognitive difficulties it has been supported in the literature to at least encompass the depressive symptoms, including anger, irritability and apathy that is frequently reported in the retired NFL population (Gavett, Stern & McKee, 2011). However, it is important to note that causality has yet to be established between CTE tauopathies and the cognitive, emotional and behavioral declines exhibited in many retired football players and the term CTE should be used with caution (McCrory, Meeuwisse, Kutcher, Jordan & Gardner, 2013).

Research has found consistent evidence of cognitive and emotional decline in retired NFL players in recent years. Strain and colleagues found that retired professional football players endorsed significantly more depressive symptomatology, especially related to cognition, as compared to normal age-matched controls with no history of concussion (Strain, Didehbani, Cullum, Mansinghani, Conover, Kraut, Hart & Womack, 2013). These results were a replication of a prior study conducted in 2009 that also demonstrated increased reporting of depressive symptoms in retired NFL players as compared to age and race matched controls (Weir, Jackson & Sonnega, 2009). Additionally, research has demonstrated that retired NFL players evidence symptoms related to mild cognitive impairment (MCI) including overall deficits across multiple cognitive domains and decreased cerebral reserve, or ability of the brain to retain premorbid functioning despite experiencing trauma or adverse events (Randolph, Karantzoulis & Guskiewicz, 2013).

Lehman and colleagues found that in a cohort of retired NFL players, regardless of position, there was a three-fold increase in neurodegenerative mortality, as compared to the overall US population that the cohort was compared to (Lehman, Hein, Baron & Gersic, 2012). This epidemiological study supported the literature that retired NFL players are at larger risk for neurodegenerative diseases overall, such as Parkinson's Disease, Alzheimer's Disease and Amyotrophic Lateral Sclerosis (ALS) (Lehman et al., 2012).

Neuroimaging of Sports-Related Concussions

Sports-related concussions result in a number of physical injuries and declines, as well as, unsurprisingly, changes in brain biology and functioning. Structural magnetic resonance imaging (sMRI) has proven more useful and effective in detecting smaller brain changes and traumatic lesions in the brain as compared to computerized tomography (CT) (Kelly, Zimmerman, Snow, et al., 1988). However, MRI has demonstrated that it cannot consistently identify small structural changes, particularly subcortically, in concussion patients, leading it to be an additional diagnostic consideration, rather than a diagnostic test of choice in concussion management (Jordan, 1993). Diffusion Tensor Imaging (DTI) measures water molecule diffusion in white matter portions of the brain to produce detailed structural images of white matter (Basser & Jones, 2002). This MRI-based approach can more easily identify white matter damage after an individual has sustained a concussion. Furthermore, it can also be utilized in determining grey matter atrophy and abnormalities (Mukherjee, Miller, Shimony, Philip, Nehra, Snyder, Conturo, Neil & McKinstry, 2002). However, its usefulness in sports concussions is limited, as there is a paucity of research on DTI in sports-related concussions, specifically.

Overall, functional MRI (fMRI) has been the most clinically useful neuroimaging tool in sports-related concussion and determining a neurocognitive return-to-baseline (Pulsipher, Campbell, Thoma & King, 2011). It appears that fMRI better demonstrates the connection between brain region activation and neuropsychological domains, such as working memory and executive functioning, making it a more useful tool for clinicians than other older neuroimaging techniques.

Specifically, professional football players, imaging studies have demonstrated white matter tract changes in players with a long-standing history of concussion as compared to matched controls (Hart, Kraut, Womack, Strain, Didehbani, Bartz et al., 2013). Hart and colleagues also found blood flow differences in the same sample of retired NFL players with decreased cerebral perfusion in the left temporal lobe, inferior parietal region and superior temporal gyrus, areas associated with memory, word finding and naming ability, tasks that are associated with impaired neuropsychological functioning (Hart et al., 2013).

Treatment and Rehabilitation of Sport Concussions

The literature suggests that a comprehensive neuropsychological battery is the most useful and clinically guided way to assess for cognitive decline following a sports-related concussion (Echemendia, Putukian, Mackin, Julian & Shoss, 2001). Sports neuropsychology, a field that has grown over the past several years, has demonstrated the clinical utility of neuropsychological measures in terms of assessing for, and tracking treatment progress in order to make more accurate determinations of return-to-play status in athletes (Echemendia, 2006). Additionally, the National Academy of Neuropsychology has provided recommendations in regards to sports-related concussion diagnosis, treatment and monitoring at all levels, including youth to professional leagues, recommending that comprehensive neuropsychological assessment be conducted to aid in these goals (Moser, Iverson, Echmendia, Lovell, Schatz, Webbe, Ruff, Barth et al., 2007).

An epidemiological study of sports-related concussion in National Collegiate Athletic Association (NCAA) athletes suggested that athletic trainers and medical staff have been withholding athletes from play longer than ever before (i.e., immediate removal from game and requiring physician clearance prior to return which is typically 7-10 days following a diagnosed concussion) after they are believed to have sustained a concussion or head injury (Zuckerman, Kerr, Yengo-Kahn, Wasserman, Covassin, & Solomon, 2015). This trend of lengthened return-to-play time has also infiltrated at all levels of sport, including youth and professional leagues (Bryan, Rowhani-Rahbar, Comstock & Rivera, 2016). Additionally, US states have recently decided to implement stricter youth concussion laws in light of extensive research on deceased professional athletes and brain pathology studies. In 2016, a survey of primary care physicians in Massachusetts reported over 90% compliance with implemented youth concussion state laws and reported substantial support and understanding for the rationale behind the state laws (Flaherty, Raybould, Jamal-Allial, Kaafarani, Lee, Gervasini, Ginsburg, Mandell, Donelan & Masiakos, 2016).

The National Football League has recently implemented changes in their concussion protocol guidelines, beginning in 2007 where it was mandated that baseline and post-concussion neuropsychological testing be implemented for current players (Casson, Pellman & Viano, 2008). Additionally, in 2009 it was then mandated that players enter a concussion protocol and be removed from games or practice after they suffer a concussion

(Ellemberg, Henry, Macciocchi, Guskiewicz & Broglio, 2009). Return-to-play is now determined by the NFL team physician and an independent neurological consultant that is not associated with the team. As it has been demonstrated that repeated head traumas and injuries can result in cumulative difficulties and neuropsychological deficits, these newly implemented changes in the monitoring and treatment of professional football player mild TBIs is well warranted (Gessel, Fields, Collins, Dick & Comstock, 2007).

A retrospective study of NFL concussion data spanning two cohorts, 1996-2001and 2002-2007, indicated that the frequency of reported concussions remained consistent. However, changes occurred in the treatment of documented concussions and hits, with team physicians keeping players out of games in which they sustained a hit to the head more frequently than in prior years, and those with documented concussions takinglonger to be cleared to return-to-play (Casson, Viano, Powell & Pellman, 2010). It was hypothesized initially that given stricter guidelines for concussion tracking in the NFL in the 2002-2007 era, that an increased number of hits and concussions would be documented. However, the epidemiological data suggests that physicians and clinicians became more conservative in the treatment and management of these events, rather than in naming more events.

While newly minted tracking and treatment of mild TBI has been implemented in the NFL and continues to be discussed currently, aging retired NFL players most often played their careers during a time in which these measures were not implemented or discussed, creating increased opportunity for them to sustain repeated head trauma without any treatment or removal from contact play or practice, preventing recovering from concussions and resulting in cumulative unresolved head injury in these individuals.

Clinical Relevance

The controversy surrounding concussions in the National Football League has garnered significant media and medical coverage in recent years. As such, the NFL and other contact sports organizations and facilities have developed an increased interest and investment regarding the issue and potential ways to address it. However, while more consideration and research has been produced in recent years, in former players this increased concern has come far after they have retired from the game (DeKosky, Jaffee & Bauer, 2018). Given this, the population of retired NFL football players, particularly of older age, is unique from those playing in the NFL now. Concussion protocols, increased training and awareness, differing game rules and better equipment have changed the landscape of the game as compared to how it was played and managed even one decade ago.

The negative impacts of repeated head trauma, especially in football players has been consistently established in the literature. These sequelae include cognitive decline, such as memory loss or dysfunction, executive functioning deficits and attentional concerns. Furthermore, significant emotional and behavioral deficits have been well-established in the literature as well and include anxiety, depression, frustration, impulsivity and self-harm behaviors (Giza & Hovda, 2001). Neuropsychologists are now more often being utilized in the diagnosis, treatment and symptom management of concussions, with increased inclusion by other medical clinicians to provide optimal treatment outcome for patients (Zillmer, 2016). By conducting this study, the researcher can provide more information regarding the validity of neuropsychological measures and their subsequent clinical interpretations, thereby helping former players and clinicians make better educated and accurate impressions regarding client functioning. Furthermore, over half of retired NFL players reported hiding concussion status from training staff when a head injury was sustained during a game (Kerr, Register-Mihalik, Kay, DeFreese, Marshall, & Guskiewicz, 2018). This suggests the need for further honing of neuropsychological sequelae in order to make it easier for clinicians to identify concussions without having to rely on disclosure from athletes themselves. Additionally, this could help to more accurately track either treatment progress, or functional decline in clients of this population.

Purpose

The purpose of the current study was multi-fold. In regards to psychometric studies, it has been consistently demonstrated that using and understanding the normative data for neuropsychological measures is critically important for accurate and helpful interpretation of test scores. As such, being cognizant of unique populations and whether or not standardization samples accurately represent such populations, is paramount.

Currently, existing studies on psychometric data of NFL neuropsychological batteries focus on brief batteries administered to current NFL players during baseline assessment at the start of each season (NFL, 2016). While this information is crucial for accurate interpretation of such batteries and tracking of cognitive difficulties following concussions sustained during a season, this data does not pertain to the focus of the current study.

Furthermore, research regarding long-term outcomes of repeated concussions from football have been well-established (Giza & Hovda, 2001; Omalu et al., 2005; McKee et al., 2009), but no studies have looked at psychometric properties of this currently used NFL battery in retired players. Retired players are currently being compared against standardization samples of existing measures when they undergo neuropsychological or basic cognitive testing. As such, a formal statistical consideration regarding the appropriateness of these norms has not yet been discussed. Within this particular analysis, there was a focus on consequential validity and the utility of the results of the analysis. The purpose of determining the appropriateness of normative data and comparing normative player performance was to provide more information regarding what it means to meet or not meet criteria for cognitive impairment within this population, thereby sharpening clinical and treatment focus. Finally, while the individual neuropsychological measures utilized in the NFL battery have been thoroughly studied and have established psychometric properties, there has been no formal factor analysis on the battery to explore or confirm its labeled factor structure. A prior psychometric and factor analysis exists solely for the brief neuropsychological baseline assessment given to current players (Lovell & Solomon, 2011). That study provided the basis for the current study, in the hopes that psychometric information could be adequately compiled for both the current player population, as well as the increasing retired player population. The present study hoped to provide the beginning groundwork regarding these lapses in psychometric information for this widely-utilized battery in this unique population and will provide clinicians and researchers with valuable information in which to pursue future research and make more informed clinical judgments regarding neuropsychological status of this particular population.

Hypotheses

Hypothesis One

It was hypothesized that average performance on test measures in a population of retired NFL players will be significantly different than existing normative data for the same measures. It was hypothesized that these differences in performance will be seen on all measures, across all cognitive domains that will be studied in this analysis. Specifically, it was hypothesized that existing normative data, broken down by age, education or ethnicity, if needed, will be significantly higher than the retired NFL players' scores broken down in the same groups or categories. Scores in the retired player sample were hypothesized to be significantly lower than the normative data, regardless of types of norms used (i.e. age or education and ethnicity corrected). Overall, it was hypothesized that retired NFL players would have lower scores as compared to the published norms.

Justification One

The literature has demonstrated differing neuropsychological performance in those with and without mild TBI (Echemendia, Putukian, Macklin, Julian & Shoss, 2001). Results indicated clinically significant differences between those with and without sports-related brain injury, as well as supported the use of a complete neuropsychological battery, rather than a single test, in measuring the cognitive impact of concussion. A second study also discovered lowered cognitive performance across several cognitive domains in older adults (those 50+ years) with a history of head injury as compared to healthy controls (An & Monette, 2018). More specifically, the literature supports long-standing negative cognitive consequences of repeated sports-related concussion even decades after injury has occurred, with decreased neuropsychological performance, especially in regards to episodic memory, seen in athletes that sustained concussions as compared to former athletes with no history of concussion (De Beaumont, Theoret, Mongeon, Messier, Leclerc, Tremblay, Ellemberg & Lassonde, 2009). When reviewing the existing literature on neuropsychological performance in those with and without a reported concussion history, it was apparent that participants' neuropsychological performance was compared with normative data from the general population. No evidence of using athlete-specific or TBI-specific measures or norms are available or were utilized, suggesting a mismatch between the population being studied and the norms that are being used. By establishing comparisons between established norms and this unique population, there can be a determination as to whether or not valuable impairment information is being obtained from existing neuropsychological administration procedures and would help to provide more accurate measurements of cognitive impairment upon a continuum within the same population so that retired athletes are being compared amongst a more comparable cohort of individuals similar to themselves.

Hypothesis Two

It was hypothesized that an exploratory factor analysis (EFA) of a comprehensive neuropsychological battery used for retired football players (i.e., NFL battery) would yield five correlated factors, each in an individual domain that has previously been established and separated. It was hypothesized that these domains or factors will include executive functioning, language, processing speed, attention and memory. Furthermore, it was hypothesized that these factors will be positively correlated with one another and that the five domains will comprise specific established neuropsychological measures from within the comprehensive battery.

Justification Two

In the existing literature, there is no evidence of psychometric work being completed on the existing NFL concussion settlement battery that is specifically used for retired NFL players. While the neuropsychological measures have been broken into domains, no formal statistical analyses have been conducted on the factor structure of the battery itself for this unique population, with a factor analysis of the measures only being performed on normal individuals. Pieroth and Hanks suggest that while strides have been taken to enhance the study of concussions in the NFL, more empirical studies are needed to determine the effectiveness of concussion management in these football players (Pieroth & Hanks, 2014). An EFA of a neuropsychological measure or battery will provide clinically relevant information, providing a better understanding the clinical assessment of retired NFL players who are assessed using this battery. EFAs have been utilized on other neuropsychological measures, such as the Wechsler Intelligence Scales, and have been shown to help increase the clinical utility of the measure by providing clinicians and researchers more in-depth information regarding what is being measured and assessed (Hill, Elliot, Shelton & Pella, 2010). Additionally, research suggests that factor analyses of established batteries should be conducted for each unique and specific population, as factor structure has been shown to change when analyzed in varying populations (Duff, Langbehn, Schoenberg, Moser, Baade, Mold et al., 2006). Furthermore, an EFA would help to establish a clear factor structure from the already named factors of the NFL battery while also clarifying if there are additional factor (s) that potentially represent an unnamed construct related to cognitive performance and concussion. Finally, it is important to note the relevance of performing psychometric analyses in unique populations to determine if the factor structure already established in a normal population theoretically and statistically matches the factor structure in a finite population of retired athletes.

CHAPTER III: METHOD

Participants

Participants were selected from a de-identified database of adult retired NFL players (N=117). Individuals were referred for testing to a private board-certified licensed neuropsychologist as part of their legal involvement with the NFL concussion settlement. Individuals were either self-referred through word-of-mouth or referred by their attorney to this particular testing location. Participants included in the study were between the ages of 31 and 69 and were used in the study if they completed a comprehensive neuropsychological evaluation including memory, language, intelligence and executive functioning measures. Participants had a mean age of 47.98 (SD=9.33). While all participants were at least enrolled in college for some time before their professional sports career, 59.0% earned Bachelor’s degrees. Time played at the professional level varied amongst participants, ranging from one year to twenty-one years, with mean years played equally 6.25 (SD=3.59). Test of Premorbid Functioning (TOPF), estimates of premorbid intelligence based off demographic factors, ranged from a standard score of 84 to a standard score of 118, average intelligence to high average intellectual ability.

The mean premorbid estimate of intellectual functioning was 102.75. Of the participants, 75.9% identified as African American, while 24.1% identified as Caucasian. Most recent NFL surveys reveal that currently 70% of the league identifies as African American (Sonnad, 2018). Tables 1 and 2 shows demographic breakdowns of the sample.

Table 1

Age, years played, pre-morbid functioning

	M	*SD*
Age	47.98	9.33
Years Played in NFL	6.25	3.59
Pre-Morbid Estimate of Intellectual Functioning	102.75	5.88

Given the population of interest, 100% of the participants were male. English was the primary language of all participants and was the language used in testing.

Table 2

Ethnicity and education breakdown of sample

	Total Sample
African American	75.9%
Caucasian	23.9%
Hispanic	<1%
Asian	<1%
Associate’s Degree/2 years of college	0.9%
3-5 years of college and no degree	28.2%
Bachelor’s Degree (16 years of education)	59.0%
Master’s Degree/Post-Bachelor’s Degree (17+ years of education)	11.1%

Participants were not excluded based on history of psychiatric diagnoses, such as depression or anxiety, in order to help maintain an adequate sample size. Additionally, information regarding medical or other psychiatric diagnoses were not reported in this dataset. The sample included a broad range of position players and was comprised of the following breakdown: Quarterback=3.4%; Running Back=15.4%; Fullback= 0.9%; Wide Receiver=16.2%; Tight End=6.0%; Offensive Lineman=12.8%; Defensive Lineman=12.8%; Linebacker=12.8%; Defensive Back=17.9% and Special Teams=1.7%. Table 3 shows player position breakdown.

Table 3

Player Position

	Total Sample
Quarterback	3.4%
Running Back	15.4%
Fullback	0.9%
Wide Receiver	16.2%
Tight End	6.0%
Offensive Lineman	12.8%
Defensive Lineman	12.8%
Linebacker	12.8%
Defensive Back	17.9%
Special Teams	1.7%

Participants were included if they completed the comprehensive neuropsychological battery and have scores for all Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) (Wechsler, 2008) and Wechsler Memory Scale-Fourth Edition (WMS-IV) (Wechsler, 2008) measures, as well as Trail Making Test (TMT) B (Reitan, R.M., 1971), Boston Naming Test (BNT) (Kaplan, Goodglass & Weintraub, 1978), Category Test (Halstead, 1947) , Wisconsin Card Sorting Test (WCST) (Heaton, Chelune, Talley, Kay & Curtiss, 1993), Boston Diagnostic Aphasia Examination (BDAE) (Goodglass, Kaplan, & Barresi, , 2001), Category Fluency-Animals (Benton, Hamsher, & Sivan, 1983) and Verbal Fluency-FAS (Benton, Hamsher, & Sivan, 1983).

Participants were excluded if they did not complete a full battery, including the effort and motivation measures. If participants failed six or more of the twelve individual effort scores, namely half of the motivation measures, they were excluded from the analysis as well to maintain efficacy of the scores and performance analysis.

Measures

The following measures are components of the existing NFL battery utilized in retired player populations for the concussion settlement (NFL Players' Concussion Injury Litigation., 307 F.R.D 407-11, 2017); Boston Naming Test, Category Fluency-Animals, Verbal Fluency-FAS, Boston Diagnostic Aphasia Exam-Complex Ideational test, Trails B, Category Test, and select subtests from the WAIS-IV and WMS-IV. WAIS-IV subtests include Block Design, Digit Span, Arithmetic, Letter-Number Sequencing, Similarities, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search, and Cancellation. WMS-IV subtests include Logical Memory I and II, Visual Reproduction I and II, and Verbal Paired Associates I and II.

Boston Naming Test (BNT)

The BNT measures confrontational word retrieval, specifically the ability to name objects. The BNT was developed to assess for anomic aphasia, an inability to name objects that can occur in stroke, Alzheimer's disease or other forms of dementia (Kaplan, Goodglass & Weintraub, 1983). Individuals are presented with sixty line drawings one at a time and are asked to name each object as it is presented. Images increase in difficulty as measured by their overall usage frequency. Examinees are given twenty seconds to respond to each image before the examiner provides them with either a semantic cue, if the individual is unfamiliar with the object itself, or a phonemic cue, if the individual knows what the object is but is struggling to retrieve the word. Scoring is based off the type of cue given, if any (Nicholas, Brookshire, MacLennan, Schumacher & Porrazzo, 1989). Language areas in the brain are implicated in performance on the BNT, specifically Broca's and Wernicke's areas of the left frontal and temporal lobes, traditionally. Naming tests, such as the BNT, are also involved in the left triangularis of the frontal lobe and the superior temporal lobe, providing an additional brain region outside of the commonly thought-of areas such as Broca's and Wernicke's regions (Mitchell & Crow, 2005; Obler, Rykhlevskaia, Schnyer, Clark-Cotton, Spiro, Hyun, Kim, Goral & Albert, 2010). Strain et al discovered that white matter structure and integrity disruptions within a group of retired NFL players exposed to concussion and sub-concussive injuries demonstrated lowered performance on the confrontational naming task (Strain, J., Didehbani, N., Spence, J., Conover, H., Bartz, E., Mansinghani, S., Jeroudi, M., et al, 2017). This same disruption was not noted in a control group, suggesting that white matter integrity and confrontational naming may be specifically impacted by the type of concussive injury commonly experience in professional football.

Category and Verbal Fluency

The Category Fluency-Animals task is a measure of semantic fluency whereas the Verbal Fluency (FAS) task is a measure of phonemic fluency. The Verbal Fluency task employed in the NFL battery is the Controlled Oral Word Association Test (COWAT). During the Category Test, individuals are asked to name as many different animals as they can in 60 seconds, essentially “freelisting” in that time period as the examiner records orally produced responses (Lezak, 2004). In the FAS Verbal Fluency task, individuals are asked to name as many words as they can think of that start with a particular letter, either F, A, or S in 60 seconds, without utilizing proper nouns, such as a person’s name or name of a place, as well as numbers, or words with the same root but different endings. Answers are again provided verbally by the respondent and are recorded by the examiner (Lezak, 2004). In general, these tests have been considered to be measures of both expressive language ability, as well as executive functioning ability (Schinka, Loewenstein, Raj, Schoenberg, Banko, Potter & Duara, 2010; Hedden & Yoon, 2006). Additionally, decline in verbal expression and verbal fluency has been demonstrated to be a predictor of long-term outcomes related to cognitive decline and dysfunction (Oulhaj, Wilcock, Smith & de Jager, 2009). Within populations that have history of mild traumatic brain injury, performance on fluency tasks was impaired as compared to controls, with more errors and fewer words expressed on both trials (Rakin, S., & Rearick, E, 1996). Interestingly, verbal fluency performance was also a clinical predictor of long-term cognitive decline in a military population that had sustained concussive injuries, suggesting the importance of this task in populations with histories of concussion or other brain injuries (MacDonald, C., Barber, J., Jordan, M., Johnson, A., Dikmen, S., Fann, J., & Temkin. N, 2017).

Boston Diagnostic Aphasia Exam – Complex Ideational Material

The Complex Ideational Material (CIM) subtest from the Boston Diagnostic Aphasia Exam is a measure of receptive language and comprehension ability (Goodglass & Kaplan, 2003). This is a measure of auditory comprehension and receptive speech abilities in which individuals are read short questions and/or passages and must respond in a "yes" or "no" manner. While the BDAE was normed on an exclusively male population with aphasia, the CIM subtest has been studied in other populations and has been shown to be effective in measuring not only receptive language deficits, but also performance validity in non-aphasic samples (Erdodi & Roth, 2017). The first six items are typically thought of an assessment of auditory comprehension, while the remaining six items are considered a measure of auditory comprehension and more complex receptive language functioning. Both a short and long form of the subtest exist, with the long-form (12 item) version being utilized in NFL battery in question. A pilot study with youth hockey players who had repeated concussive injuries indicated that 67% of players had language difficulties, including having to read items several times for comprehension (Konin, J., & Horsley, D, 2017). More complex language disruption has been shown consistently in populations that have sustained concussion, with deficits in auditory processing, speech perception, comprehension and other more complex linguistic abilities (Stockbridge, M & Newman, R., 2019; Norman, 2017; Biddle, K., McCabe, A., & Bliss, L, 1996). This suggests the impact of concussion on more complex language functioning, including auditory comprehension and receptive functioning, as measured by the CIM in the BDAE, making it an important component to the assessment of cognitive functioning in retired NFL players with long-standing history of head injury.

Trail Making Test A and B

The Trail Making Test (parts A and B) are a subtest from the Army Individual Test (1944) used as measures of attention, scanning, visuomotor tracking, divided attention, and set-shifting abilities. In Trails A, the patient is given a page with a set of numbered circles scatters about the page, and is asked to draw a line between consecutive numbers. In Trails B, the patient is given a sheet with randomly distributed circled numbers and circled letters, and asked to draw a line connecting A-1, B-2, C-3, and so forth in a sequencing pattern. Scores are based on total time to complete task, and the number of errors made. Cut-off scores were used in the original interpretation of the test (Reitan & Wolfson, 1985), but contemporary practitioners favor the sensitive of the use of *t*-scores based normative groups established by Heaton in 2004 (Strauss, Sherman, & Spreen, 2006). Test reliability is acceptable but there is significant variability across studies using different samples (Strauss, Sherman, and Spreen, 2006). Both parts of the test measure processing speed and visuo-spatial skills (Strauss, Sherman, and Spreen, 2006), and the two tasks are moderately correlated with one another, though Trails B is considered to be a more specific measure of executive functioning as it requires reasoning ability other higher-order processes (Golden, Espe-Pfeifer, & Wachsler-Feider, 2000; Kortte, Horner, & Windham, 2002). Several studies have shown the utility of the TMT in predicting cognitive, functional and emotional outcomes following brain injury in populations that have sustained multiple head injury events (Leininger, S., Strong, C., & Donders, J, 2014; Barco, P., Wallendorf, M., Snellgrove, C., Ott, B., & Carr, D, 2014; DeGuise E., Belanger, S., Tinawi, S., Anderson, K., LeBlan, J., Lamoureux, J., Audrit, H., & Fey, M, 2016). Additionally, Lovell and Solomon found that Trails B performance was higher in African American as compared to the Heaton norms and interestingly discovered that Trails A performance was lower than the Heaton norms in a sample of current African American NFL players who had 16 years of education (Lovell & Solomon, 2011).

Category Test

The Category test measures perceptual reasoning and set-shifting and mental flexibility aspects of executive functions. The task consists of a presentation of 208 individual items. There are no time limits. There are six item sets, each organized on the basis of different principles (number, shape, size, color, intensity, and location), followed by a seventh set made up of previously shown items which require recall of previously learned ‘rules’ from earlier sets. The patient’s task is to deduce the principle presented in each set and indicate which one of four target stimuli correctly adhere to the current rule. The total number of errors across subtests is used as a measure of abstract reasoning ability. Correct performance requires the selection of a correct response based upon the stimulus and positive or negative feedback given, maintenance of the response pattern, and shifting of cognitive set, when appropriate. Of the other subtests from the Halstead Neuropsychological Battery, the Category Test is the most sensitive to neurological insult regardless of the location of insult (King & Snow, 1981; Cullum & Bigler, 1986), indicating that it is sensitive to damage in areas beyond the frontal lobes. The test is sensitive to the effects of age and education; Heaton, Grant, and Matthews (1991) devised correction factors for age, education and gender based upon a large normative sample.

Pang and colleagues used functional connectivity imaging to determine that functional connectivity and mental flexibility were negatively impacted in individuals who experienced concussion, when measured in resting state (Pang, E., Dunkley, B., Doesburg, S., da Costa, L., & Taylor, M., 2016). Additional studies have demonstrated mild rates of neuropsychological or self-reported executive dysfunction in football players with histories of concussion (Seichpine, D., Stamm, J., Daneshvar, D., O'Reilly, D., Baugh, C., Gavett, B., Tripodis, Y., et al., 2013; Hampshire, A., MacDonald, A., & Owen, A., 2013). However, there is also inconsistency in the literature regarding the relationship between concussion and the impact that it has on mental flexibility and other aspects of executive functioning that are measured in the Category Test, namely that there are no clinically significant impairments in executive functioning between healthy controls and individuals with history of concussion, making it an important addition to try and expand on the existing literature currently available (Willer, Tiso, Haider, Hinds, Baker, Miecznikowski & Leddy, 2018; Lohues & Gonzales, 2018).

Block Design

The Block Design subtest is the first subtest on the Wechsler intelligence tests, and for the purposes of this battery, the first subtest of the Wechsler Adult Intelligence Scale-Fourth Edition, and a component of the Perceptual Reasoning Index (WAIS-IV; Pearson, 2008). It is a measure of visual ability, and specifically, visuospatial ability (Silverman, Choi, & Peters, 2007). Individuals are presented with two-dimensional images that they must reconstruct with three-dimensional blocks. Images become increasingly more complicated and move from a sample item with two blocks, to four-block images and finally, nine-block designs. The subtest is also timed, creating a need for both speed and accuracy. Block Design tasks have been shown to measure parietal and frontal lobe functioning, given the motor, planning and visual components of the task (Groth-Marnat & Teal, 2000). It has also been demonstrated to show decreased or impaired performance in head injured individuals, as well as those with stroke or Alzheimer's disease (Lezak, 1995). More specifically, visuospatial ability, as measured on Block Design, has been found to be negatively impacted in retired athletes, specifically those with history of concussion (Zhang, Y., Ma, Y., Chen, S., Liu, X., Kang, H., Nelson, S., & Bell, S., 2019).

Digit Span

Digit Span is a subtest that makes up the Working Memory Index on the WAIS-IV intelligence test. It is a measure of working memory, specifically in regards to attention and concentration (Lezak, 1995). Individuals are presented with a series of numbers orally and must recall the numbers either in the order they heard them, backward, or in sequential order. The series of numbers are read by the examiner at the pace of one number per second and are not allowed to be repeated. Individuals cannot write numbers down or use their hands to help with their responses. Given the nature of the subtest, there is an auditory processing component in addition to the attentional requirement (Lezak, 1995).

Iring and colleagues demonstrated increased cerebral blood flow and decreased cognitive performance on digit span tasks in individuals who suffered from concussion during contact sports (i.e. rugby). These individuals were assessed immediately following a concussion and compared to normal controls (Iring, Favre, Brewer, De La Cruz, Liu, et al., 2019).

Arithmetic

Arithmetic is a subtest that comprises the Working Memory Index of the WAIS-IV intelligence test, along with Digit Span, discussed above (Lezak, 1995). Individuals are read short math word problems and are required to remember and solve the problem utilizing mental math under timed conditions. Word problems may only be repeated once and increase in difficulty as the test proceeds in regards to the complexity and difficulty of the information that must be remembered and manipulated. Paper and pencil usage is not permitted. This test is sensitive to working memory deficits, but is also impacted by the mathematical nature of the material, leading to increased frustration and anxiety in many individuals who perceive the test to be a measure of math ability, rather than of attention and concentration (Lezak, 1995).

As discussed above regarding an additional task, (i.e., digit span), working memory performance and ability was impacted immediately following concussions in professional rugby players (Iring et al., 2019). Additionally, electrophysiology research has demonstrated that individuals with a history of concussion require more time to accurately respond during working memory tasks that are cognitively demanding, such as with Arithmetic (Ozen, Itier, Preston & Fernandes, 2013).

Letter-Number Sequencing

This subtest is a component of the optional subtests on the WAIS-IV. It may be used in place of Digit Span or Arithmetic in order to obtain a Working Memory Index Score (Wechsler, Coalson & Raiford, 2008). Individuals are presented with a series of numbers and letters orally and must recite them back to the examiner by first stating all numbers in sequential order, followed by all letters in sequential order. The examiner is not permitted to re-read the series and must present the sequence at a rate of one item per second. This subtest involves working memory, specifically attention and concentration abilities through an auditory modality (Lezak, 1995). Literature has suggested that Letter-Number Sequencing is highly correlated with performance on the Digit Span subtest of the WAIS-IV, but that it also incorporates other functions, specifically processing speed and visual-spatial ability, over and above what is required of those functions on Digit Span (Crowe, 2000).

A small study comparing concussed versus non-concussed individuals' performance on letter-number sequencing demonstrated that individuals with concussions had shorter forward spans during the task as well as slowed EEG functioning (Kiss, 2020). Shah-Basak and colleagues also suggested, through the use of magnetoencephalography, that repetitive concussion history can have a detrimental impact on attention and visual working memory ability, two skills needed to adequately perform on the letter-number subtest (Shah-Basak, Urbain, Wong, da Costa, Pang, Dunkley & Taylor, 2018). Finally, an older study showed adequate criterion validity on the Letter-Number Sequencing subtest, demonstrating that it produced significant differences in performance amongst severe TBI, mild TBI and control groups when administered amongst demographically matched populations (Donders, Tulsky & Zhu, 2002).

Similarities

Similarities is a component of the Verbal Comprehension Index on the WAIS-IV. It consists of the examiner presenting the individual with two words and asking how they are similar to each other (Lezak, 1995). Word pairs increase in difficulty as they move from more concrete similarities and commonalities to more abstract rationale. Similarities requires knowledge of the words being presented, as well as the capacity to form abstract connections and apply verbal abstract reasoning (Lezak, 1995). Similarities performance has been shown to be impacted by years of education received (Brooks, Holdnack & Iverson, 2011).

Several studies have demonstrated that overall verbal ability can be negatively impacted by a history of concussion in both children, adolescents and adults across the population (Stockbridge, Newman, Zukowski, Slawson, Doran & Ratner, 2020; Ketcham, Bowie, Buckley, Baker, Patel & Hall, 2017). Furthermore, a meta-analysis of concussion research suggested that mild traumatic brain injury commonly results in multiple affected cognitive domains, which in turn significantly impacts language comprehension and abstraction (Rowley, Rogish, Alexander & Riggs, 2017).

Visual Puzzles

Visual Puzzles is a component of the Perceptual Reasoning Index on the WAIS-IV (Wechsler et al., 2008). Individuals are presented with a two-dimensional puzzle and are given a choice of six stimulus pieces from which they must choose three that will fit together to make the puzzle under timed conditions. Individuals are instructed that pieces cannot overlap and that they must always pick three pieces (Wechsler et al., 2008). Visual Puzzles is thought to be a better measure of spatial intelligence overall as compared to other perceptual reasoning subtests on the WAIS-IV, given its high item count and high ceiling, allowing individuals to progress further in the subtest with increased spatial manipulation demands (McCrea & Robinson, 2011).

Brown and colleagues found that individuals with a history of traumatic brain injury were significantly less efficient in finding and understanding visual patterns as compared to non-TBI counterparts (Brown, Thiessen, Freeland & Brewer, 2019). Additionally, research has demonstrated that adults with at least one TBI showed worse performance on tasks of non-verbal abstract reasoning as compared to adults without a history of TBI (Livny, Biegon, Kushnir, Harnof, Hoffmann, Fruchter & Weiser, 2017).

Matrix Reasoning

Matrix Reasoning is the only untimed subtest comprising the Perceptual Reasoning Index on the WAIS-IV (Lezak, 1995). The individual is presented with a two by two visual stimuli or a row of several boxes, with one empty space. Individuals are asked to choose a correct response from five presented options that best completes the puzzle or pattern. The task involves not only visual ability, but also spatial reasoning and visuospatial perceptual abilities (Lezak, 1995). It is thought to be an adequate estimate of nonverbal IQ and of overall intellectual functioning in those taking the WAIS-IV with limited or decreased English proficiency (Lezak, 1995). Matrix reasoning has overall been found to be fairly insensitive to mild traumatic brain injury, with research suggesting that scores between normal controls and mild brain injured individuals do not differ significantly on this subtest (Ghaffar, McCullagh, Ouchterlony & Feinstein, 2006).

As discussed above, a history of TBI has been demonstrated to negatively impact performance on visual pattern tasks, especially in regards to identifying visual patterns, such as what is necessary in Matrix Reasoning (Brown et al., 2019). Interestingly, however, Matrix Reasoning has been shown to be fairly resilient to the negative cognitive effects of TBI in general, suggesting that it may be useful as a helpful indicator of pre-morbid performance or effort (Ryan, Carruthers, Miller, Souheaver, Gontkovsky & Zehr, 2009; Sussman, Peterson, Connery, Baker & Kirkwood, 2019).

Coding

Coding is one of two subtests comprising the Processing Speed Index on the WAIS-IV (Wechsler et al., 2008). It involves visual spatial ability and motor speed. Individuals are asked to fill in an empty box with the correct symbol that corresponds to a number in the upper part of the box. A key is provided at the top of the page where each number (1-9) has a unique symbol associated with it. The individual must use visual scanning and tracking to move between the key and the stimulus in order to quickly and accurately fill in as many boxes as possible under timed conditions (Wechsler, 2008). Research has demonstrated that impaired performance on tests of processing speed, such as coding, can be seen several years after traumatic brain injury in individuals as compared to controls who have never experienced brain injury (Draper & Ponsford, 2008).

Processing speed has been shown to be largely impacted by concussion and other types of head injury insults, producing reduced reaction time and cognitive efficiency in individuals with concussion and/or TBI histories (Green, Keightley, Lobaugh, Dawson & Mihailidis, 2019; Hume, Theadom, Lewis, Quarrie, Brown, Hill & Marshall, 2017).

Symbol Search

Symbol Search is a component of the Processing Speed Index on the WAIS-IV (Wechsler, 2008). It is comprised of a number of pages in which the individual must decide if one of two target items is located within a series of geometric designs. If a target itemis within that series, the individual must draw a line through it, indicating that they found the shape. If the target shape is not present, the individual must indicate this by drawing a line through a “no” box. The test is timed and individuals are instructed to work as quickly as they can, in order (Wechsler, 2008). This subtest involves visuospatial ability, motor speed and visual scanning, as the individual must be able to quickly look back and forth across a page with multiple geometric designs. Similar to coding, symbol search is impacted by brain injury, as processing speed deficits are a common neurocognitive consequence of mild traumatic brain injury (Draper & Ponsford, 2008).

As mentioned within the context of the Coding subtest, processing speed is negatively impacted in individuals with a history of TBI and concussion. Additionally, as demonstrated above, visual-spatial ability and efficient processing of visual stimuli is also impacted. Given the combination of time and quickly assessing in a visual modality, Symbol Search performance is also largely impacted by concussion history (Stenberg, Haberg, Follestad, Olsen, Iverson, Terry, Karlsen, Saksvik,Karaliute, Ek, Skandsen & Vik, 2020).

Cancellation

Cancellation is a component of the optional measures on the WAIS-IV (Wechsler, 2008). Cancellation is a motor and visual processing speed task that requires the individual to quickly scan lines of shapes in two different colors in order to quickly identify and cross out target stimuli that were taught to them in a practice trial while also avoiding responding to distractor items. There are two trials, each with its own target stimuli. Each trial is thirty seconds long and requires the individual to be able to quickly scan a page line by line without the ability to go backwards if the examinee misses a target. Missed targets are subtracted from the examinee's total score, ultimately lowering the total score and penalizing the individual (Lezak, 1995). Cancellation is a task that could be used to assess visual neglect, response inhibition and motor perseveration, having been modeled after existing cancellation-type tests used for these assessments (McCrea & Robinson, 2011).

Imaging on other cancellation tasks similar to the one on the WAIS-IV have demonstrated disruption in the frontoparietal and fronto-occipital lobes, particularly of the right hemisphere (Urbanski et al., 2011). Of note, however, McCrea and Robinson found that the WAIS-IV cancellation subtest was not as heavily reliant on right hemisphere visual function as compared to existing cancellation tests in the literature. Rather they discovered that WAIS-IV cancellation had a strong verbal labelling and verbal mediation characteristic suggesting increased left hemisphere involvement (McCrea & Robinson, 2011).

Given the complexity of the Cancellation task, namely with its motor, processing speed and visual tracking elements, it is particularly interesting in a concussion population. Maruta and colleagues suggested that visual tracking ability could be used as a measure of concussion severity and presence (Maruta, Suh, Niogi, Mukherjee & Ghajar, 2010). Furthermore, research has suggested that the left hemisphere shows some metabolic and microstructural changes in some athletes who have sustained concussions, demonstrating the importance of using measures that can help identify difficulties in this area (Chamard, Lassonde, Henry, Tremblay, Boulanger, De Beaumont & Theoret, 2013).

Logical Memory I and II

Logical Memory I and II are the immediate and delay components of an auditory verbal memory subtest on the Wechsler Memory Scale-Fourth Edition (WMS-IV; Wechsler, 2008). Logical Memory involves the examiner reading a story aloud to the examinee and then asking for immediate recall of the story, as close to the same words that the examiner used as possible. A second story is then read in the same manner and the examinee is asked to recall the second story as well. Logical Memory II is the delay component of Logical Memory I, 20-30 minutes after the initial reading of the stories.

Logical Memory performance decline has been demonstrated to be impacted in players who participant in contact sports and whom have experienced head injuries (Matser, Kessels, Jordan, Lezak & Troost, 1998). However, more recent testing that looked at memory performance in individuals with mild head injury suggested that auditory verbal memory performance was not significantly impacted by the traumatic injury event as compared to other memory modalities (Carlozzi, Grech & Tulsky, 2013).

Gaines and colleagues demonstrated that combat Veterans with a history of concussion performed significantly worse on both the immediate and delayed components of Logical Memory, in addition to other cognitive tasks as compared to individuals without a history of concussion (Gaines, Soper, & Berenji, 2016). A study from 2019 suggested that head injury severity was indicated of long-term verbal memory performance with increased injury severity correlated with worsening cognitive performance on verbal memory tasks (Lindsey, Lalani, Mietchen, Gale, Wilde, Faber, MacLeod, Hunter, Chu, Aitkenn, Ewing-Cobbs & Levin, 2019).

Visual Reproduction I and II

Visual Reproduction I and II are the immediate and delay components of a visual memory test on the Wechsler Memory Scale-Fourth Edition (WMS-IV; Wechsler, 2008). The examinee is asked to study a stimulus page with either one or two designs for ten seconds, and then is immediately asked to draw the designs from memory. The delay portion (Visual Reproduction II) occurs 20-30 mins after Visual Reproduction I and involves the examinee re-drawing the images presented in the earlier section, from memory. Research has demonstrated that Visual Reproduction performance can be negatively impacted in individuals who have suffered mild traumatic brain injury, or concussion (Lovell, Iverson, Collins, McKeag & Maroon, 1999). Recent research has demonstrated that visual memory is impacted more significantly than verbal memory in the event of mild and/or moderate traumatic brain injury (TBI), suggesting larger right hemisphere and namely parietal and occipital lobe involvement in these types of mild sports-related head injuries (Carlozzi et al., 2013).

Matser and colleagues found significant differences in performance on Visual Reproduction and other neuropsychological tests in boxers who had sustained concussions as compared to normal controls, with boxers performing significantly worse on this measures, and others (Matser, Kessels, Lezak, Troost & Jordan, 2015). More broadly, a study with college athletes found that individuals with significant concussion histories had poorer visual working memory outcomes, including impaired electrophysiology during the tasks themselves (Theriault, De Beaumont, Tremblay, Lassonde & Jolicoeur, 2011).

Verbal Paired Associates I and II

The Verbal Paired Associates I and II tasks are components of the WMS-IV auditory and verbal memory indices (Wechsler, 2008). Individuals are read a list of related and unrelated word pairs and then provided with the first word in each pair. He or she is then required to supply the word that goes with the presented word, in other words, complete the word pair. The individual is provided with feedback, either being told that they are correct, or being provided with the correct response should they answer incorrectly (Wechsler, 2008). Verbal Paired Associates II is the delay portion that occurs 20-30 min after the immediate trial. Individuals are given the first word in each pair and are then asked to supply the second word, this time without receiving feedback from the examiner. A recognition component involves the examiner reading several word pairs and asking the examinee to respond "yes" if he or she believes it was a word pair originally presented to them, or "no" if they believe that it was not. Similar to Logical Memory I and II, Verbal Paired Associates I and II has been demonstrated to be less impacted by mild or moderate TBI as compared to visual memory measures and performance (Carlozzi et al., 2013). Of note, receiver operating characteristic (ROC) analysis studying the discriminative ability of the VPA subtest in general suggested that VPA may struggle to differentiate those with and without mild amnestic cognitive impairment, decline that is commonly seen in retired NFL players (Pike, Kinsella, Ong, Mullaly, Rand, Storey, Ames et al., 2013).

An older study looking at the Verbal Paired Associates task on the Wechsler Memory Scale-Revised version found that individuals with history of closed head injury performed worse than healthy controls (Reid & Kelly, 1993). Additionally, Terry and colleagues found that a history of multiple concussions in adolescence was associated with overall poor verbal learning and memory in adulthood (Terry, Adams, Ferrara & Miller, 2015), indicating that concussions may have a significant effect on verbal processing and memory in general. Finally, in a study looking at retired NFL players, neuropsychological performance and neuroinflammation, players demonstrated variable performance on a verbal memory task and showed potential inflammatory changes within their brain, suggesting that repeated concussions have long-term cognitive and biological consequences related to verbal memory ability (Coughlin, Wang, Munro, Ma, Yue, Chen, Airan, Kim, et al., 2015).

All measures listed above, aside from the WAIS-IV and WMS-IV subtests, are stratified by age, gender and education and are scored using the revised normative data for the expanded Halstead-Reitan Battery (HRB) compiled by Heaton and colleagues (Heaton, Miller, Taylor & Grant, 2004). All norms used in the HRB are stratified across age groups, education levels and gender, in addition to being categorized into two ethnicity categories i.e. Caucasian or African American. Norms begin at an education level of seven years and continues to twenty years. Furthermore, ages ranged from 20-85 years old. For WAIS-IV and WMS-IV subtests, scores are gathered based off age norms, stratified across varying age groups ranging from 16 to 89.

Statistical Analysis

For the purposes of this study, results were analyzed at the .05 level of significance with an appropriate Bonferroni adjustment in SPSS, given the sample size. Statistical analyses were conducted in SPSS. For the purposes of this study, standardized scores (i.e. T scores or standard scores) and raw scores on neuropsychological measures were analyzed in order to produce more accurate interpretations of differences in performance, if any.

For hypothesis one, raw and standardized scores of former NFL players were compiled for each neuropsychological measure to be studied. From these scores, ranges, means and standard deviations were produced in order to provide basic test data. These averages, or normative, scores were compared with the existing norms of each neuropsychological measure in order to assess for differences amongst varying populations on the same test. Single-sample T-tests will be used to determine if differences between NFL players normative scores and established normative scores are clinically significant. Specifically, each measure in the NFL concussion battery has existing normative data, including normative sample information and details regarding average performance as determined based on the utilized sample. This existing normative data, specifically the raw and standardized scores, was compared to the average performance on the same measures in a unique sample of retired NFL players completing a comprehensive neuropsychological battery. Comparisons were made between appropriate age, ethnicity or education groups, i.e. if existing neuropsychological measures are normed by age, ethnicity or education, the collected data will also be broken down into comparable groups in order to ensure accuracy of the normative data comparisons. Of note, the HRB measures include a stratification for ethnicity and education, in addition to age, but the Wechsler scales (i.e. WAIS-IV and WMS-IV) do not, as they only use age for norming scores. Scores from the appropriate subgroups of players were compared against the matching subgroup for the existing norms, whether it be based on age or education and ethnicity, depending on the test being compared.

Each measure from the neuropsychological battery was used in comparisons of normative samples and this specific sample of retired NFL players. For the Boston Naming Test (BNT) the total score will be used to in comparisons. Additionally, for Category Fluency-Animals and Verbal Fluency-FAS, the total scores were utilized to compare norms across groups. The Boston Diagnostic Aphasia Exam-Complex Ideational task utilized the total score (out of 12) and for Trails B, the total time (in seconds) was compared. The computerized Category test was compared based on number of errors made on the measure. On the WAIS-IV subtests, scaled scores for all subtests were compared between existing normative data and the NFL players' normative performance on each individual subtest, including Block Design, Digit Span, Arithmetic, Letter-Number Sequencing, Similarities, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search and Cancellation. Additionally, the same method was used on WMS-IV subtest comparisons, again using the total subtest scored compared between the players and the existing data on Logical Memory I and I, Visual Reproduction I and II and Verbal Paired Associates I and II.

For hypothesis two, an exploratory factor analysis (EFA) of test measures was conducted in SPSS. EFA is a data-reduction technique used when a researcher is interested in determining the amount of common variance between variables. EFA is applied to enhance theoretical understanding of constructs, and is often used to generate explicit hypotheses to be tested using confirmatory techniques. This furthered understanding of theoretical constructs impacts clinical utility and understanding. EFA demonstrates that tests measuring similar constructs cluster together on a common factor based upon the shared variance among measures. EFA involves several steps, which include testing the validity of underlying statistical assumptions, deciding upon the type of extraction method, choosing the number of factors to be retained in the final interpretation, how to rotate the factor structure to improve its interpretation, and interpreting the final solution. The literature has provided several methodological recommendations for use in conducting EFA, and whether or not a confirmatory factor analysis (CFA) may be more appropriate for some psychological research. However, very few definitive guidelines, if any, are widely accepted by most researchers in the field.

Before conducting an EFA in SPSS, statistical and theoretical assumptions were tested. Furthermore, determining the extraction method to be utilized in the analyses will be based off sample size, statistical assumptions and appropriateness to the research question. Factors were retained based off clinical judgment and interpretation, as well as based on scree plot and eigenvalue interpretations. Furthermore, an appropriate rotation was applied to the data and the overall EFA will be interpreted, giving rise to a factor structure of the existing NFL battery.

In regards to data for the EFA, variables were comprised of standardized scores for all measures. In order to promote uniformity, all standardized scores were converted to a single type, namely T-scores. Standardized T-scores were obtained for the BNT, Category and Verbal Fluency tests, BDAE Ideational Complex test, Category and Trails B from the HRB norming system. Scaled scores obtained from the WAIS-IV and WMS-IV subtests were converted to T-scores in order for the EFA to be appropriately managed and interpreted.

Institutional Review Board requirements

Institutional Review Board (IRB) approval was acquired at Nova Southeastern University prior to the beginning of this study. To remain in accordance with the IRB and the American Psychological Association (APA), all data was de-identified.

CHAPTER IV: RESULTS

Preliminary Analyses

Preliminary analyses were conducted to assess the skewness and kurtosis of the performance on the variables utilized in the study and results are presented in Table 4. All variables utilized in the analysis were normally distributed with the exception of Letter-Number Sequencing. For this subtest, the Kurtosis value exceeded +/-3 indicating that the range of scores fell more heavily in the tails of the distribution curve as compared to a normal distribution. As such, Letter-Number Sequencing was excluded from future analyses.

Table 4

Descriptive Statistics of Performance on Cognitive Variables

Variables	*M*	*SD*	Skewness	Kurtosis
Digit Span	46.04	10.37	0.31	0.58
Arithmetic	44.19	9.29	0.50	0.01
Letter-Number	46.10	7.21	0.98	**3.84**
Symbol	44.27	10.81	0.42	0.91
Search Coding	42.15	8.68	0.42	0.39
Cancellation	44.16	10.41	0.59	0.67
Logical Memory I	39.61	10.17	0.24	-0.51
Logical Memory II	38.74	9.32	0.37	0.24
VPA I	41.74	8.19	0.51	1.34
VPA II	42.40	8.64	0.59	0.53
Visual Reproduction I	44.68	10.05	-0.15	-0.34
Visual Reproduction II	48.26	8.91	0.47	1.29
Block Design	44.70	8.54	0.15	0.01
Matrix Reasoning	47.87	10.90	0.19	-0.64
Visual Puzzles	45.72	9.89	0.57	0.87
Boston Naming Test	36.71	8.81	0.45	0.64
Category – Animals	40.81	12.51	-0.13	-0.38
BDAE Complex Ideation	35.24	15.95	-0.19	-0.95
Verbal Fluency (FAS)	44.16	11.35	0.19	-0.27
Similarities	46.35	8.95	0.18	0.18
Trails B	46.09	9.92	0.10	0.47
Category	41.92	9.57	-0.41	0.49

In order to carry out a factor analysis as part of hypothesis 2, several statistical assumptions were tested in SPSS. Bartlett's Test of Sphericity was conducted in SPSS to evaluate the first assumption related to the appropriateness of the factor analysis. The analysis was shown to be significant (χ^2(210) =13.67.29, p<.001) indicating that the null hypothesis stating that the distribution aligns with an identity matrix, thereby indicating no relationship amongst variables, can be rejected. In other words, the correlation matrix of variables was not an identity matrix. A significant test of sphericity indicates that an analysis of the factor structure is appropriate. Additionally, the Kaiser-Meyer- Olkin

(KMO) test, a measure of the proportion of variance amongst the above variables that may be attributed to common variance, was .881, indicating adequate sampling and appropriateness of proceeding with a factor analysis of the data.

Values greater than .6 are generally considered adequate to proceed with the analysis. The determinant was 0.00025, and while that is low and suggests some level of multicollinearity, it is above the generally supported cutoff of 0.0001. This indicates that while some of the variables within this study are correlated with one another, there are no predictor variables that are too highly correlated with other predictor variables, thatwould cause a disruption in data interpretation.

Pearson correlation matrices for all variables are displayed in Tables 5 – 9. Matrices were divided into several tables to assist with easier interpretation of the results given the large number of variables. Of note, the alpha level was adjusted through a Bonferroni correction to control for family-wise error (FWE) rates (Bonferroni, 1936; Shaffer, 1995). Table 5 depicts the correlations for the subtests that are considered part of the complex attention factor. Subtests include Digit Span, Arithmetic, Symbol Search, Coding and Cancellation. Digit Span was significantly correlated with all subtests in the battery with the exception of BDAE-Ideational Complex. According to Cohen's guidelines for correlation interpretation, effect sizes were primarily moderate (Cohen, 1988).

The Arithmetic subtests was significantly correlated with Digit Span, Symbol Search, Coding, Cancellation, Logical Memory I and II, Verbal Paired Associates I and II, Visual Reproduction I and II, Block Design, Matrix Reasoning, Visual Puzzles, FAS-Fluency, Similarities and Trails B. Effect size was generally small to moderate. The Symbol Search and Coding subtests were significantly correlated with all battery subtests with the exception of BDAE-Ideational Complex. Effect sizes were predominantly moderate. Finally, the Cancellation subtest was significantly correlated with all battery subtests except for BDAE-Ideational Complex and Category Test. Effect sizes were small to moderate.

Table 5

Pearson's Correlation for Complex Attention Subtests

Subtests	1	2	3	4	5
1. Digit Span	-	**.57**	**.63**	**.54**	**.48**
2. Arithmetic	**.57**	-	**.41**	**.36**	**.31**
3. Symbol Search	**.63**	**.41**	-	**.70**	**.67**
4. Coding	**.54**	**.36**	**.70**	-	**.56**
5. Cancellation	**.48**	**.31**	**.67**	**.56**	-
6. Logical Memory I	**.39**	**.39**	**.34**	**.35**	**.37**
7. Logical Memory II	**.38**	**.36**	**.37**	**.37**	**.43**
8. Verbal Paired Associates I	**.42**	**.32**	**.40**	**.36**	**.29**
9. Verbal Paired Associates II	**.34**	**.29**	**.36**	**.39**	**.34**
10. Visual Reproduction I	**.45**	**.33**	**.47**	**.49**	**.41**
11. Visual Reproduction II	**.48**	**.29**	**.54**	**.51**	**.36**
12. Block Design	**.38**	**.42**	**.50**	**.52**	**.46**
13. Matrix Reasoning	**.56**	**.41**	**.41**	**.37**	**.33**
14. Visual Puzzles	**.44**	**.45**	**.52**	**.43**	**.56**
15. Boston Naming Test	**.28**	.23	**.32**	**.29**	**.31**
16. Animals	**.38**	.27	**.47**	**.48**	**.40**
17. BDAE – Ideational Complex	.24	.17	.14	.17	.07
18. FAS – Fluency	**.41**	**.37**	**.52**	**.46**	**.42**
19. Similarities	**.44**	**.49**	**.45**	**.37**	**.41**
20. Trails B	**.43**	**.38**	**.50**	**.46**	**.37**
21. Category Test	**.33**	.28	**.37**	**.28**	.26

Note. Correlations significant at the 0.002 level are in boldface. N=117. 1=Digit Span; 2=Arithmetic; 3=Symbol Search; 4=Coding; 5=Cancellation

Table 6 reveals correlations for subtests considered part of the learning and memory factor. Subtests include Logical Memory I and II, Verbal Paired Associates I and II, and Visual Reproduction I and II. Logical Memory I was significantly correlated with all subtests in the battery. Effect sizes of correlations ranged from moderate to large. Logical Memory II was significantly correlated with all subtests in the battery with the exception of BDAE-Ideational Complex. Correlations were predominantly moderate. Verbal Paired Associates I was significantly correlated with Digit Span, Arithmetic, Symbol Search, Coding, Cancellation, Logical Memory I and II, Verbal Paired Associates II, Visual Reproduction I and II, Block Design, Matrix Reasoning, Boston Naming Test, Animals, FAS Fluency, Similarities, and Category Test. Effect sizes were predominantly moderate.

Table 6

Pearson's Correlation for Learning and Memory Subtests

Subtests	6	7	8	9	10	11
1. Digit Span	**.39**	**.38**	**.42**	**.34**	**.45**	**.48**
2. Arithmetic	**.39**	**.36**	**.32**	**.29**	**.33**	**.29**
3. Symbol Search	**.34**	**.37**	**.40**	**.36**	**.47**	**.54**
4. Coding	**.35**	**.37**	**.36**	**.39**	**.49**	**.51**
5. Cancellation	**.37**	**.43**	**.29**	**.34**	**.41**	**.36**
6. Logical Memory I	-	**.87**	**.48**	**.48**	**.39**	**.33**
7. Logical Memory II	**.87**	-	**.50**	**.49**	**.42**	**.38**
8. Verbal Paired Associates I	**.48**	**.50**	-	**.81**	**.39**	**.44**
9. Verbal Paired Associates II	**.48**	**.49**	**.81**	-	**.39**	**.44**
10. Visual Reproduction I	**.39**	**.42**	**.39**	**.39**	-	**.69**
11. Visual Reproduction II	**.33**	**.38**	**.44**	**.44**	**.69**	-
12. Block Design	**.31**	**.34**	**.36**	**.34**	**.52**	**.48**
13. Matrix Reasoning	**.37**	**.36**	**.39**	**.42**	**.44**	**.52**
14. Visual Puzzles	**.39**	**.44**	.24	**.29**	**.58**	**.46**
15. Boston Naming Test	**.35**	**.38**	**.40**	**.35**	**.34**	**.33**
16. Animals	**.37**	**.38**	**.44**	**.34**	**.39**	.23
17. BDAE – Ideational Complex	**.31**	.21	.23	.25	.23	.26
18. FAS – Fluency	**.37**	**.31**	**.40**	**.38**	**.35**	**.31**
19. Similarities	**.41**	**.40**	**.36**	**.39**	**.38**	**.35**
20. Trails B	**.29**	**.30**	.22	.16	**.29**	.27
21. Category Test	**.29**	**.37**	**.39**	**.33**	**.37**	**.46**

Note. Correlations significant at the 0.002 level are in boldface. N=117. 6=LM I; 7=LM II; 8=VPA I; 9=VPA II; 10=VR I; 11=VR II.

Verbal Paired Associates II was significantly correlated with all subtests with the exception of BDAE-Ideational Complex and Trails B. Effect sizes were mostly moderate. Visual Reproduction I was significantly correlated with all subtests with the exception of BDAE-Ideational Complex, with moderate correlation effect sizes. Finally, Visual Reproduction II was significantly correlated with all subtests with the exception of Animals, BDAE-Ideational Complex, and Trails B, with largely moderate effect sizes of the correlations.

Table 7

Pearson's Correlation for Visual Perceptual Subtests

Subtests	12	13	14
1. Digit Span	**.38**	**.56**	**.44**
2. Arithmetic	**.42**	**.41**	**.45**
3. Symbol Search	**.50**	**.41**	**.52**
4. Coding	**.52**	**.37**	**.43**
5. Cancellation	**.46**	**.33**	**.53**
6. Logical Memory I	.31	**.37**	**.39**
7. Logical Memory II	**.34**	**.36**	**.44**
8. Verbal Paired Associates I	**.36**	**.39**	.24
9. Verbal Paired Associates II	**.34**	**.42**	**.29**
10. Visual Reproduction I	**.52**	**.44**	**.56**
11. Visual Reproduction II	**.48**	**.52**	**.46**
12. Block Design	**-**	**.46**	**.63**
13. Matrix Reasoning	**.46**	**-**	**.46**
14. Visual Puzzles	**.63**	**.46**	-
15. Boston Naming Test	**.36**	**.32**	**.29**
16. Animals	**.34**	**.29**	.25
17. BDAE – Ideational Complex	.18	**.34**	.18
18. FAS – Fluency	**.33**	**.37**	.21
19. Similarities	**.41**	**.42**	**.45**
20. Trails B	**.36**	**.28**	**.34**
21. Category Test	**.52**	**.44**	**.35**

Note. Correlations significant at the 0.002 level are in boldface. N=117. 12=Block Design; 13=Matrix Reasoning; 14=Visual Puzzles.

Table 7 depicts correlations for the subtests considered part of the Visual Perceptual factor. Subtests include Block Design, Matrix Reasoning and Visual Puzzles. Block Design was significantly correlated with all subtests except Logical Memory I and BDAE-Ideational Complex. Correlations were moderate. Matrix Reasoning was significantly correlated with all subtests in the battery. Correlations were small to moderate. Visual Puzzles was significantly correlated with all subtests except Animals, BDAE-Ideational Complex and FAS-Fluency. Effect sizes of the correlations were mostly moderate.

Table 8

Pearson's Correlation for Language Subtests

Subtests	15	16	17
1. Digit Span	**.28**	**.38**	.24
2. Arithmetic	**.23**	**.27**	.17
3. Symbol Search	**.32**	**.47**	.14
4. Coding	**.29**	**.48**	.17
5. Cancellation	**.31**	**.39**	.07
6. Logical Memory I	**.35**	**.37**	**.31**
7. Logical Memory II	**.38**	**.38**	.21
8. Verbal Paired Associates I	**.40**	**.44**	.23
9. Verbal Paired Associates II	**.35**	**.34**	.25
10. Visual Reproduction I	**.34**	**.39**	.23
11. Visual Reproduction II	**.33**	**.23**	.26
12. Block Design	**.36**	**.34**	.18
13. Matrix Reasoning	**.32**	**.29**	**.34**
14. Visual Puzzles	**.29**	**.25**	.18
15. Boston Naming Test	**-**	**.43**	.18
16. Animals	**.43**	**-**	.19
17. BDAE – Ideational Complex	.18	.19	-
18. FAS – Fluency	**.48**	**.59**	.24
19. Similarities	**.33**	**.36**	**.39**
20. Trails B	**.34**	**.52**	.13
21. Category Test	**.42**	**.40**	.14

Note. Correlations significant at the 0.002 level are in boldface. N=117. 15=BNT; 16=Animals; 17=BDAE.

Table 8 shows correlations for the subtests related to the Language factor. Subtests include Boston Naming Test, Animals, and BDAE-Ideational Complex. Boston Naming Test was significantly correlated with all subtests except BDAE-Ideational Complex. Effect sizes of the correlations were small to moderate. Animals was significantly correlated with all subtests with the exception of BDAE-Ideational Complex. Effect sizes were moderate. Finally, BDAE-Ideational Complex was significantly associated with Logical Memory I, Matrix Reasoning and Similarities. Effect sizes of the correlations were moderate.

Table 9 reveals correlations for subtests associated with the Executive Functioning factor. Subtests here include FAS-Fluency, Similarities, Trails B and Category Test. FAS was significantly correlated with all subtests except for Visual Puzzles and BDAE-Ideational Complex. Effect sizes of correlations were predominantly moderate. Similarities was significantly associated with all subtests with the exception of Trails B and Category Test. Correlation sizes here were moderate as well.

Trails B was significantly associated with all subtests except Verbal Paired Associates I and II, Visual Reproduction II, BDAE-Ideational Complex and Similarities. Effect sizes of the correlations were moderate. Finally, Category Test was significantly correlated with all subtests except Arithmetic, Cancellation, BDAE-Ideational Complex and Similarities. Correlations were moderate.

Table 9

Pearson's Correlation for Executive Functioning Subtests

Subtests	18	19	20	21
1. Digit Span	**.41**	**.44**	**.43**	**.33**
2. Arithmetic	**.37**	**.49**	**.38**	.28
3. Symbol Search	**.52**	**.45**	**.50**	**.37**
4. Coding	**.46**	**.37**	**.46**	**.28**
5. Cancellation	**.42**	**.41**	**.37**	.26
6. Logical Memory I	**.37**	**.41**	**.29**	**.29**
7. Logical Memory II	**.31**	**.40**	**.30**	**.37**
8. Verbal Paired Associates I	**.40**	**.36**	.22	**.39**
9. Verbal Paired Associates II	**.38**	**.39**	.16	**.33**
10. Visual Reproduction I	**.35**	**.38**	**.29**	**.37**
11. Visual Reproduction II	**.31**	**.35**	.27	**.46**
12. Block Design	**.33**	**.41**	**.36**	**.52**
13. Matrix Reasoning	**.37**	**.42**	**.28**	**.44**
14. Visual Puzzles	.21	**.45**	**.34**	**.35**
15. Boston Naming Test	**.48**	**.33**	**.34**	**.42**
16. Animals	**.59**	**.36**	**.52**	**.40**
17. BDAE – Ideational Complex	.24	**.39**	.13	.14
18. FAS – Fluency	**-**	**.40**	**.45**	**.28**
19. Similarities	**.40**	**-**	.24	.22
20. Trails B	**.45**	.24	**-**	**.47**
21. Category Test	**.28**	.22	**.47**	**-**

Note. Correlations significant at the 0.002 level are in boldface. N=117. 18=FAS; 19=Similarities; 20=Trails B; 21=Category Test.

Data Analysis

Analyses were conducted using IBM SPSS Statistics V.25 statistical software.

Hypothesis One

Hypothesis one stated that the normative performance of retired NFL players on each test within the concussion protocol battery would be significantly lower than the normative performance of the normed sample for all of the measures used in the battery.

Single sample T-tests, analyzed at the 0.002 level, were utilized to analyze significant differences between means.

Heaton Tests. Retired NFL players' performance on the Boston Naming Test was significantly lower than the normative sample's performance, $t(116)=-4.51$, $p<.001$. Players' performance on the BDAE was also significantly lower than existing normative sample performance, $t(116)=-9.11$, $p<.001$.

Table 10

Means and Standard Deviations for Heaton Tests

Subtests	NFL M(SD*)*	Standardization Sample M*(*SD*)*
Boston Naming Test	48.56 (6.48)	51.26 (6.80)
BDAE	9.84 (1.79)	11.36 (0.87)
FAS	36.15 (12.57)	38.93 (12.17)
Animals	16.88 (5.44)	18.95 (5.57)
Trails B	82.94 (36.27)	85.68 (51.76)
Category Test	58.98 (26.86)	49.21 (30.19)

Additionally, players' performance on a semantic fluency task, Animals, was significantly lower, $t(116)=-4.11$, $p<.001$. Category test performance within the NFL sample was also significantly lower, $t(116)=3.93$, $p<.001$. Average player performance on Trails B or FAS did not differ significantly from performance in the normative sample. Table 10 shows normative performance for NFL players and standardization sample.

Wechsler Tests. Player performance on Digit Span differed significantly from that of the existing normative sample, $t(116)=-4.15$, $p<.001$. The same performance trend was also seen on the Arithmetic subtest, $t(116)=-6.26$, $p<.001$. Furthermore, NFL normative performance was significantly lower on Symbol Search, Coding and Cancellation as compared to the existing normative performance, $t(116)=-5.95$, $p<.001$; $t(116)=-9.64$, $p<.001$ and $t(116)=-6.74$, $p<.001$, respectively. Block Design normative performance amongst retired NFL players was also significantly lower, $t(116)=-7.63$, $p<.001$. Normative player performance on Matrix Reasoning did not significantly differ from the normative performance within the population sample.

On the Wechsler Memory Scale (WMS) subtests, Logical Memory I and II normative performance amongst retired NFL players as compared to the general normative sample was significantly lower, $t(116)=-12.17$, $p<.001$ and $t(116)=-8.73$, $p<.001$. Additionally, player performance on Verbal Paired Associates I was significantly lower, $t(116)=-9.96$, $p<.001$, as was performance for Verbal Paired Associates II, $t(116)=-8.46$, $p<.001$. Visual Reproduction I performance amongst retired players was significantly lower $t(116)=-5.69$, $p<.001$. Finally, normative player performance on Visual Reproduction II was not significantly lower than sample normative performance, $t(116)=-2.30$, $p=.023$. Table 11 shows the means and standard deviations on each measure for the standardization sample and retired player sample.

Table 11

Means and Standard Deviations for Wechsler Test

Subtests	NFL M *(SD)*	Standardization M *(SD)*
Digit Span	8.80 (3.11)	10.00 (2.90)
Arithmetic	8.28 (2.79)	9.90 (2.80)
Symbol Search	8.32 (3.24)	10.10 (2.90)
Coding	7.68 (2.61)	10.00 (3.00)
Block Design	8.41 (2.54)	10.20 (2.90)
Matrix Reasoning	9.75 (5.48)	10.10 (3.10)
Visual Puzzles	8.70 (2.97)	10.00 (2.80)
Similarities	8.92 (2.69)	9.90 (2.80)
Cancellation	8.25 (3.13)	10.20 (2.80)
Logical Memory I	6.89 (3.03)	10.30 (2.90)
Logical Memory II	6.94 (4.16)	10.30 (2.80)
Verbal Paired Associates I	7.53 (2.47)	9.80 (3.10)
Verbal Paired Associates II	7.77 (2.59)	9.80 (3.00)
Visual Reproduction I	8.42 (3.00)	10.00 (2.80)
Visual Reproduction II	9.54 (2.64)	10.10 (2.80)

Hypothesis Two

Hypothesis two stated that the exploratory factor analysis conducted on the neuropsychological battery for a unique population of retired NFL players would yield the same factor structure as previously determined in a normal population, namely five factors. The current factor structure is based off analyses conducted on individual measures in the general population resulting in factors related to executive functioning, language, processing speed, attention and memory. There were four criteria used to determine the number of factors to rotate in the analysis. There criteria include (a) the a priori hypothesis generated from the literature review, (b) scree test, (c) parallel analyses and (d) interpretability of the factor solution itself. Since extracting the appropriate number of factors is paramount to maintain accurate conclusions regarding the data, both scree plot analysis and Kaiser's greater-than-one rule were implemented. Furthermore, a parallel analysis, or Monte Carlo simulation (Costello & Osbourne, 2005) was performed to better assess statistically significant eigenvalues in an effort to determine the appropriate number of factors to retain. A Monte Carlo simulation was conducted using 1000 iterations with 21 variables and 117 subjects. Alpha level was set at 0.05. Data from the Monte Carlo simulation are presented in Table 12.

The simulation revealed that the first six Eigenvalues were larger than the simulated random Eigenvalues determined in the analysis. This would suggest that a six-factor model would be the best fit, however, it was also important to explore a five-factor model given a priori hypotheses about the factor structure as described below. Principal Axis Factoring (PAF) with an oblique (promax) rotation was run, following standard recommendations when conducting an EFA (Fabrigar, Wegener, MacCullum & Strahan, 1999). An oblique rotation, as compared to an orthogonal rotation, was selected given that factors were considered to be sufficiently correlated and had correlations above a suggested .32 cutoff (Tabachnick, Fiddell & Ullman, 2007, pp. 281- 498).

Table 12

Eigenvalues Retrieved from Monte Carlo Simulation

Factor	Raw Data Eigenvalue	Random Data Eigenvalues
1	**8.81**	**2.01**
2	**1.80**	**1.56**
3	**1.67**	**1.38**
4	**1.55**	**1.24**
5	**1.45**	**1.23**
6	**1.26**	**1.21**
7	0.91	1.20
8	0.75	1.18
9	0.61	1.13
10	0.58	1.06
11	0.48	1.00
12	0.44	0.94
13	0.41	0.88
14	0.40	0.82
15	0.34	0.77
16	0.28	0.71
17	0.26	0.66
18	0.21	0.61
19	0.18	0.56
20	0.14	0.50
21	0.11	0.44

Note. Bold factors represent those that had Eigenvalues greater than the related random data Eigenvalue obtained at the 95th%ile from the Monte Carlo simulation analysis.

Model One. A PAF with promax rotation was conducted in SPSS. Six factors were retained in the analysis based off a Monte Carlo simulation run in SPSS syntax. Additionally, eigenvalue greater-than-one guidelines and scree plot analysis were congruent with this finding. Table 13 depicts the factor loadings for the six factors that were retained in this model. Subtests with factor loadings of .40 or greater were retained in the interpretation. It is important to note that there are differing opinions in the field regarding the cutoff for factor loadings in an EFA. Some researchers have suggested that a cutoff of .3 is sufficient in larger sample sizes (Field, 2013) while others state that factor loadings upwards of .5-.7 are more conservative and can help with conservative interpretation (Hair, Anderson, Babin & Black, 2010). Stevens (1992) , Guadagnoli & Velicier (1988), Matsunaga (2011) and Ertz, Karakas & Sarigollu (2016) noted that .4 satisfies both the need to prevent cross-loadings on factors as well as being conservative enough in smaller sample sizes. As such, .4 was utilized in this study.

Factor 1 accounted for 41.96% of the variance with the following subtests loading onto this factor; Digit Span, Symbol Search, Coding, Cancellation, Visual Reproduction I and II, Block Design, and Visual Puzzles. This factor was associated with visual spatial manipulation and learning. Factor 2 accounted for 7.44% of the variance. Animals, FAS-Fluency, and Trails B loaded onto this factor, with this factor associated with speeded language fluency. Factor 3 accounted with 6.59% of the variance with Verbal Paired Associates I and II loading on to this factor. Factor 3 was associated with rote verbal learning andmemory. Logical Memory I and II loaded onto Factor 4, which accounted for 5.41% of the variance and was associated with contextual verbal learning and memory. Factor 5 accounted for 5.17% of the variance and Arithmetic, Matrix Reasoning, BDAE-Ideational Complex and Similarities loaded onto this factor. Factor 5 was associated with abstract reasoning.

Finally, Factor 6 accounted for 4.84% of the variance with the Category Test loading onto this factor. This factor was associated with mental flexibility. Boston Naming Test did not load on to any of the six retained factors.

Table 13

Factor Loadings for Model One

Subtests	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	**.49**	.13	-.05	-.05	.35	-.08
2	.26	.09	-.20	.06	**.48**	-.03
3	**.93**	.21	.03	-.09	-.15	-.09
4	**.81**	.18	.13	-.07	-.14	-.09
5	**.87**	.10	-.01	.14	-.24	-.14
6	-.04	.06	.06	**.80**	.17	-.07
7	.08	-.02	.07	**.96**	-.11	.05
8	-.03	.11	**.77**	.06	.02	.05
9	.07	-.05	**.83**	.06	.04	-.05
10	**.46**	-.09	.15	.03	.11	.18
11	**.44**	-.18	.28	-.11	.10	.26
12	**.48**	-.04	-.02	-.04	.05	.37
13	.09	-.01	.09	-.08	**.52**	.20
14	**.64**	-.22	-.18	.18	.15	.15
15	-.09	.35	.12	.09	.09	.27
16	.03	**.68**	.09	.05	-.002	.11
17	-.27	.06	.09	-.00	**.65**	-.05
18	.10	**.61**	.10	-.08	.23	-.06
19	.15	.09	.02	.06	**.64**	-.21
20	.20	**.56**	-.25	.03	-.01	.28
21	-.12	.22	-.01	.00	-.14	**.96**

Note. Factor Loadings greater than .40 are in boldface.

Model Two. Given the existing format of the NFL neuropsychological battery, it was anticipated that Digit Span, Arithmetic, Symbol Search, Coding and Cancellation would load onto the processing speed/attention factor. It was also expected that the learning and memory factor would have loadings from Logical Memory I and II, Verbal Paired Associates I and II, and Visual Reproduction I and II, while it was anticipated that Block Design, Matrix Reasoning, and Visual Puzzles would load onto the visual perceptual factor.

It was further expected that Boston Naming Test, Category-Animals, and BDAE-Ideational Complex would load onto the language factor and that FAS-Fluency, Similarities, Trails B and Category Test would load onto the mental flexibility factor. Based on the above expectations hypothesized from an a priori factor structure, five factors were retained using a PAF with promax rotation in model two. Table 14 shows the factor loadings for this model.

Table 14

Factor Loadings for Model Two

Subtests	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	**.66**	.17	.00	.00	-.08
2	**.57**	.07	-.12	.13	-.02
3	**.68**	.39	-.01	-.14	-.12
4	**.58**	.33	.09	-.12	-.12
5	**.58**	.26	-.07	.06	-.15
6	.06	.04	.04	**.91**	-.06
7	.10	.02	.07	**.78**	.03
8	-.09	.13	**.83**	.04	.03
9	.04	-.03	**.86**	.04	-.06
10	**.60**	-.07	.16	.02	.11
11	**.62**	-.17	.30	-.12	.18
12	**.63**	-.01	-.02	-.06	.28
13	**.51**	-.08	.17	.01	.16
14	**.87**	-.20	-.18	.17	.08
15	-.05	.35	.15	.11	.25
16	-.15	**.77**	.10	.07	.12
17	.16	-.05	.19	.12	.00
18	.06	**.65**	.15	-.02	-.02
19	**.49**	.05	.12	.16	-.13
20	.13	**.64**	-.26	.04	.26
21	.02	.19	-.01	-.03	**.83**

Note. Factor Loadings greater than .40 are in boldface.

Again, subtests with factor loadings greater than .40 were retained for interpretation. Factor 1 accounted for 40.08% of the variance with Digit Span, Symbol

Search, Coding, Cancellation, Visual Reproduction I and II, Block Design and Visual Puzzles loading on this factor. Factor 1 was associated with visual spatial memory and manipulation. Factor 2 accounted for 6.05% of the variance and Animals, FAS-Fluency and Trails B loaded onto this factor which was namely associated with speeded language abilities.

Factor 3 accounted for 4.53% of the variance with Verbal Paired Associates I and II loading onto this factor. This factor was thereby associated with rote verbal learning and memory. Factor 4 had Logical Memory I and II loading on to it, therefore being associated with contextual verbal learning and memory and accounting for 3.99% of the variance. Finally, Factor 5 accounted for 3.42% of the variance with Category Test loading on to this factor. This factor was associated with mental flexibility. Boston Naming Test and BDAE did not load on to any of the five retained factors.

CHAPTER V: DISCUSSION

The current study was meant to analyze the factor structure of an existing neuropsychological battery used with retired NFL players with histories of concussions. Additionally, this study aimed to offer preliminary insight into whether or not existing neuropsychological norms on well-established measures were appropriate for this unique population. Overall, this study was designed to evaluate psychometric properties of a specific neuropsychological battery, namely the NFL concussion settlement battery, for a unique population of retired NFL players.

Hypothesis One

Hypothesis One stated that the normative performance of retired NFL players would be significantly lower than the published normative performance for each of the neuropsychological tests within the concussion battery. Both Heaton and Wechsler normed tests were evaluated within this analysis through t-test statistics. The results largely supported the hypothesis that player performance was significantly lower (i.e., poorer) than performance of the normative sample on these established neuropsychological tests.

The Heaton-normed tests included BNT, BDAE, FAS, Animals, Category test and Trails B. As stated above, hypothesis one was largely supported by the analyses. Players' normative performance on BNT, BDAE, FAS, Animals and Category test was significant lower than performance of the standardization sample given the t-test results. This suggests that concepts and abilities measured by these specific tests may differ between a population of retired athletes with histories of multiple concussion events as compared to a general population sample without this unique head injury background.

Given that Animals was significantly lower in the retired sample, this may suggest that frontal lobe involvement and executive functioning ability differ in this population as compared to the normative sample. Namely, impaired Animals performance is largely indicative of executive functioning difficulties in individuals. Furthermore, this is a timed task with increased efficiency in responses leading to a higher score in general. If there is impairment in processing or response speed, performance will thusly be impaired. Finally, there is a general language component as well and specifically, semantic fluency processes. Occasionally poor performance on these tasks can be attributed to overall deficits in language or verbal abilities. Results of this analysis corroborate existing findings in the literature related to fluency performance and individuals with a history of mild traumatic brain injury. Lower Animals performance in the retired NFL sample aligns with Rakin and Rearick's findings (Rakin & Rearick, 1996) that overall fluency performance was impaired in a mild TBI sample versus healthy controls, with this current study adding to the literature and demonstrating this performance trend in a retired athlete sample, rather than a general TBI population sample. Furthermore, as noted, verbal fluency performance has been shown to be a predictor of long-term cognitive outcomes in a military TBI population. Given that semantic fluency performance was impaired in this athlete population, it may warrant investigation into whether or not players' cognitive outcomes could also be extrapolated based off these fluency results (Macdonald et al., 2017). Interestingly, phonemic fluency, as measured by FAS performance, was not significantly different amongst retired players and the normative sample. This suggests differing processes at play, with semantic cognitive processes being negatively impacted, as compared to phonemic processes. This may suggest alternate brain region involvement or under-involvement, in the case of concussion damage, in those individuals with a history of mild TBI.

Category test is a measure of mental flexibility and lower T scores (i.e., higher number of errors) on this measure can be indicative of difficulties with complex planning and set shifting, again within the domain of executive functioning. The results that were obtained from this analysis add to the literature on the Category test and provide more insight into performance trends in those individuals with a history of concussion. Given that retired player performance was significantly lower than the normative sample, various studies were supported by these findings. Of note, Pang and colleagues noted decreased mental flexibility, a process measured by Category test, in those individuals with a history of concussion (Pang et al., 2015). Additionally, Hampshire and colleagues found an increase in self-reported executive dysfunction in active football players, again aligning with the findings of this study (Hampshire et al., 2013). BNT is a measure of confrontational naming ability, requiring verbal and visual knowledge of an object. Results of the analysis demonstrate significantly lower BNT performance in the retired player sample, aligning with, and supporting, previously discussed literature that noted that BNT was impaired in another retired NFL player sample and was associated with decreased white matter integrity (Strain et al., 2017). BDAE is a measure of language comprehension ability. Lower scores on these tests could be indicative of language deficits, including receptive and expressive language, as could be the case with FAS and Animals, mentioned above. Findings from this study support existing findings in the literature that state that complex language comprehension is negatively impacted by history of repeated concussions in athlete populations (Korin & Horsley, 2017). Furthermore, impaired BDAE performance in the retired NFL sample suggests that general complex linguistic functioning is disrupted in individuals with a history of concussion, as was demonstrated in two recent studies (Stockbridge & Newman, 2019; Norman, 2017). Generally, as mentioned above, Hart and colleagues found impairment in word finding and naming ability with decreased blood flow in the left temporal and superior temporal gyrus (Hart et al., 2013). Results of this current analysis support these findings given that many measures involved in confrontational naming, verbal comprehension and speeded language functioning were impaired in the retired NFL sample.

The WAIS-IV measures included Block Design, Digit Span, Arithmetic, Letter-Number Sequencing, Similarities, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search and Cancellation. It was found that all of these measures, with the exception of Matrix Reasoning, yielded significant lower scores in the retired NFL player sample as compared to their respective normative samples. The results of the current study are largely supported by the existing literature.

Visuospatial ability, as needed in Block Design, has been shown to be negatively impacted in those with a history of concussion (Zhang et al., 2019). Furthermore, less efficient understanding of visual stimuli and patterns has been noted in those with mild TBI (Brown et al., 2019). This type of cognitive process is paramount in Visual Puzzles and lower scores would then be expected on this measure in those with dysfunction in that ability. Additionally, Livny and colleagues demonstrated that non-verbal abstract reasoning was impaired in those with a concussion history, thereby suggesting that Visual Puzzles performance would also be worse due to that as well in the retired NFL player sample.

As discussed in regards to Heaton tests with verbal components, concussion histories have a largely negative impact on verbal comprehension and language ability. As such, it is unsurprising that Similarities performance in the retired NFL sample was worse than in the normative sample. A recent study by Stockbridge and colleagues, as well as Ketchum and colleagues, found that verbal abilities were profoundly and negatively affected in groups across the lifespan, in pediatric, adolescent and adult populations (Stockbridge et al., 2020; Ketchum et al., 2017).

Digit Span, and Arithmetic were found to have lower retired NFL player performance as compared to the normative sample for each measure. A study completed in 2019 found that Digit Span performance, specifically, was decreased in professional rugby players with a history of concussion, both on neuropsychological testing and through cerebral blood flow analysis in prefrontal regions of the brain (Iring et al., 2019). Additionally, Iring suggested that working memory tasks, such as Digit Span and

Arithmetic, would be negatively impacted by concussions.

Another study found that individuals with a history of concussion needed more time to respond on working memory tasks that are considered demanding, such as Arithmetic (Ozen et al., 2013). Given that Arithmetic is timed, with a time limit on each question, longer response time would negatively impact performance and scoring. Crowe noted that Letter-Number Sequencing was highly correlated with Digit Span (Crowe, 2000). This suggests that impairments seen on Digit Span in a population noted for concussion history may also hold true for performance on Letter-Number Sequencing. Additional research is also supported by this current study's finding that performance on this measure was, in fact, significantly lower in the retired player sample. Shah-Basak and colleagues showed that visual working memory and attentional abilities were decreased in those with a repeated concussion history (Shah-Basak et al., 2018) and this current study supported the criterion validity research conducted on Letter-Number Sequencing in a severe TBI, mTBI and healthy control sample (Donders et al., 2000).

Coding, Symbol Search and Cancellation performance was found to be significantly lower in the retired player sample as compared to the normative sample. These results support the existing literature. Overall, processing speed has been shown to be sensitive to the effects of mTBI, and given that Coding and Symbol Search are the two primary measures that comprise the Processing Speed Index (PSI) of the WAIS-IV, and Cancellation is a secondary measure that may be swapped for one of the above-mentioned tasks, it is unsurprising that performance on these tasks were lower in the player sample (Green et al., 2019; Hume et al., 2019). Specifically, for Symbol Search, Sterberg and colleagues also demonstrated that timed and visual modality components, such as what is assessed in this measure, were negatively impacted in concussed individuals (Sternberg et al., 2020). Urbanski and colleagues showed that the frontoparietal and fronto-occipital regions, largely within the right hemisphere, may be disrupted in those with a history of concussion, as discovered by performance on the Cancellation task (Urbanski, de Schotten, Oppenheim, Touze, Meder, Moreau, Loeper-Jeny, Dubois, & Bartolomeo, 2011). Interestingly, McCrea and Robinson found left hemisphere involvement for Cancellation, namely due to what they determined to be strong verbal mediation requirements (McCrea & Robinson, 2011). Left hemisphere disruption was supported by a 2013 study in which metabolic and microstructural changes were found in mTBI samples (Chamard et al., 2013). Finally, visual tracking is an important component to all of the processing speed tasks mentioned above, however it is extremely important in Cancellation due to the page layout. Maruta and colleagues found that visual tracking ability was a good measure of concussion severity, suggesting the importance of the Cancellation task in concussion assessment and supporting the idea that Cancellation performance would be impaired in a concussion sample (Maruta et al., 2010).

Matrix Reasoning was the only WAIS-IV subtest that did not demonstrate significant differences in performance between the normative sample and retired players sample. While some literature regarding Matrix Reasoning suggests that those with a history of concussion would struggle more with discerning visual patterns (Brown et al., 2019) it has also been shown that Matrix Reasoning is fairly resistant to negative impacts of TBI (Ryan et al., 2019). Results of this analysis would suggest that this is in fact accurate, especially as other visual tasks, such as Visual Puzzles, Coding and Symbol Search yielded poorer performance in the retired player groups.

The Wechsler memory measures included Logical Memory I and II, Visual Reproduction I and II and Verbal Paired Associates I and II. Again, performance on these measures largely supported Hypothesis One, as retired NFL player performance was significantly lower on Logical Memory I and II, Verbal Paired Associates I and II and Visual Reproduction I.

Given that these measures were significantly lower in the retired NFL player sample, it may suggest that areas of the brain involved in memory are impacted, just as Hart and colleagues hypothesized (Hart et al., 2013). Specifically, this may indicate left temporal involvement with regard to logical memory and verbal paired associate performance, as this area of the brain is often associated with verbal memory ability, and as Hart and colleagues noted, the left temporal region was noted to have decreased blood flow in individuals with histories of traumatic brain injury as compared to healthy controls (Hart et al., 2013).

Interestingly, retired player performance on Visual Reproduction II (VR II) was not found to be significantly different than the normative sample performance, in contrast to Visual Reproduction I (VR I) where player performance was significantly lower. Impairment in visuospatial processing and memory has been found in individuals with histories of concussions, including college athletes and former professional boxers (Theriault et al., 2011; Matser et al., 2015). Given the current literature, it is not surprising that VR I performance was lower in the retired NFL player sample as this task involves immediate visual memory ability. Following this logic, it was expected that VRII performance would also be impaired in this sample. However, as mentioned, there was no significant difference in performance. This suggests that VR I and VR II involve different cognitive skill sets and brain processes. It may be that the delayed component to VR II performance (i.e. retrieval) was aided by the memory consolidation process, rather than relying mainly on short-term immediate recall that would be required in VR I.

Hypothesis Two

Hypothesis Two stated that an EFA would yield five factors within the aforementioned battery including executive functioning, language, processing speed, attention and memory. The results of the EFA do not support the hypothesis that there are five domains or factors in the neuropsychological battery.

Five-Factor Model

The five-factor model that was originally hypothesized was not supported by the analyses. Given the a priori assumptions regarding the test battery and the tests that comprised the battery, it was expected that five factors, including executive functioning, language, processing speed, attention and memory, would be retained. Instead, when the analysis was set to produce five factors, the factors retained were associated with visual spatial memory and manipulation, speeded language ability, rote verbal learning and memory, contextual verbal learning and memory and a factor dedicated to Category test, which is a measure of set shifting and more complex executive functioning. BNT and BDAE did not load onto any of the five factors.

The model failed to align with the predetermined categories or "factors" identified in the neuropsychological battery in the concussion settlement. Namely, the general factors that are used in the current battery may not fully explain the constructs and abilities that are actually being measured by the tests. Interestingly, the five-factor model did not support the inclusion of an "attention" factor, more so incorporating some of the attention-based tasks into the speeded language ability and visual spatial manipulation factors. This may suggest that there are more complex processes occurring during these tasks, rather than just attentional ability. Additionally, this may suggest then that these individuals are having difficulties at various levels of cognitive processing, making their patterns of performance difficult to fully interpret.

The presence of a Category test factor suggests that this measure is unique from the other measures within the battery. Category test is a measure of set-shifting ability, cognitive flexibility and more complex abstract reasoning; these are important concepts related to executive functioning. Given this, it was expected that other measures related to executive functioning and abstraction, such as Trails B, FAS and Similarities, would load onto this factor as well. Since they did not, it is possible that with this grouping of tests, Category test measures additional or different cognitive processes, thereby warranting a separate factor loading. Category test is both visually and verbally mediated, requiring both of these processes, along with increased mental flexibility, abstract reasoning, set-shifting, memory and ability to respond to feedback guidance. While other tasks require visual and verbal mediation, such as Trails B, or abstract reasoning, such as Similarities, Category test is unique in the complexity and amount of different processes that it requires. This unique factor loading suggests that higher-order processing, particularly the complex executive functioning skills required in Category test, can be parsed out separately from other neuropsychological processes and abilities, making it important to analyze independently from a clinical perspective.

Six-Factor Model

A six-factor model was generated based on Eigenvalues greater than 1 that were obtained from the Monte Carlo simulation. In this model, six factors were also supported by the general Eigenvalue greater-than-one rule and scree plot analysis independent of the Monte Carlo simulation. Interestingly, the factors obtained were less general and more related to specific neuropsychological domains. Within the six-factor model, labeled factors again failed to align with many of the pre-identified categories in the battery. Within this model there appeared to be a greater emphasis on where function was localized given the breakdown of constructs across more factors. Factors retained within this model included visual spatial manipulation and learning, speeded language fluency, rote verbal learning and memory, contextual verbal learning and memory, abstract reasoning and a Category test factor. BNT did not load onto any of the six retained factors.

Within the expanded six-factor model, a new abstract reasoning factor was retained. This aligns more closely with the concept of the executive functioning factor that exists in the original breakdown of the battery. However, the measures included in the abstract reasoning factor in this analysis do not align with the measures placed in the executive functioning category within the battery. Interestingly, Trails B and FAS loaded onto the speeded language ability factor, rather than the abstract reasoning or executive functioning factor. Arithmetic, Matrix Reasoning, BDAE-Ideational Complex and Similarities comprised the abstract reasoning factor and therefore suggests that there may be underlying properties and cognitive processing requirements that load more heavily in abstraction rather than other properties such as language or visual spatial domains. Given this, individuals with impairment in frontal lobe areas, a brain area susceptible to injury in concussion, may thereby struggle on the tasks loaded onto the abstract reasoning factor. It is also important to note that Trails B and FAS did not load onto this factor (factor 5), rather loading onto factor 2, the speeded language domain. This is important given that these measures are traditionally seen as measures of executive functioning. Their loadings in this analysis may suggest that the speed and language components that they both utilize are more strongly represented in this battery.

General Discussion

In neuropsychology it is important to understand not only the constructs that are used but also how various measures can relate to different constructs. Furthermore, now, more than ever, it is critical that appropriate normative and comparative data is used in neuropsychological analyses in order to assess unique populations of individuals accurately and within a continuum of their own normative samples. This study aimed to provide initial data on these topics for an established neuropsychological concussion battery for retired NFL players.

It has been established that norming for the target population is paramount in being able to make accurate statements and performance interpretations. Given that there is a paucity of normative data research on a larger scale, it can be difficult to truly know if appropriate interpretations are being made based off an individual's performance on varying measures. It has been suggested that using inappropriate reference norms can not only make interpretation difficult, but actually result in incorrect inferences (Mitrushina, Boone, Razani & D'Elia, 2005). Furthermore, an individual's background should also be taken into account when interpreting data and performance (Lezak, Howieson, Loring & Fischer, 2004). Importantly, it is also the case that one normative sample will not unilaterally fit a certain demographic perfectly, and so one must be aware of what limits that may pose when making test performance interpretations.

The results of this analysis, specifically with hypothesis one, demonstrate that the above- mentioned ideology around appropriate normative data holds true for this population of retired NFL players as well. These individuals' performance on most of the neuropsychological measures within this battery were significantly below performance of the normative sample. As mentioned, the normative sample was a general sample of the population, largely Caucasian and without a documented history of significant head trauma. Conversely, the population of retired NFL players was predominantly African American with reported cognitive complaints due to repeated head injury (i.e., concussion).

The factor analysis also demonstrated that a one-size-fits-all approach may not work in this setting as well. While the domains that were pre-determined for this battery (i.e. executive functioning, language, learning and memory, complex attention and processing speed and visual perceptual ability) intuitively make sense, there was no psychometric analysis done to determine if this fit a model with this population of retired players. The results of the analysis show that they do not and that a six-factor model may be a better fit given the inclusion of the Category test. Furthermore, the factor structure suggests that the tests are measuring more complex and interrelated processes than simple the domain that they were originally placed into, leading to questions about performance interpretation and what "poor" or "strong" performance may actual represent in terms of cognitive functioning and brain localization.

Through this analysis a discussion of consequential validity may be warranted. Consequential validity deems that there are potential positive and/or negative social outcomes or consequences related to test performance and subsequent test interpretation.

Messick (1989) defined consequential validity in two parts; one part based on test interpretation and one on the use of the test itself. He stated that construct validity is "the appraisal of the value implications of the construct label, of the theory underlying the test interpretation, and the ideologies in which the theory is embedded……the appraisal of both the potential and actual social consequences of applied testing." (Messick, 1989; pg. 20).

Consequential validity related to this battery and the potential outcomes is important to consider here. From a legal perspective, there can be profound consequences if an individual meets criteria for various levels of cognitive impairment, as determined through the existing test's structure and organization. There are monetary, legal and healthcare factors at stake, that are dependent on individuals' performance on set areas and domains within the battery. As such, there is a substantial amount of importance placed on test interpretation, and for the case of this analysis, the construct labels. Furthermore, this analysis also spoke to the "theory underlying the test interpretation", namely the issue related to the normative sample being used. While it is impossible to determine or assess for all potential outcomes, both positive and negative, it would be important to consider the potential ramifications alluded to above.

Limitations

Although this study provided interesting and valuable information regarding test battery psychometrics and a discussion about appropriate testing norms, there are several limitations. First, the NFL player sample is comprised of individuals who were actively involved in a litigation settlement with the NFL. Although malingering and motivation measures were administered and only those who passed the majority of effort measures were included in the analysis, it is important to note the uniqueness of this sample even within the larger context of retired NFL players in general. These individuals were willing to undergo neuropsychological testing and were involved in the settlement because they believed they were suffering from cognitive impairment or other difficulties due to sustained concussions throughout their careers.

Along the same lines, each player's concussion history is unique and was not quantified or categorized in this analysis. Therefore, it is impossible to say if concussion frequency or severity impacted performance on neuropsychological testing and such conclusions cannot be drawn from this study. Additionally, players were not excluded on the basis of psychiatric or neurological diagnoses (ex., ADHD, Major Depressive Disorder) and so it is unknown what effects, if any those diagnoses had on neuropsychological performance independent of concussion history. Furthermore, each player's performance was assessed for each individual test, rather than on the entire battery as a whole. Therefore, no generalized conclusions could be drawn regarding overall cognitive changes or difficulties in this population. Rather, the analyses allowed for discussion based on individual tests yet limited the discussion regarding cognitive or neuropsychological profiles of the players. The NFL player sample was all male, majority African American and all individuals had at least a Bachelor's degree; these demographic features are unusual when discussing normative data for neuropsychological tests, significantly adding to the uniqueness of the sample itself but making it difficult to generalize to a larger population. Additionally, the sample size was small in nature, with 117 participants. A larger sample size would have increased the power of the statistical analyses and helped to strengthen the factor structures discovered during the factor analysis portion of the study. Of course, a larger sample size can also help to increase the generalizability of the study, overall.

As discussed above, players were excluded from the analyses if they failed more than half of the effort measures within the battery. It is important to note that several of the embedded measures are not considered formal measures of motivation or effort and were treated with a lenient cutoff point. Additionally, since players were excluded based off a simple ratio of passed to failed measures, none of the effort measures were weighted differently, meaning that standalone and embedded measures were treated the same in terms of importance. By not performing a more sophisticated analysis of effort measure performance and utilizing a more stringent way of excluding players with subpar motivation, it is possible that scores were impacted by lapses or difficulties in motivation. By nature, an exploratory study of the battery's structure lends itself to description of the data itself, rather than the ability to make statistical inferences. Therefore, future studies are needed in order to make far-reaching inferences or conclusions with the battery or data itself. Furthermore, in regards to the actual analyses themselves, there were subtests that did not load onto any factor across any of the various retention methods. This was due to wide variability in factor loading strengths and small correlations amongst the subtests themselves. These statistically significant, but largely small correlations limit the statistical power and generalizability of the findings in this present study. Of note, the exploratory factor analysis was conducted on a battery in which all of the measures themselves had already had significant amounts of psychometric research within the literature. Additionally, the neuropsychological battery was already divided into named cognitive domains. As such, a confirmatory analysis may have been more detailed and novel than the exploratory analysis itself.

Future Research

A confirmatory factor analysis (CFA) would bolster the statistical power of this line of research and allow researchers to better understand the factor structure of the existing battery. Furthermore, inferences and larger generalizability would result from a CFA analysis, helping to better understand neuropsychological constructs that are being measured and assessed when this battery is administered. By having that information, clinicians, researchers and the players can more accurately understand neuropsychological functioning in this population and make better clinical, functional and legal interpretations to that point.

Given the nature of the study, future research could build upon the findings and hypotheses here by including different demographics and populations of athletes. A future study could include current NFL players and then additionally stratify or characterize former NFL players by years removed from playing, or number of years playing in general. By doing this and then comparing normative performance across all of the samples, researchers may gain more insight into the temporal relationship between neuropsychological functioning, concussions and career length within this group of athletes. This would also provide additional psychometric information regarding the utility of this battery across different age ranges and player profiles.

A study with a more diverse group of retired players would also be necessary. Given that this sample was majority African American, it would be useful to increase heterogeneity across player profiles, particularly with the inclusion of Hispanic individuals as well as inclusion of older adults. Given the established literature on neuropsychological changes over time as a function of aging, it would be important to include older adults in future studies, and stratify statistical analyses by age to better understand functional impacts of concussions as a function of age. Furthermore, there were instances where this study's results failed to align with existing literature. Namely, the Lovell and Solomon study from 2011 with psychometric data from a baseline neuropsychological battery for current NFL players, found that race was a mediating factor in neuropsychological performance (Lovell & Solomon, 2011). Specifically, they discovered that Trails B and FAS performance was actually higher in African American players as compared to normative data. While this study did not demonstrate a significant decline in performance by retired players on these tasks as compared to normative samples, it also failed to show a significant increase, namely demonstrating comparable, or no significant differences in performance between retired players and normative samples on these two tasks. Future work could take a more in-depth look at race and ethnicity as a mediating factor for performance on this NFL battery as a whole, as well as on each individual test within this battery. This would provide useful information regarding how to best use the psychometric data of this NFL battery in order to make appropriate comparisons for individuals, even within the retired NFL player population itself.

Additionally, results from the EFA demonstrated that Category test loaded on to its own unique factor in both the five factor and six factor models. Given a preliminary literature review, there was not an extensive amount of research surrounding the unique importance of the Category test in concussion assessment. It is possible that this test holds more importance and can measure more neuropsychological processes in retired athletes. This can also be an important direction for future research as this could have multiple clinical implications in this population.

In order for the above data to be analyzed and interpreted, future studies and data would also need to include information regarding concussion frequency, severity and temporal information (i.e. length of time between injuries, most recent injury, etc). The inclusion of this specific concussion data could prove extremely useful when discussing normative player performance as compared to existing norms from a standardization sample. It could help to potentially establish causal links between various concussion demographics and neuropsychological performance. Furthermore, it could further make the case for the uniqueness of this population and the need for more appropriate norms when measuring performance. While this study provided some evidence for the need to create more appropriate standardization norms for a retired NFL sample, future research could look more in depth at this need by including the above-mentioned concussion information, as well as by working towards creating this normative performance information. An incredibly large sample size would be needed to do so. This would be the ultimate goal of this line of research.

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