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Cognitive Performance In A Retired NFL Population: Does Position Played And Racial Identity Impact Cognition?

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COGNITIVE PERFORMANCE IN A RETIRED NFL POPULATION: DOES POSITION PLAYED AND RACIAL IDENTITY IMPACT COGNITION?

by

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To my family and friends who have encouraged me to persevere throughout my graduate career.

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ABSTRACT

Cognitive functioning is integral to everyday life as it involves mental processes crucial to everyday survival. Over the last decade, there has been increasing focus and controversy surrounding concussions sustained by players in popular contact sports. This attention has sparked national debates that continue to polarize both the sports and scientific communities on the long-standing neuroanatomical, cognitive, and psychiatric challenges that many retired NFL players experience later in life (Alosco et al., 2017; Hart et al., 2013). While studies have been conducted on the predictors of long-term neuropsychiatric and psychosocial outcomes following a traumatic brain injury, there are few studies that have explored the factors that affect long-term effects of playing football through using a comprehensive neuropsychological battery. As emerging studies continue to shed light on the association between concussions and the neurological changes of the brain that lead to behavioral, mood and cognitive deficits of individuals who participate in these sports, it is imperative to understand factors that could mitigate these effects in order to inform policy at all levels of play. Thus, the current study examined the impact of player position and racial identity as predictors of cognitive performance among retired NFL players and found that retired athletes who identified as Black had lower cognitive performance when compared to White athletes. Furthermore, position played while in the NFL did not independently account for differences in cognitive performance but accounted for sociodemographic differences within this population. Racial identity and player position revealed unique interaction effects that indicate the need to study these variables further. Taken together, this study highlights the need for continued involvement of Black participants in traumatic brain injury and chronic traumatic encephalopathy related research.

CHAPTER I: INTRODUCTION

Sports, such as football, are national pastimes that have become deeply embedded within our culture. However, despite the vast importance of sports within our society, they come at a cost to players' financial and personal health. Within recent years, there has been a microscope placed on associations who regulate these sports. The National Football League (NFL), for one, has been criticized and faced legal charges, for its policies, which impact player's acute and chronic brain health (Kain, 2008; Samson, 2011). As a result, public awareness of concussions has increased particularly when high profile athletes (e.g. Mike Webster, Aaron Hernandez, Adrian Robinson, Junior Seau) miss games or die by suicide due to concussions and the associated symptoms. With this increase in public attention, several sports leagues have adopted new policies and procedures meant to safe-guard against sports-related injuries. The NFL even saw a significant decrease in the number of reported concussions in 2018 following a dramatic spike in incidences the previous year (NFL Player Health and Safety, 2019). However, this decline did not follow a downward trend as the incidence of concussions increased again in 2019. One of the largest concerns surrounding head injuries in the NFL are the neurobehavioral changes, both in terms of cognition and mood that appear to occur as a result of repeated concussions or trauma to the brain (Plassman et al., 2000; Yi et al., 2013; Omalu, 2014). As the debate on concussion sequelae mounts, recent studies have shown an association between traumatic brain injuries (TBIs) and the presence of neurodegenerative diseases such as chronic traumatic encephalopathy (CTE) and Alzheimer's disease (AD) later in life, suggesting these injuries may be a precursor for cognitive decline (Plassman et al., 2000; Yi et al., 2013; Omalu, 2014).

Thus, although the long-term neurological consequences associated with concussion injuries are of great concern, to date, there has been a lack of research examining these effects in retired professional athlete populations. As such, there is a need to increase understanding of the factors that impact the onset and progression of cognitive and functional deficits among vulnerable populations, such as athletes and military personnel, in order to continue to refine and develop rehabilitative strategies and protective measures (Helmick 2010; Karr et al., 2014; Helmick et al., 2015). Given the paucity of data that addresses these factors, this dissertation study will examine the relationship among factors such as position played and racial identity on cognitive outcomes in retired NFL football players.

Traumatic Brain Injury

According to the Centers for Disease Control and Prevention (CDC), a traumatic brain injury (TBI) is defined as a disruption in normal brain function caused by an external physical force, and characterized by the following: (a) any period of loss or decreased level of consciousness (LOC), (b) any loss of memory for events immediately before or after the events, (c) any neurological deficits, and (d) any alteration in metal state at the time of injury (CDC, 2015). The National Institute of Mental Health (NIMH) and the CDC, estimates that approximately 16% of all yearly emergency room visits, hospitalizations and deaths are TBI-related (CDC, 2015). Individuals between the ages of 15-24 and over the age of 75 have the highest rates of reported TBI cases, with children and older adults recognized as the most vulnerable groups (Thurman et al., 1998). The Department of Veterans Affairs (VA) and Department of Defense (DoD) reports the leading cause of TBIs as assaults, falls, motor vehicle accidents, being struck by or against an object, and sport injuries (VA/DoD, 2016).

The mechanisms of a TBI are understood as focal, multifocal, and diffuse injury due to direct contact or acceleration and/or deceleration motion of the brain that results in a range and variety of injury severity (Casey & McIntosh, 1994; Werner & Engelhard, 2007) As such, there is no universal presentation of a TBI as the characteristics are dependent on the mechanism, location, and severity of the injury; however the majority of symptoms typically fall within the cognition, behavior/emotion and physical domains (McCrea et al., 2014). In response to this variability several classification systems, such as the Mayo classification system, Brussels Coma Grades, Grady Coma Grades, Innsbruck Coma Scale, and the Full Outline of UnResponsiveness (FOUR) score have been developed over the years to capture the severity levels of a TBI (Benzer et al., 1991; Brihaye et al., 1978; Fisher, 1969; Malec et al., 2007; Wijdicks et al., 2005). However, the most extensively used and recognized system is the Glasgow Coma Scale (GSC; Teasdale & Jennett, 1974).

The GCS examines the extent and severity of neurological deficits with a particular emphasis on central nervous system function including eye-opening, verbal and motor responses (Teasdale & Jennett, 1974). The GCS uses a scoring methodology graded on a 3 to 15-point scale based on levels of consciousness and such categorizes TBIs as mild (13-15), moderate (9-12) or severe (3-8). The utility of this scale has been essential in emergency cases to assess the initial severity of an injury and the implications regarding recovery have been invaluable (Iverson & Lange, 2011). Particularly, research suggests that those with GSC scores in the mild range stand a greater chance of recovery through therapy and clinical treatment, while those in the moderate to severe range face a more complicated recovery processes (Ashman et al., 2004) and greater risk of mortality (Moore et al., 2006). Fortunately, the majority of head injuries that occurs in contact sports, like football, fall within the mild range (Iverson, 2011).

Despite the popularity and utilization of the GCS classification system, in 2015 the Department of Defense released a memorandum recommending against the use of the GCS to diagnose TBIs (VA/DoD memorandum, 2016). Instead the DoD released a classification of TBI severity based on structural imaging, loss of consciousness (LOC), alteration of mental status, and posttraumatic amnesia (refer to Appendix A). Currently, a diagnosis of traumatic brain injury is based on meeting the criteria outlined in the following classification systems: 1) the *Department of Veteran Affairs and Department of Defense (*refer to Appendix A) and 2) *Diagnostic Statistical Manual of Mental Disorders*, 5th edition (DSM-5; refer to Appendix B).

TBIs in Football: Incidence and Impact

Concussions[1] are associated with acute adverse changes in one's cognitive, physical, and emotional abilities without a loss of consciousness (Iverson & Lange, 2011). Given the milder nature of these types of injuries, it is generally understood that continued improvement is expected with time as most of the recovery following a mild TBI (mTBI) occurs within the first 3-6 months (Pellman et al., 2004b,). While prognosis is good, it is made under the assumption that the injury has been followed by a period of

[1] By definition, a concussion is a mild TBI (mTBI) and is the preferred nomenclature used in sports medicine and within the general population. As such this term will be used interchangeably with mTBI throughout. For additional information please see Iverson and Lange's chapter Mild Traumatic Brain Injury in Schoenberg and Scott's (Eds) 2011 book *The Little Black Book of Neuropsychology*.

cognitive rest, and no underlining factors or conditions (e.g. pre-injury medical/psychiatric conditions, age, culture, premorbid levels of functioning) are present that could slow the period of recovery (Velikonja et al., 2014). Unfortunately, athletes may sustain multiple concussions within a short period of time or over the course of their careers , which then increases risk of slower recovery time, future injury, and chronic structural and functional changes to the brain (Guskiewicz et al., 2003; Iverson et al. 2004; Zemper, 2003).

Furthermore, evidence exists that playing football in childhood, which is common practice for athletes seeking professional football careers, has a high likelihood of resulting in the first instance of mTBIs. Specifically, of the more than 500,000 children between the ages of 8 and 19 who sought emergency room treatment for a concussion over a four-year span, more than 50% of injuries were attributable to football alone (Bakhos et al., 2010). This alarming number is likely due to the fact that children make up 70% of organized football players in the United States and child football players as young as 7 and 8 experienced head impacts at the same rate as high school and collegiate athletes despite wearing protective helmets and gear (Bakhos et al., 2010). In examining the effects of these early concussions, Moser and colleagues (2005) found that high school athletes with recent concussions performed significantly worse on neuropsychological measures of attention and concentration than athletes with no history of concussion and those with recent or multiple concussions demonstrated significantly lower grade point averages indicating evidence for possible prolonged neuropsychological deficits. Despite this evidence on the effects of multiple concussions, to date, the majority of research on the sports-related concussions has focused on collegiate and professional athletes, including those who play for the National Football League (NFL).

To wit, in 2017, the NFL preliminary injury data for the pre-, regular, and full seasons reported players suffered from 291 concussions representing a 16% increase compared to the 2016 season (NFL, 2017). In response, the NFL's executive vice president of Health and Safety noted that there was a large increase in the number of concussions suffered by players in practice before the start of the season, which he attributed to the types of preseason practice drills being conducted (NFL, 2017). With regards to regular and full season concussions, data showed an increase in the number of concussions sustained by players in Thursday games compared to Saturday, Sunday, and Monday games (NFL, 2017). League officials noted that Thursday night games are often closely scrutinized due to complaints from players that games are unsafe due to short rest periods after playing the previous Sunday, perhaps resulting in a higher awareness of concussions (NFL, 2017).

Regardless of professional, collegiate, or junior league status, quantifying the true impact of concussions in football has historically proven challenging due to the tendency of players to underreport in order to avoid the effects of disclosing their symptoms. Several qualitative studies have examined reasons athletes did not disclose concussions and found the most common reasons for nondisclosure were lack of knowledge regarding concussion severity, internal pressure and attitudes (i.e., fear of letting team down, expectation of concussions, fear of missing future games, fear that a diagnosis could affect standing with current and future teams), concussion history, and external pressures (i.e., received negative feedback from coaches and teammates; Chrisman et al., 2013;

Delaney et al., 2015; Kerr et al., 2018). Although advancements are attempting to address this problem through the use of technology (i.e. helmet-mounted accelerometers to determine the frequency and severity of helmet impacts), as well as procedure and policy changes (i.e. limit certain types of contact, providing access to trained medical professionals at the sidelines, guidelines concerning return-to-play issues), diagnosis and management of sports related head injuries remains difficult (Collins et al., 1999a; Duma & Rowson, 2014). Despite these limitations, understanding brain pathology and function can provide a clear understanding of what consequences of a concussion, and multiple lifelong concussions, may look like. Specifically, repeated impact injuries to the head have been shown to result in severe repercussions such as chronic neuropsychological deficits and the development of severe diseases such as white matter brain injury and chronic traumatic encephalopathy (Guskiewicz, 2005; Omalu et al., 2005).

Brain Injury due to Repeated Impact Injury

Research investigating recovery after concussions has shown that the neurological insult of mTBIs results in a cascade of complex neurochemical changes, rendering the individual vulnerable to re-injury (Aubry et al., 2002, Giza & Hovda, 2001). Animal studies have shed insights into the pathophysiology of concussion demonstrating the presence of axonal sheering, beta-amyloid deposits, and cognitive impairment due to repetitive concussive and sub-concussive blows to the head within a 3 to 5 day interval (Grant et al., 2018; Longhi et al., 2005; Prins et al., 2011). When the interval between successive head injuries is closer together there appear to be significantly more negative cognitive consequences (Giza & Hovda, 2014). Specifically, the risk of conditions such as chronic traumatic encephalopathy (CTE) and second impact syndrome (SIS)[2] increases. This is particularly problematic given research that has documented the high likelihood of recurrent head injury within the first week of returning to play among football players (Guskiewicz et al., 2003).

Chronic Traumatic Encephalopathy

Chronic traumatic encephalopathy (CTE) was first described by a medical examiner, Dr. Harrison Martland, in 1928 as a constellation of symptoms in boxers (Martland, 1928). The disease was originally coined “Punch Drunk” syndrome and later renamed as dementia pugilistica (Saulle & Greenwald, 2012). In the 1960s, CTE was found in additional sports outside of boxing, particularly in American football, and was renamed chronic traumatic encephalopathy (Saulle & Greenwald, 2012). CTE is defined as a progressive neurodegenerative disease caused by repeated sub-concussive hits to the head (Thurman et al., 1998) resulting in cognitive (i.e. memory problems) and emotional/behavioral problems, including suicide (Omalu et al., 2010).

Postmortem studies have also highlighted an association between these problems and CTE. Specifically, the Boston University Center for the Study of Traumatic Encephalopathy (CSTE) brain bank has performed over 70 retrospective clinical examinations of deceased athletes and military workers, documenting specific neuropsychological changes (Cherry et al., 2016). Particularly they have noted that duration of repetitive head impacts and the severity of CTE were associated with reactive

[2] Second impact syndrome (SIS) is a highly debated condition, where the result of a second TBI occurring before the neurochemical changes of the first TBI have fully resolved purportedly result in coma or death (Please see Cantu, 2016; McLendon et al., 2016 for additional information).

microglial morphology and ptau pathology (Cherry et al., 2016). With regards to prevalence, McKee, and colleagues (2009) found that of the neuropathologically diagnosed cases of CTE, 90% of those occurred in professional athletes who participated in American football, boxing, soccer, and hockey. While the exact incidence of CTE is still largely unknown, it is believed to vary depending on the type of sport, position played, career length, number of injuries, age of first injury and genetic-biological factors (Gavett et al., 2011).

It has been well documented that repetitive concussive or sub-concussive blows to the head is a risk factor for CTE (Cherry et al., 2016; Stern et al., 2011; Stern et al., 2013), however there is no clear consensus on the frequency of trauma that is needed to cause CTE. More recently, research has showcased that some individuals who suffer from repetitive brain injury do not develop CTE, but rather that CTE can occur in patients who may have suffered a single traumatic brain incident during their lifetime (Johnson et al., 2012). Therefore, it is evident that repetitive brain trauma is not sufficient alone to cause CTE, and other risk factors are involved. For example, the age at which CTE-related brain changes begin to occur may be a crucial factor in the development of the disease. McKee et al. (2009) documented a case of CTE in an 18-year-old high school football player with a history of concussions and who died as a result of these brain injuries. Many athletes begin their playing "career" before the age of 10 (McKee et al., 2009). Younger individuals may be particularly susceptible to brain damage, in part due to the vulnerability of the developing brain to numerous assaults that can lead to a cascade of devastating events and become exacerbated over time given the onslaught of additional traumas (Field et al., 2003; Pullela et al., 2006). However as stated above, the nature and culture of sports susceptible to CTE, such as football players, may result in a lack of report of mild cases of TBIs due to individual devotion and the pressures to perform (Yi et al., 2013). Thus, the exact incidence of brain injuries and CTE may never be known due to a lack of reported cases by those who sustain mild to moderate brain insults, and subsequent lack of clinical attention. Nevertheless, CTE is one of the only preventable neurodegenerative diseases and it is evident from the research that anyone who suffers from any form of trauma to the brain, regardless of mechanism, may run the risk of developing CTE.

***Symptoms of CTE*.**

Cognitive and behavioral symptoms are the most notable changes that have been shown to affect CTE patients (Baugh et al., 2012). Typically, the brain regions that tends to be affected by CTE are the cerebral cortex, the amygdala, and hippocampus (Stern et al., 2001). The neuropsychological and neuropsychiatric changes can be broadly classified into three categories of cognition, mood, and behavior (Sauelle & Greenwald, 2012). The severity of clinical presentations progress throughout the course of the degeneration and symptoms become noticeable years after the trauma or when the neurodegeneration becomes severe enough (Stern et al., 2013). However, there are early and perhaps subtle changes that can be observed with proper neuropsychological evaluation. Specifically, early cognitive symptoms include learning and memory impairment, executive function impairment; mood disorders in the form of depression, irritability, and suicidality; behavior and personality changes that lead to poor impulse control, increased aggression, violence, disinhibition and problems with substance abuse (Stern et al., 2013). All these symptoms can worsen over time and lead to degenerative conditions, which are often misdiagnosed as Alzheimer's disease (AD; Crane et al., 2016; Hay et al., 2016; Yuan & Wang, 2018). Given that CTE has been well documented in its association with athletes who participate in contact sports, there has been a rapid development of concussion management strategies in the NFL supported by research dedicated to increase the evaluation of players with mTBIs (Collins et al., 1999b).

Neuropsychological Assessments of Head Injuries in Football

The assessment of neuropsychological function has become an integral part of the management of individual functional abilities in distinguishing between normal brain function and neurological dysfunction due to sports related TBIs (King et al., 2014; McCrory et al., 2017). Neuropsychologists are trained to assess and interpret objective test data in order to detect neurobehavioral changes not easily observed during sideline or on-field examinations of athletes (Harmon et al., 2019). As part of an interdisciplinary team, neuropsychologists' accurate evaluations can guide appropriate treatment and rehabilitation outcomes (Ott et al., 2018). However, as stated previously, a number of individual variables can make it challenging to determine the incidence and impact of head injuries. Furthermore, other underresearched and overlooked individual identity variables (e.g. cultural background, gender, racial identity, socioeconomic status) can lead to inconsistency in research and neuropsychological findings. For example, one study looking at neuropsychological recovery in NFL athletes found that, as a group, athletes tended to rapidly return to baseline cognitive performance following a concussion, which is in contrast to several studies that found long-lasting neuropsychological deficits in athletes (Alosco et al., 2017; Moser et al., 2005; Stern et al., 2011).

Despite a lack of consensus regarding neuropsychological outcomes following a history of concussions, neuropsychological assessments provide insight into the interaction of acquired cognitive deficits, psychological factors, and recovery from sports-related concussion (Broshek et al., 2015; Echemendia et al., 2012). The benefits of these types of assessments have received endorsements from several organizations such as the American Medical Society for Sports Medicine, and the American Psychological Association, which have resulted in recognition by national sport entities, like the NFL, of the importance of neuropsychological informed concussion management and evidenced based return to play guidelines (Echemendia et al., 2012; McCrory et al., 2017; Ott et al., 2018).

Neuropsychological Informed Concussion Management

The nature of a concussion infrequently renders an athlete unconscious and thus the athlete and others may be unaware that they have been injured given the lack of immediate signs and symptoms (Iverson, 2011). Furthermore, as mentioned above, athletes are more likely to hide symptoms for various reasons, which creates the potential for further injury (Chrisman et al., 2013; Delaney et al., 2015; Kerr et al., 2018). Thus, appropriate treatment for concussions begins with the initial sideline evaluation, which consists of assessing level of consciousness, confusion, motor incoordination, and amnesia (Lovell, 2009). The common physical signs and symptoms of a concussion are also assessed carefully including headaches (most commonly reported), visual disturbances, nausea, fatigue, and sensitivity to noise/light (Lovell, 2009). While some of these symptoms may not be readily evident during gameplay, teammates are usually alerted to problems when difficulties in play calling, slow and perseverative responses to questions, or dazed facial expressions occur (Lovell, 2009).

In addition to these symptoms, cognitive and mental status changes are also seen after an injury. Specifically, the neurocognitive presentation of mTBIs is most often seen in the cognitive domains of processing speed, attention, working memory, verbal learning, and verbal memory (Echemendia et al., 2001; King et al., 2014). On-field cognitive testing is brief and includes orientation questions (e.g. “what city is this?”), immediate and delayed memory recall for three words, concentration questions (e.g. digits-backwards, days of the week backwards) and recall of events prior to and after the trauma (e.g. “What happened in the previous quarter?,” or “Do you recall the hit?”; Lovell, 2009).

Beyond initial sideline evaluations and on-field cognitive testing, follow-up neuropsychological testing is conducted post game to further analyze aspects of cognition that are likely affected by the head injury to provide return-to-play decisions (Echemendia et al., 2001). Traditional paper-and-pencil neuropsychological testing and computerized formats have provided reliable information in determining cognitive deficits due to a mTBI during follow-up. Specifically, the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT; Alsalaheen et al., 2016), primarily used in collegiate settings, has allowed for rapid and standardized administration in the days after an injury to determine initial neurocognitive status (Resch, et al., 2013). In fact, neuropsychological performances alterations across different TBI severities from both single and repetitive concussion have further validated the importance of a comprehensive neuropsychological battery in assessing the effect of cognitive deficits associated with concussions (Belanger et al., 2010; Karr et al., 2014; Mills et al., 2001). However, in reviewing the literature on cognitive performance, it remains evident that a comprehensive systemic analysis of cognitive, effort and emotional performance in those with and without a history of mild or severe traumatic brain injury would greatly clarify the nature of domain specific impacts (Pellman et al., 2004; Solomon et al., 2015).

Return to Play Guidelines

The multitude of neurological compromise, outlined above, whether short or long-term, following repetitive head injury justifies the need for evidence-based return to play (RTP) guidelines for these sports. The last 3 decades have seen more than a dozen concussion management and evidence based RTP guidelines adopted by numerous organizations (Carson et al., 2014). The premise behind RTP guidelines emphasizes a graduated, stepwise return to play dependent on the resolution of cognitive and physiological symptoms (Harmon et al., 2019; McCrory et al., 2017). Any endorsement of concussive symptoms would lead to a drop back to a previous level (Harmon et al., 2019; McCrory et al., 2017). Unfortunately, return-to-play decisions are often made under intense pressures from coaches, fans and players who may make determinations based on limited information and observations (Lovell, 2009). In fact, an epidemiological study found that, in cases where a concussion was reported, 92% of concussed players returned to game play (usually practice) in less than 7 days, with this value only decreasing by 23% among the 9.3% players who experienced loss of consciousness and the 2.4% of players who required hospitalization (Pellman et al., 2004a).

While concussion symptoms tend to resolve in a relatively short period of time, this expected timeline is complicated by the significant degree of variability amongst athletes. Specifically, differences have been noted with regards to age when injuries are sustained, history of concussions, racial identity/cultural factors, and level/type of sports performance such as position played (D'Lauro et al., 2018). Thus, management of concussions is not a singular universal system, but rather these differences highlight the importance of tailoring the management of concussions based on the individual while adhering to objective standards of assessments.

Factors Impacting Assessment and Recovery

As previously stated, although cognitive symptoms following a concussion are often short-lived (i.e., 7 to 14 days), symptom persistence has been attributed to several individual and interactive variables such as age, concussion history, racial identity, and position played (D'Lauro et al., 2018).

Age. Age is believed to interact negatively with repeated concussions. Older individuals have a limited degree of recovery, worse psychological and physiological outcomes, and are at a higher risk for progressive cognitive decline (Marquez de la Plata et al., 2007; Czosynka, 2005). However, studies have also shown that younger individuals, specifically high school athletes, take longer to return to cognitive baseline following a concussion and may be more vulnerable to re-injury than other groups, including professional NFL players (Field et al., 2003; Zuckerman et al., 2012; Pellman et al., 2006). This contradiction in findings is likely driven by the fact that, as we age, our brain undergoes a number of anatomical and neurophysiological changes beginning with brain development and ending with degeneration or atrophy, which make early people particularly susceptible to concussions in early and late life (Bishop et al., 2010; Steinberg, 2008).

With regards to a younger age, research has found that the brain takes roughly 25 years to fully develop (Andersen, 2003; Johnson et al., 2009). This prolonged period of development creates a window of vulnerability for external forces (e.g. repeated head injuries) to disrupt the normal progression of brain formation which can, in turn, impact the rate of recovery and susceptibility to neurodegenerative disorders (Andersen, 2003; Crane et al., 2016). As such, youth exposure to high contact sports, like American football, during brain development has been theorized to result in more prolonged structural and neurochemical changes after a concussion (Fields et al., 2003), and thus greater neurobehavioral consequences. In one sample of former American football players, those who began playing before age 12 were more than two times more likely to have clinically significant changes in cognitive, behavioral and emotional function compared to those who began playing at an older age (Alosco et. al., 2017). These effects were seen independent of age at assessment, education, and length of playing career (Alosco et al., 2017). Since many professional football players began playing before the period of adolescence and are likely to have suffered a higher lifetime concussions rate than is officially documented (Shuttleworth-Rdwards & Radloff, 2008), the likelihood of repetitive injury due to a long-lasting history of brain trauma is thought to increase with age within this population.

Concussion History. In addition to age of injury, or age of first exposure to contact sports, the history of head injury has been identified as an important factor in the assessment and recovery of mTBIs (Collins et al., 1999a; Sancar, 2019). This is in part due to the cumulative and negative effects of repetitive trauma to the brain (Graham et al., 2014). Studies on collegiate contact sport athletes have documented the impact of concussions on neuropsychological performance and neuroanatomy. Specifically, long-term subtle neurocognitive deficits within the areas of learning have been documented among college football players who endorsed two or more concussions (Collins et al., 1999a). Similarly, a study of college contact-sports athletes revealed a reduction of white matter integrity within the right midbrain postseason compared to healthy controls (Sancar, 2019). Of note, the 38 football players within the sample reported 19,128 head hits during a single season (including practice and competition) and reductions in midbrain white matter integrity appeared to be strongly correlated with the number of twisting head impacts rather than head-on impacts (Sancar, 2019). While the details of concussion history (e.g. length of time between head injuries, number of head injuries, impact location, and severity of injury) are also thought to mitigate the rates of recovery, few studies have investigated these factors systematically (Cantu, 1992).

Racial Identity. Racial disparities in cognitive health are well documented in the United States (Zhang et al., 2016). Specifically, older Black[3] and Hispanic/Latinx individuals perform worse than non-Hispanic/Latinx Whites on measures of overall cognition (Diaz-Venegas et al., 2016), memory (Masel and Peek, 2009), and executive functioning (Early et al., 2013). There is also a well-documented increased risk for

[3] Note, because the term African American historically refers to descendants from enslaved Africans in North America, the term Black will be used throughout this paper as it is inclusive of all individuals within the broader African diaspora who descended from sub-Saharan Africa regardless of specific ancestry or ethnicity. (For additional information please see https://apastyle.apa.org/style-grammar-guidelines/bias-free-language/racial-ethnic-minorities).

Alzheimer’s disease, TBI, and cerebrovascular disease, at an earlier age among Blacks and Hispanics/Latinx when compared to non-Hispanic/Latinx Whites (Brickman, et al., 2008; Garcia et al., 2017a ; Garcia et al., 2019; Gary et al., 2009; Hale et al., 2020; Waldstein et al., 2017; Zahodne et al., 2016;).

With regards to TBI, there is also an increased likelihood of worse outcomes for individuals who identify as Black (Gary et al., 2009; Houck et al., 2018; Lincoln et al., 2018; Alosco et al., 2018). Specifically, following a TBI, Black individuals are shown to have worse treatment, functional, psychosocial, neuropsychological, emotional, and neurobehavioral outcomes compared to Whites (Gary et al., 2009). Racially based neurological changes in later life due to repeated concussions have also been found, with former Black NFL players exhibiting higher CVD-mortality rates, white matter alterations and increased presence of tau-proteins (Lincoln et al., 2018; Alosco et al., 2018).

Research among US Blacks seeking to better understand these cognitive health disparities has identified a number of social-environmental, psychosocial and economic conditions that underlie and perpetuate inequalities (i.e. geographical segregation and socioeconomic position, including financial resources, which combine to impact education quality and literacy; health disparities stemming from social inequality, such as discrimination, and unequal resources access leading to mental and physical dysfunction; accumulated stressors, such as an increased likelihood of experiencing death of a child and lead exposure, resulting in greater perceived stress)[4], but our understanding remains

[4] Readers interested in further explanation of these conditions are directed to Glymour & Manly’s (2008) Lifecourse Social Conditions and Racial and Ethnic Patterns of Cognitive Aging.

incomplete (Cassidy-Bushrow et al., 2018; Chen, & Zissimopoulos, 2018; Glymour & Manly, 2008; Reuben, 2018; Turner et al., 2017; Umberson et al., 2019). Because the complex processes by which these disparities are accumulated and maintained remain unclear, incorporating a lifecourse perspective is key in understanding racial patterns that impact cognitive health and the neuropsychological test performance that captures this phenomenon (Thorpe et al., 2013; Thorpe et al., 2015; Glymour & Manly, 2008).

To wit, the field of clinical neuropsychology has acknowledged a number of barriers to provision of culturally competent neuropsychological services, including lack of adequate training, appropriate representation, and issues of construct validity, (Manly & Echemendia, 2007; Rivera-Mindt et al., 2010). Specifically, the fact that development, administration, and interpretation of established measurement tools may lead them operate differently across groups, has been of particular concern given most norms utilize samples of normal-Westernized individuals (Glymour & Manly, 2008, Ardila, 2007). Therefore, our current understanding of cognitive process and functional organization skills remains biased. This bias may, in part, explain the mixed findings as to if cognition differences with regards to race remain after controlling for known confounds (i.e. age, gender, and education; Manly & Mayeux, 2004b) or not
(Diaz-Venegas et al., 2016).

While research on the role of Black racial identity on neurological outcomes after repeated head injuries for football players is limited, poorer memory and processing speed performance have been noted in black student athletes (Houck et al., 2018). In examining Black retired NFL players, the only study conducted to date found both demographic (i.e., 4 years younger, had lower academic achievement scores, and higher

BMI and systolic blood pressure) and pathophysiological differences, (i.e. lower gray matter volume, lower right hippocampal volume, higher phosphorylated and total tau ratios) compared to White retired players (Alosco et al., 2019). Since long-term endurance and participation in the NFL are associated with an increased prevalence of heart-related complications (i.e. atrial fibrillation, left ventricular hypertrophy; Aagaard et al., 2019; Smith et al., 2019), and Black former athletes demonstrate higher risk of chronic health conditions such as cerebrovascular disease and associated neurological and cognitive decline (Manly & Echemendia, 2007; Alosco et al., 2019), further inquiry into the impact of racial health disparities as potential moderators appears warranted. This may be of particular importance in understanding how the disproportionate dispersion of race within the NFL by player position, which is described below, impacts concussion risk and prognosis. Although the 2019 racial and gender report card for the NFL census found that Blacks accounted for 58.9% of players, and White players made up 26.8%, with 78% of Quarterbacks reported to be White (NFL, 2017). Taken together, it is likely that differences in neuropsychological outcomes within the NFL population may occur on basis of race and culture group.

Playing Position. The severity and/or frequency of traumatic brain injuries are known to impact severity of cognitive impairment regardless of population. However, American football players face several unique factors that may potentially impact severity, including length of time played and player position. Research indicates that, with each game played, there is a statistically significant increased risk of concussion with an injury proportion ratio of 1.39 (Daneshvar et al., 2011) and position played has been linked to the level and severity of impacts, as well as the presence of greater white matter damage and subsequent impairment (Pellman et al., 2004a; Crisco et al., 2011; Lehman et al., 2012; Clark et al., 2017). There are several American football positions, each having specific tactical and varying levels of physical activity demands for game play. The playing positions can be generally understood in three major categories: offensive players (i.e. quarterbacks, running backs, fullback, offensive linemen, wide receivers, and tight end), defensive players (i.e. defensive line, linebacker, cornerback, and safety) and special teams (i.e. kicker, punter, return specialists, long snapper). Microtechnology such as accelerometers have quantified and determined positional differences in impacts among athletes (Funk et al., 2017; Hamberger et al., 2009; Wellman et al., 2017). Specifically, research indicates that offensive linemen, defensive linemen and linebackers had the greatest frequency of impacts, while quarterbacks and running backs had the greatest magnitude of impacts (Crisco et al., 2011). Except for quarterbacks, running backs experienced more severe impacts compared to other offensive positions, whereas wide receivers sustained lighter impacts (Wellman et al., 2017).

To better understand the impact of player position, Lehman et al. (2012) operationalized positions as speed (i.e. quarterback, wide receiver, tight end, defensive back, fullback, halfback, running back, linebacker) and nonspeed (i.e. defensive end/lineman/tackle, guard, nose guard, tackle, center, and offensive end/guard/lineman/tackle) with specials teams (i.e. punters and kickers) as other. Among retired NFL players, playing in a speed position has been found to be related to black racial identity (62% of speed position players), higher incidence of concussions, greater physical (i.e. headaches, dizziness, blurred vision) and cognitive (i.e. immediate recall, retrograde amnesia and information-processing difficulties) mTBI symptoms, and greater mortality rates from all neurodegenerative causes of death (i.e. AD and ALS) when compared to playing in a non-speed position (Pellman et al., 2004a; Lehman et al., 2012). Speed positions have also been showed to yield higher incidence of concussions as these players build up greater momentum before tackling another player or being tackled themselves and then are injured by acceleration impact from their helmet (Pellman et al., 2004a). The type of speed position can also increase risks; quarterbacks have been found have the highest risk of impact highest with 1.62 concussions per 100 game-positions, followed by wide receivers, tight ends, and defensive secondaries (Pellman et al., 2004a).

Although speeded positions players are at greater risk, players in non-speed positions who endorse three or more concussions demonstrate lower fractional anisotropy (FA) in frontal white matter and lower blood-oxygen level-dependent (BOLD) percent signal change (PSC) during working memory tasks compared to those with fewer concussions (Clark et al., 2017). Further complicating the picture, chronic traumatic encephalopathy (CTE), caused by sub-concussive impacts, has been found in both speeded (i.e. linebacker, wide receivers, safety) (McKee, et al., 2009; Cherry et al., 2016) and non-speeded positions (i.e. offensive linemen, defensive linemen) (McKee, et al., 2009), suggesting that there may be other factors mitigating the risk of CTE (Cherry et al., 2016).

In addition to the differences in frequency of concussions based on position group, position groups also require distinct technical and physical demands related to athletic qualities and abilities such as physical build/stature and running speed. Historically, there have been significant differences in mean height, weight, body surface area, and speed based on NFL positions that are necessary to effectively carry out the challenges of the job (Ward et al., 2018; Wellman et al. 2007). As such, position groups experience differences in specific-training drills, and physical preparation for the game, both of which exert greater levels of physical load compared to the general population (Ward et al., 2018). As such, the level of endurance overtime based on position played has been shown to be associated with greater risk of cardiac complications, with offensive players showing a greater risk (Smith et al., 2019). Altogether, the likelihood of sustaining at least one or more recurrent concussions during one's football career and subsequent consequences increases with the length of time spent playing, as well as the type of positioned played, but factors modifying this relationship are remain unknown.

Long-Term Impact

Long-term pathological consequences of traumatic brain injuries and repeated concussions due to contact-related sports include psychological (i.e. depression, agitation, dementia, parkinsonism, psychosis, irritability, and aggression) and neurological effects (i.e. presence of tauopathy, patchy distributions of neurofibrillary tangles, neuropil threads and diffused amyloid plaque; Saulle & Greenwald, 2012; Dekosky et al., 2013; McKee et al., 2009). These documented neurological effects included common features of both Alzheimer's disease (AD) and chronic traumatic encephalopathy (CTE; Dekosky et al., 2013; McKee et al., 2009). Generalizing known pathology of neurodegenerative disorders, a hypothetical temporal sequence of events within TBI and CTE has been suggested by DeKosky and colleagues (2013) known as a "diffuse axonal injury" which appears to be linked to changes in several physiological processes, as well as the formation of insoluble abnormal proteins.

Although there are clear anatomical differences distinguished between AD and CTE, similarities in clinical presentation while the individual is alive can lead to misdiagnoses. CTE patients have tau tangle proteins similar to the ones seen in Alzheimer's disease, but differ in the pattern by which the tangles are organized (Omalu et al., 2005). Similarly, CTE brains do not show the classic amyloid beta plaques that have been the hallmark presentation in Alzheimer's (Omalu et al., 2005). However, the distinction becomes more difficult when the patient is alive as both CTE and AD are associated with memory loss, confusion, personality changes, erratic behavior, and motor skills (Breunig, Guillot-Sestier & Town, 2013). As such, research to better understand the neuropsychological functioning following a lifetime of head injuries and the impact of known course modifiers following sports-related play (i.e., age, concussion history, racial identity, and position played) is desperately needed.

CHAPTER II:PURPOSE AND SPECIFIC AIMS

The purpose of this dissertation study is to extend the body of research on neuropsychological deficits that can occur from the long-term effects of playing football. While studies have acknowledged the association between recurrent concussions and long-term cognitive effects, these studies have largely consisted of self-report questionnaires among retired NFL players. Little is known about how inter-individual differences among professional players impacts cognitive outcomes within this population. Therefore, this study will examine the impact of those individual factors such as racial identity, position played, and years played that may influence the likelihood of individual cognitive deficits within domain specific cognitive function which will be important in future rehabilitative research. Also, given that the majority of NFL players are Black, this study will assess whether these factors serve as a greater predictor of cognitive changes within this population compared to other White athletes.

This dissertation was designed to fulfill four specific aims, which, along with the related research questions, are detailed below.

Specific Aim 1: To Examine the Differences in Various Psychosocial Characteristics of Retired NFL Players Based on Position Played While in the NFL.

Research Question 1a. When retired NFL athletes are grouped by playing position are there statistically significant differences in levels of education?

Research Question 1b. When retired NFL athletes are grouped by playing position are there statistically significant differences in mean age group?

Research Question 1c. When retired NFL athletes are grouped by playing position are there statistically significant differences in number of years played in the NFL?

Research Question 1d. When retired NFL athletes are grouped by playing position are there statistically significant differences in racial identity?

Research Question 1e. When retired NFL athletes are grouped by playing position are there statistically significant differences in premorbid level of functioning?

Research Question 1f. When retired NFL athletes are grouped by playing position are there statistically significant differences in occupation type after retiring from the NFL?

Research Question 1g. When retired NFL athletes are grouped by playing position are there statistically significant differences in marital status?

Specific Aim 2: Explore Whether Position Played in the NFL Determines Levels of Cognitive Impairment Across the Domains of Complex Attention/Processing Speed, Learning and Memory, Language, Visuo-spatial and Executive Function after Controlling for Covariates.

Research Question 2a. After controlling for covariates, are there differences on complex attention and processing speed measures by former NFL playing position?

Research Question 2b. After controlling for covariates, are there differences on learning and memory measures by former NFL playing position?

Research Question 2c. After controlling for covariates, are there differences on visuo-spatial measures by former NFL playing position?

Research Question 2d. After controlling for covariates, are there differences on executive functioning measures by former NFL playing position?

Research Question 2e. After controlling for covariates, are there differences on language measures by former NFL playing position?

Specific Aim 3: To Examine Whether Racial Identity Determines Level of Cognitive Performance Within a Retired NFL Population after Controlling for Covariates.

Research Question 3. After controlling for covariates, are there differences across multiple cognitive domains based on racial identity/group?

Specific Aim 4: To Determine if Race and Position Played in the NFL Serve as Better Predictors of Cognitive Performance Compared to Demographic Variables and Premorbid Functioning.

Research Question 4a: How much variation in complex attention and processing speed performance is explained by player position and race?

Research Question 4b: How much variation in learning and memory performance is explained by player position and race?

Research Question 4c: How much variation in visuo-spatial performance is explained by player position and race?

Research Question 4d: How much variation in language performance is explained by player position and race?

Research Question 4e: How much variation in executive functioning performance is explained by player position and race?

CHAPTER III: METHODS

Participants and Procedure

This dissertation study examined 144 male retired NFL players (mean age = 48.88 years, SD= 10.63). All participants were enrolled in college before their NFL careers with a range of education from 14-18 years (mean = 15.94; SD=1.03). Time played at the professional level ranged from 1-21 years with a mean number of years played of 6.17 (SD=3.62). Participant data was selected from an ongoing study at Nova Southeastern University, which was designed to measure the psychiatric and neurological status of retired NFL players. Participants in this study were self-referred or referred by an attorney for comprehensive neuropsychological testing by a private board-certified licensed neuropsychologist as part of a stipulation of the NFL concussion settlement. Background information was obtained through a brief clinical interview, which included the Mini International Neuropsychiatric Interview (M.I.N.I; Lecrubier & Sheehan, 1997) and Clinical Dementia Rating Scale (CDR; Morris, 1993). All participants were administered a standard neuropsychological battery. Measures selected for this study, which are described below, took approximately 4 hours to complete and included subtests from the Wechsler Adult Intelligence Scale—Fourth Edition (Wechsler, 2008), Wechsler Memory Scale-Fourth Edition (Wechsler, 2009), Controlled Oral Word Association Test (COWAT; Benton, 1969), Trail Making Test (Reitan, 1958), Boston Naming Test (Kaplan et al. 1983), Boston Diagnostic Aphasia Exam-Complex Ideational test (Kaplan et al., 2001), Minnesota Multiphasic Personality Inventory-2-Restructured Form (MMPI-2rf; Ben-Porath & Tellegen, 2008) and Test of Premorbid Functioning (Advanced Clinical Solutions, Pearson, 2009). Symptom validity tests were also administered.

These particularly tests were selected as outlined by the settlement. Before any analysis of the data was conducted, approval from the Institutional Review Board at Nova Southeastern University was obtained on October 19, 2018 (Protocol #: 2018-525). In accordance with the IRB and the American Psychological Association (APA), all data was de-identified.

All participants were at least enrolled in college for some time before their professional sports career, 56.6% earned bachelor's degree, 28.7% completed 3-5 years of college with no degree conferred and 14.0% completed a post bachelors or master's degree. 24.5% of the sample identified as White, and 75.5% identified as Black. Given the nature of the population of interest, 100% of the participants were male. English was the primary language for all participants. Participants differed in terms of position played during the NFL and consisted of Wide Receivers (16.7%); Offensive Lineman (13.2%); Running Back (13.9%); Defensive Back (cornerback and safety, 19.4%); Defensive Lineman (tackle and end, 13.9%); Linebacker (11.1%); Quarterback (4.2%); Tight End (5.6%); Special Teams (1.4%); and Fullback (0.7%).

All participants completed a comprehensive neuropsychological evaluation inclusive of measures of complex attention and processing speed, learning and memory, visual spatial, language, and executive function. There were no participants excluded from this study, although participants did occasionally not provide information and for specific aim 2 playing positions that had fewer than two members were excluded (Fullback, N=1). As this was an exploratory study, participants were not excluded if they had pre-existing psychiatric diagnoses. Table 3-1 shows the demographic breakdown of the overall sample.

There are a number of factors that have to be considered when administering and interpreting neuropsychological tests. Individuals are cultural beings, whether or not we acknowledge ascription to a culture; we each have our own unique sets of ideas and values that govern our lives. These cultural differences have a significant impact on predispositions to particular abilities and functions. Given the majority of neurocognitive tests to date have been developed using a limited sample of normal-Westernized individuals, and the cultural differences within our sample, it was not presumed that participants would respond in similar ways to test items. As previously stated, numerous demographic factors are known to significantly impact performance on most neuropsychological tests, thus where available and appropriate adequate normative corrections, inclusive of race and education, were used. Additionally, in interpreting observable differences between Black and White participants, aspects of an ECLECTIC[5] framework were utilized to interpret and understand these differences.

[5] Individual components of the ELECTIC framework include; E: education and literacy; C: culture and acculturation; L: language; E: economics; C: communication; T: testing situation- comfort and motivation; I: intelligence conceptualization; and C: context of immigration. (Please see Fujii, 2018 for additional information).

Table 3- 1. Descriptive Statistics on the Study Variables and Sample Characteristics

Characteristic	N	Mean (SD), %
Age (years)	144	48.88 (10.63)
Education (years)		15.94 (1.03)
Associate degree/2 years of college	1	0.7
3-5 years of college and no degree	41	28.5
Bachelor's Degree	82	56.9
Master's Degree/Post-Bachelor's Degree	20	13.9
Racial Identity		
Black	109	75.7
White	35	24.3
Position Played		
Quarterback	6	4.2
Running Back	20	13.9
Fullback	1	0.7
Wide Receiver	24	16.7
Tight End	8	5.6
Offensive Lineman	19	13.2
Defensive Lineman	20	13.9
Linebacker	16	11.1
Defensive Back	28	19.4
Special Teams	2	1.4
Number of Years Played	143	6.17 (3.62)
Psychiatric		
No Diagnosis	82	60.4
Psychiatric Diagnosis (depression, dysthymia, GAD)	50	37.3
Neurological Diagnosis	3	2.2

GAD=Generalized Anxiety Disorder

Measures

The following measures traditionally used to evaluate sports related concussions (Echemendia et al., 2001; Pellman at al., 2004; Solomon et al., 2015) will be described below: WAIS-IV (Block Design, Similarities, Digit Span, Matrix Reasoning, Arithmetic, Visual Puzzles, Coding, Symbol Search, Letter-Number Sequencing and Cancellation); WMS-IV (Visual Reproduction I &II, Logical Memory I & II, and Verbal Paired Associates I and II), Test of Premorbid Functioning, COWAT, Boston Naming Test, Complex Ideational test from the Boston Diagnostic Aphasia Exam, Category Test, Trails A and B.

Wechsler Adult Intelligence Scale – Fourth Edition.

The Wechsler Adult Intelligence Scale – Fourth Edition is an assessment of intelligence and cognitive abilities. An individual completes a series of subtests that examine verbal ability, working memory, perceptual reasoning, and processing speed. An overall Full-Scale Intelligence Quotient (FSIQ) is obtained by examining performance across all score indexes, which include the Verbal Comprehension Index (VCI), the Working Memory Index (WMI), the Perceptual Reasoning Index (PRI), the Processing Speed Index (PSI), and the Full-Scale IQ (FSIQ). Raw scores are converted to scaled scores for each subtest based on age and the sum of the scaled scores are converted into composite scores which have a mean of 100 and a standard deviation of 15. The WAIS-IV is considered to have excellent reliability, as determined by internal consistency methods for 13 age groups ranges from .97 to .98 (M r_{xx}=.98) for full-scale IQ; and by test-retest interval over 8 to 82 days was r=.96 (Wechsler, 2008). Notably, the mean retest scores for the WAIS-IV showed improvement between first testing and second testing, suggesting the influence of practice effects. However, since only select subtests of the WAIS-IV were administered to the participant (Block Design, Similarities, Digit Span, Matrix Reasoning, Arithmetic, Visual Puzzles, Coding, Symbol Search, Letter-Number Sequencing and Cancellation), those will be described below. Of note, IQ scores are a reasonably good measure of overall functioning, however, there have been criticisms regarding the misinterpretations of differential performance between racial groups regarding intellectual differences (Thaler et al., 2015; Washington et al., 2016). Racial group differences on the WIAS-IV and other measures are a complex problem resulting from a myriad of factors that still need to be explored.

Block Design. The block design subtest is designed to assess non-verbal reasoning, visual perception, organization, problem-solving and ability to analyze and synthesize designs (Growth-Marnat, 2009; Sattler & Ryan, 2009). It assesses the ability of an individual to reproduce designs with six-sided blocks that have two sides with red surfaces, two sides with white surfaces and two sides divided diagonally into red and white surfaces. The individual has to assemble blocks identical to a model that was constructed by the examiner and by looking at two-dimensional designs in a stimulus book. The patterns reproduced increase in complexity as the test proceeds and require a range of cognitive abilities such as visual-constructive skills, spatial visualization ability, motor skills and nonverbal reasoning to complete the task successfully (Golden, Espe-Pfeifer & Wachsler-Felder, 2000). Block design is scored for both accuracy in reproducing the correct design, including the degree of rotation, and speed of completing each task. It is considered to be a sensitive measure of many types of brain dysfunction (Sattler, 2008).

Internal consistency and test-retest reliability for block design are good, with coefficients of .87 and .80, respectively (Wechsler, 2008). Reliability coefficient of Block Design among a sample group of 22 participants with a TBI was .96 (Wechsler, 2008). Block Design has proven to be a good measure of fluid intelligence and demonstrated to show impaired performance in individuals with TBIs, strokes and Alzheimer's disease (Lezak, 1995; Mills et al., 1993).

Matrix Reasoning. The matrix reasoning subtest is a measure of spatial ability, visual-spatial pattern analyses, nonverbal abstract problem solving and inductive reasoning (Wechsler, 2008). In this subtest, the individual is asked to look at a two by two matrix or a row of several boxes, with a missing piece. Participants are asked to identify the correct response from five choices, with no timed demands. This subtest is thought to provide an accurate estimate of nonverbal IQ and overall intellectual functioning for individuals with limited English proficiency (Lezak, 1995). Although matrix reasoning has not been found to be exceptionally sensitive to the effects of TBIs, it has shown to be sensitive to the cognitive sequelae of dementia (Carlozzi et al., 2015; Ryan et al., 2005). Test-retest coefficients for 298 subjects retested over intervals of eight to 82 days was acceptable ($r=.74$), while internal consistency reliability is good at .90.

Visual Puzzles. The visual puzzle subtest requires the individual to view a completed puzzle and select three out of six responses that reconstruct the puzzle. It is thought to be a measure of visual-spatial organization, construction, nonverbal reasoning, and spatial ability. While the visual puzzles subtest is a measure of visuospatial and perceptual reasoning, performance on this subtest is dependent on mental flexibility, processing speed, and memory (Fallows, & Hilsabeck, 2012). Visual puzzles significantly correlates with measures of attention and visual constructional abilities (Fallows, & Hilsabeck, 2012). The sequelae of TBIs includes visual information processing deficits (Groffman, 2016). Individuals with complicated mild to severe TBIs perform worse on almost all subtests of the WAIS-IV, including visual puzzles (Carlozzi et al., 2015). The difficulties noted in visual information processing within TBI severity deficits in pattern recognition and discrimination (Brown et al., 2019). Test retest reliability is acceptable (r=.74), while overall internal consistency good (r=.89).

Similarities. The similarities subtest is a measure of verbal conceptualization ability, abstract verbal skills, verbal reasoning, and concept formation. It involves one's ability to use auditory comprehension, memory, and verbal expression (Wechsler, 2008). This test requires the individual to identify how two objects/concepts are similar or what two seemingly dissimilar things have in common. Unlike block design, the similarities subtest is not timed and is relatively easy to administer but has strict criteria of scoring responses. Responses are scored by how well the individual was able to perceive the similarities between the two words and combining them into meaningful and abstract concepts that reflect higher cortical functioning ability. It is generally thought of as a measure of crystalized intelligence as it requires knowledge of the words presented, but is considered particularly sensitive to individuals who have had brain injuries and thus a poor estimate of premorbid functioning in this group (Golden et al., 2000). Similarities require the individual to find connections between words that may be opposites that are not readily evident. Memory and word retrieval play a significant role in a person's ability to perform this test successfully. Subcortical functions are also important, as the individual has to remain focused on the task at hand. Additionally, the subtest assesses several cognitive aspects of functioning including language development, lexical knowledge, verbal comprehension, abstract thinking ability, reasoning ability, flexibility, capacity for associative thinking, ability to prune non-essential details, long term memory, vocabulary, and receptive and expressive language (Sattler, 2008). Even after controlling for years of education, racial differences are observed on verbal abstraction subtests, like similarities, which is consistent with previous findings that show the impact of cultural differences in organizational and information processing strategies such as holistic or detail-oriented descriptions (Manly et al., 1998). Thus, environmental influences such as quality of education, cultural exposure and enrichment of environment determine performance on similarities (Brooks, Holdnack & Iverson, 2011; Lezak, 1995). In TBI samples, patients with diffuse axonal injury and particularly focal frontal contusions also have demonstrated impairments on similarities (Fork et al., 2005). Internal consistency and test-retest reliability tends to be good (r=.87).

Digit Span. The digit span subtest is sub-divided into three distinct conditions: Forward, Backward, and Sequencing. These conditions require the individual to repeat sequences of orally presented numbers in the same order as the examiner, repeat the numbers in reverse order and repeat a string of numbers and organizing them in ascending order, respectively. The overall subtest is considered to be a measure of attention and concentration, with regards to working memory (Lezak, 1995). The forward condition of digit span is involved in several aspects of function including rote learning and memory, attention, encoding and auditory processing (Wechsler, 2008). The backward condition involves working memory, transformation of information, mental manipulation, and visuospatial imaging (Growth-Marnat, 2003). The sequencing condition involves working memory, transformation of information, and visuospatial imaging (MacDonald et al., 2001). Patients with ranging severities of TBIs show particular impairment on digit span backward (Guskiewicz et al., 2001; Fork et al., 2005). Reliability, determined by internal consistency and test-retest methods, are excellent (r = .93) and good (r = .83), respectively (Wechsler, 2008). Digit Span has been shown to demonstrate good convergent and divergent validity when compared to other subtests such as vocabulary (Wechsler, 2008).

Arithmetic. The arithmetic subtest is one of two subtests that make up the Working Memory Index of the WAIS-IV. It involves mental manipulation, concentration, attention, and mental alertness (Sattler, 2008). The individual is required to mentally calculate answers to a series of arithmetic word problems under timed constraints. This measure is also designed to capture short and long-term memory. Measures of working memory have consistently shown impairments in TBI samples, though contradicting findings have been reported for the clinical utility of the arithmetic subtest investigating the cognitive correlates of TBI (Carlozzi et al., 2015; Donders et al., 2001; Guskiewicz et al., 2001). Test-retest reliability and overall internal consistency is good (r=.83, r =.88).

Letter-Number Sequencing. This subtest is given as a supplemental measure on the WAIS-IV. It may be given in place of other working memory subtests such as Digit Span or Arithmetic. The individual is asks to arrange letters and numbers in sequential order. It is designed to measure mental manipulation, attention, short-term memory, and visuospatial imaging. In performance differences among TBI severity and control groups, letter–number sequencing produced statistically significant differences and satisfactory criterion validity, but need to be used in conjunction with other measures (Donders et al., 2001)Test retest reliability overall internal consistency are good (r=.80; r=.88, respectively).

Coding. The coding subtest is a measure of processing speed but also measures finer-motor control, memory, stress tolerance and sustained attention. The individual is required to match numbers with symbols using a provided key by copying down the symbols that are paired with the correct numbers under timed conditions. It is also a measure of visual spatial and sequencing ability. Measures of processing speed are particularly sensitive to acquired brain injuries (Hawkins, 1998; Martin et al., 2000). The coding subtest, in combination with other measures of processing speed, has proven useful in the differentiating patients with moderate to severe TBIs and patients with mild TBI or normal cognition (Donders et al., 2001). Test retest reliability overall internal consistency are good (r=.86; r=.89, respectively).

Symbol Search. Symbol search is another measure of processing speed and short-term visual memory. The individual is required to identify whether a target symbol matches a symbol in a search group, thus requiring them to scan a series of shapes and identify whether the shapes match (Wechsler, 2008). It is designed to be a measure of visual-motor coordination, visual discrimination, cognitive flexibility, and concentration. As with the coding subtest, symbol search is a clinically valuable inclusion to the assessment of neurocognitive sequelae of TBIs (Donders et al., 2001). Test retest reliability overall internal consistency are good (r=.81).

Cancellation. The cancellation subtest is a supplemental and optional processing speed measure in which the individual is asked to examine a structured arrangement of shapes and mark the target shape in order within a time limit (Wechsler, 2008). It is proposed to measure attention and concentration, visual scanning, processing speed, visual-motor ability, and visual-perceptual speed (Bate et al., 2001; Sattler, 2008). Cancellation subtests have clinical utility in wide range of neuropsychological settings in demonstrating visual neglect, motor deficits and inhibition deficits as well as age-related change in visual processing outside of clinical populations (Lezak et al., 2004; Folk & Hoyer, 1992). Though normal age-related effects on cancellation subtest is not well understood (Pezzuti & Rossetti, 2017). In TBI populations, patients typically perform worse on measures of attention, and information-processing speed (Mathias & Wheaton, 2007; Raskin et al., 1998). Test retest reliability overall internal consistency are acceptable (r=.78; r=.89, respectively).

Wechsler Memory Scale -4th Edition (WMS-IV)

The WMS-IV is a measure of immediate and delayed memory ability across multiple domains such as auditory memory, visual memory, and visual working memory. There are two batteries, and adult battery (ages 16-69) and an older adult (65-90). Both batteries were used for this study, depending on the age of the participant. An index of general memory is also provided. (Wechsler, 2009). Additionally, delayed memory components include a recognition condition that translates to a cumulative percentage based on level of performance (Wechsler, 2009). In a sample of 32 adults, ages 19-45 with a history of moderate to severe TBI, WMS-IV index mean scores were significantly lower compared to a matched control group (Wechsler, 2009). Reliability studies demonstrate that most of the primary subtests of the WMS-IV have moderate to high reliability coefficients. Immediate and delayed memory index scores have excellent internal consistency for the adult battery and the older adult battery (r=.92-.95). In a sample of 555 individuals diagnosed with different clinical conditions such as Alzheimer's, mild cognitive impairment, depression and TBI, reliability coefficients for the delayed memory index score among TBI participants was excellent at .98. As only some subtests of the WMS-IV were administered, those are described below.

Logical Memory I and II (LM I and II). The WMS-IV LM subtests measure auditory learning and memory through immediate (LMI) and delayed (LMII) story recall. The participant is read aloud two storied by the examiner and asked to immediately recall the stories, using as close to the same words the examiner used. After a 20-30-minute delay, participants are asked to recall these stories from memory. The recognition subtest provides a series of "yes," or "no" questions about details of both stories. LM subtests are particularly sensitive to the effects of normal aging and have also demonstrated lower performances in athletes who have sustained a head injury (Lezak et al., 2004; Master et al., 1998). However, studies investigating previous LM versions have varied in their ability to discriminate between individuals with mild TBI and normal controls (Guilmette & Rasile, 1995). Stability coefficients for LM I and II are both adequate at .74, and .71, respectively. Across all age groups and WMS-IIV subtests, Logical Memory I is the most highly correlated with Logical Memory II (r=.87) and Verbal Paired Associates I (r=.44). Logical Memory II is also the most highly correlated with Verbal Paired Associates I (r=.42).

Visual Reproduction I and II (VR I and II). The WMS-IV VR subtests assess immediate (VRI) and delayed (VRII) visual memory. The participant is given 10-seconds to study a stimulus page with either one or two designs and then is immediately asked to reproduce those designs. After a 20-30-minute delay, participants are then asked to reproduce those designs from memory. The recognition subtest provides a multiple-choice option for each design that was presented. Several studies have demonstrated that visual memory was significantly impacted in mild to moderate cases of TBI, implicating primarily parietal and occipital lobe dysfunction in sports-related concussions (Carlozzi et al., 2013; Collins et al., 1999a). Reliability coefficients for a normative and TBI sample for both age batteries are excellent for both VRI and VRII r=.93- .99). Test-retest reliability among 244 examinees over an interval of 14-84 days, for both VRI and VRII were low (*r*=.67 and .64).

Verbal Paired Associates I and II (VPA I and II). The WMS-IV VPA subtests assess an immediate and delayed auditory and verbal memory. Participants are presented and read aloud a list of word pairs (related and unrelated pairs). They are then asked to complete each word pair after being prompted with the first word in each pair. The participant is provided corrective feedback for all four trials if they provide an incorrect response. Thus, they are given several opportunities to learn the word-pairs. After a 20-30-minute delay, the participant is presented with the first word in each pair and asked to provide the word that goes with it. This time they are not given feedback on whether their recalled response was correct (Wechsler, 2009). For the recognition subtest, the examiner reads several word pairs and asks the participant to respond whether the word-pairs were originally presented to them. This subtest is not particularly sensitive to mild cases of cognitive impairment seen in mTBIs, however the measure provides a good indication of difficulties associated with learning new associations and failure to improve performance after multiple learning trials (Carlozzi et al., 2013; Wechsler, 2009). Test retest reliability for VPA I (*r*=.76) and VPA II (*r*=.74) are adequate.

Test of Premorbid Functioning

The Test of Premorbid Functioning (TOPF, ACS) was developed to provide an estimate of an individual's intellectual and cognitive functioning prior to the onset of a neurological disease process or acquired injury (Holdnack et al., 2013). In the context of determining an individual's current level of functioning, information regarding prior functioning is not always available. It was developed for use with the WAIS-IV and WMS-IV and provides premorbid predictions based on demographic factors and/or a word reading task. Historically, while demographic characteristics such as education and occupation were useful in estimates of premorbid functioning, it is prone to bias and estimation errors (Drozdick et al., 2013). For the word list, the individual is asked to read aloud atypical or irregularly pronounced words. This type of test is believed to be a more statistically sound approach to estimating premorbid functioning as these types of tasks are shown to be less sensitive to the insults of injury and degeneration compared to other cognitive measures (Grober &Silwinski, 1991; Holdnack et al., 2013; Nelson, 1982; Pearson, 2001). Low performance on a test based on normative averages does not mean there has been a decline as the individual may have had low functioning prior to a neurological insult.

In TBI samples, the use of demographic norms aids in the identification of cognitive deficits, while controlling for the impact of high or low education on test performance (Pearson, 2009). The use of the TOPF has been shown to be mildly affected in moderate to severe cases of TBI which result in lower estimated VCI and WMI, but not other

WAIS-IV indexes and thus is useful in identifying cognitive deficits associated with TBIs (Iverson et al., 2013). An oversample of education and race were collected for the TOPF to ensure that there was an adequate representation of minority groups and participants with very low and very high education (Pearson, 2009). The TOPF demonstrates high internal consistency reliability for age groups and special groups (e.g. TBI, AD, MCI) of .96 and greater (Chu et al., 2009; Pearson, 2009). Test-retest reliability is also good for age groups with a range from .89 to .95 (Chu et al., 2009; Pearson, 2009).

Trail Making Test (TMT).

The Trail Making Test (parts A and B) are subtests 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 et al. 2006).

In mild TBIs, certain frontal lobe executive skills, like that required to complete the trail making test, are shown to be lower than cognitively healthy individuals (Brooks et al. 1999). Both parts of the test measure processing speed and visuo-spatial skills (Strauss et al. 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 et al., 2000; Kortte, et al., 2002). Test reliability is acceptable but there is significant variability across studies using different patient populations (e.g., .41 to .79 for Trails A and .44 to .89 for Trails B; Strauss et al. 2006). Convergent validity studies have also shown strong correlations with other tests of processing speed and measures of executive function (i.e., the Wisconsin Card Sorting Test; Strauss et al., 2006).

Halstead Category Test

The Category Test, developed by Halstead (1947) as a core part of the Halstead Neuropsychological Battery, is a measure of abstraction, mental flexibility, problem solving, and learning. The standard 208-item computer version was used for the purposes of this study. There are seven sets of items, each of which has a basic principle or idea that runs throughout that set. For instance, a set can be organized based on a number of objects, or a position of a stimulus. The patient's task is to determine the principle presented in each set and indicate which one of four target stimuli correctly follows the current rule. The total number of errors across subtests is used as a measure of abstract reasoning ability. The examinee receives feedback as to whether their response was correct or incorrect on each item and every set, thus, learning is a key component to this test along with aspects of executive function (Strauss, 2006). The raw score (i.e. total errors) is converted into a T-score using the Heaton et al., (2004) norms. In comparison to the other tests included in the Halstead Neuropsychological Battery, the Category Test is the most sensitive to head injury regardless of injury location (King & Snow, 1981; Cullum & Bigler, 1986), suggesting that it is sensitive to damage in areas outside the frontal lobes.

Split half reliability was found to be good (*r*=.98) with a standard error of measurement of 4.47 among a sample of 674 adults (Choca et al., 1997; Shaw, 1966). Test-retest reliability was found to be low (*r*=.60) among cognitively normal adults, probably because of practice effects or due to the restricted range of scores used (Matarazzo et al., 1976; Russell, 1992). Studies have reported similar findings and one study found that by expanding the restricted range of scores through a mathematical redistribution, reliability coefficients improve from .60 to .88 (Russel, 1992). Among clinical samples though the reliability coefficients tend to be higher (*r* = .82–.96 with brain damage; Matarazzo et al., 1976).

Boston Naming Test-2 (BNT-2)

The BNT-2 is considered an important measure of visual confrontational word retrieval in aphasia and dementia studies (Kaplan et al., 1978). Poor performance on this measure has also been documented in several clinical conditions such as left-hemisphere cerebrovascular accidents (Kohn & Goodglass, 1985) and anoxia (Tweedy & Schulman, 1982). In TBI population the BNT has been shown to be highly correlated with other neuropsychological tests that assess confrontation naming tests such as the Naming Test of the Neuropsychological Assessment Battery (NAB; Zgaljardic et al., 2013). The test is made up of 60-line drawings of common objects with increasing naming difficulty. The individual is given twenty seconds to respond to each drawing before they are provided with either a semantic or phonemic cue if they are unable to spontaneously provide the correct response. Scoring is included for spontaneous responses and the numbers of cues given (i.e. semantic or phonemic; Strauss, 2006). With regards to racial differences, Black participants have been shown to score lower than Whites on the BNT particularly due to differences in educational attainment (Manly et al., 2002), cultural appropriateness of test items (McCaffey et al., 2010; Whitfield et al., 2000) and test construct validity concerns with racial groups (Pedraza et al., 2010).

Internal consistency for the BNT-2 ranges from .78 to .96 (Graves et al., 2004; Fastenau et al., 1998; Franzen et al., 1995; Saxton et al., 2000). Test-retest reliability varies depending on the length of time between administrations. An interval of 1-2 weeks showed higher reliability (r = .91) compared to longer intervals of 1 year which had reliability coefficients of .62 to .89 among samples of healthy adults (Flanagan & Jackson, 1997; Mitrushina & Satz, 1995). Practice effects seem to be more modest, with one study using 55 normal adults reporting a coefficient of .92 after an average interval of 11 months (Dikemen et al., 1999).

Controlled Oral Word Association Test (COWAT)

The COWAT is a measure of lexical and semantic fluency (Benton, 1969). In order to measure phonemic fluency, the individual names as many words that begin with a particular letter (F-A-S) within 60-seconds and given restrictions from using proper nouns or variations of the same word (Lezak, 2004). For the semantic fluency component, the category used was animals, with the participant asked to produce as many animal names they can within 60-seconds. Errors are reviewed carefully as the type of error (perseverative, set loss errors or intrusions) can be important for differential diagnoses. Within the 60-second time limit the number of words in each 15-second block to determine difficulties with task initiation or whether they recall the majority of their responses towards the beginning or towards the end (Delis et al., 2001). This test is considered a good measure of receptive and expressive vocabulary as well as executive function (Schinka et al., 2010; Hedden & Yoon, 2006). Research has shown that a decline in verbal expression is a reliable predictor of long-term outcomes of cognitive decline (Oulhaj et al, 2009). In TBI patients, there is a significant deficit in phonemic and semantic fluency that appears to go beyond variations in education, processing speed, verbal IQ, and premorbid functioning (Henry & Crawford, 2004; Kave et al., 2011). Additionally, racial differences are noted in performance on fluency measures, with older Black adults scoring lower than non-Hispanic/Latinx individuals (Manly et al, 1998). These differences are still evident in semantic fluency even after controlling for educational achievement, likely due to the cultural variability in the way information is categorized (Manly et al., 1998). Test-retest reliability has varied depending on testing interval and age but has found to be adequate for both phonemic and semantic fluency (*r*=.74 to .77; Dikmen et al., 1999; Strauss et al., 2006). Internal consistency for phonemic fluency is generally high (*r*=.83; Tombaugh et al., 1999).

Boston Diagnostic Aphasia Exam – Complex Ideational Material.

The Complex Ideational Material (CIM) subtest from the Boston Diagnostic Aphasia Exam (BDAE-3) is a measure of auditory comprehension and receptive language (Spreen & Risser, 2003). This subtest requires the participant to listen, understand and express agreement or disagreement concerning factual material that does not relate to a stimulus immediately in view. Starting with simple facts (e.g. “will a cork sink in water?” or “will a stone sink in water”), then increasing in difficulty with demand for reference to knowledge or inferences beyond the mere recall of the words. Thus, there is an intellectual component that, does not go beyond average adult ability, even in the most difficult items. The long-form (12 item) version was utilized for this battery.

Scoring is obtained from Heaton Norms (Heaton et al., 2004) for individuals aged 20 to 85 years. Unlike other measures of language, little variation in performance based on racial identity and socioeconomic status have been found for most expressive subtests on the BDAE-3, which has been liken to the structure and nature of these subtest (Molrine & Pierce, 2002; Strauss et al.2006). However, acculturation differences have been noted between English and Spanish-speaking older adults particularly on an abbreviated version of the CIM, with Spanish speakers scoring lower (Strauss et al., 2006). On a whole, the BDAE has acceptable to high internal reliability but there is variability amongst the subtests (Goodglass et al., 2001). There are no stability coefficients presented in the manual as the authors state that the degree of variability among the aphasia population is too great on repeated testing (Strauss et al., 2006).

Scoring

All measures listed above were stratified by some component or combination of age, gender, racial identity and education Some measures were scored using the revised normative data for the expanded Halstead-Reitan Battery (HRB) compiled by Heaton and colleagues (Heaton et al., 2004). Norms from the HRB are classified across gender (i.e. male and female), age (range from 20-85 years old), education (range from 7-21 years) and racial group (i.e. White or Black). Clinicians have argued that neuropsychological impairment using limited normative standards greatly overestimated impairments in minority group and have developed demographically corrected normative data that have allowed for more comparable rates of impairment amongst racial groups, though this is not without its issues[6] (Norman et al., 2011), All scores were converted to T-scores ($t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$; M=50, SD=10), please see Table 3-2 for mean performance across measures.

[6] For more information on using race specific norms, please refer to Manly's (2007) Advantages and disadvantages of separate norms for African Americans. *The Clinical Neuropsychologist, 19*(2), 270-275.

Table 3- 2. Mean Performance for Entire Sample Across the Individual Measures

Characteristic	N	Mean T-scores (SD)
WAIS4 Digit Span	143	44.29 (10.89)
WAIS4 Arithmetic	143	42.44 (9.97)
WAIS4 Letter Number Sequencing	137	44.45 (8.24)
WAIS4 Symbol Search	143	42.02 (11.92)
WAIS4 Coding	143	40.59 (9.75)
WAIS4 Cancellation	137	42.15 (11.25)
WMS Logical Memory I	143	38.47 (10.38)
WMS Logical Memory II	143	37.73 (9.71)
WMS Verbal Paired Associates I	143	40.97 (8.53)
WMS Verbal Paired Associates II	143	41.37 (9.11)
WMS Visual Reproduction I	143	42.63 (10.95)
WMS Visual Reproduction II	143	46.55 (9.71)
WAIS4 Block Design	143	43.49 (8.93)
WAIS4 Matrix Reasoning	143	46.45 (11.33)
WAIS4 Visual Puzzles	143	44.30 (9.97)
Boston Naming Test	142	36.72 (9.92)
Category-Animals	143	39.43 (12.80)
BDAE Complex Ideational	142	31.87 (17.29)
Verbal Fluency (FAS)	143	42.83 (11.44)
WAIS4 Similarities	143	45.52 (9.30)
Trails B	143	43.73 (10.88)
Category Test	143	40.15 (10.45)

Impairment criteria

As outlined in the NFL settlement, each subtest was characterized across five cognitive domains: complex attention/processing speed (e.g. digit span, arithmetic, coding, symbol search, letter-number sequencing, and cancellation); learning and memory (e.g. logical memory, verbal paired associates, and visual reproduction-immediate and delayed); visuospatial (e.g. block design, matrix reasoning, visual puzzles); language (e.g. semantic fluency (animals), Boston naming test, complex ideational); and executive functioning (e.g. phonemic fluency (FAS), trails B, similarities, category). Test measures that correspond to each domain can be seen in Table 3-3. An overall domain level of impairment criteria was set for each domain. There were four levels of impairment: no impairment, level 1, level 1.5 and level 2, based on the number of T-scores within or below 1-2 standard deviations below the norm.

Table 3- 3.Overall Level of Impairment Criteria for Cognitive Domains

Complex Attention and Processing Speed	Learning and Memory	Visual-Perceptual	Language	Executive Functioning
Digit Span	Logical Memory I	Block Design	Boston Naming	Verbal Fluency (FAS)
Arithmetic	Logical Memory II	Matrix Reasoning	Category-Animals	Similarities
Letter Number Sequencing	Verbal Paired Associates I	Visual Puzzles	BDAE-CIM	Trails B
Symbol Search	Verbal Paired Associates II			Category Test
Coding	Visual Reproduction I			
Cancellation	Visual Reproduction II			

CHAPTER IV: RESULTS

The main objective of this study was to examine the cognitive performance of player position type and racial group of retired NFL athletes. All statistical analyses were conducted using the Statistical Package for the Social Sciences-Version 26 (SPSS-26). For every analysis that was run, statistical assumptions such as normality, outliers, linearity, homoscedasticity, and independence of residuals were assessed. Each of the study's four specific aims and their associated results are presented below:

Specific Aim 1: To Examine the Differences in Various Psychosocial Characteristics of Retired NFL Players Based on Position Played While in the NFL.

An important assumption of a chi-square test for independence is that the two variables are measured at a nominal level (i.e. categorical data) and that the two variables consist of two or more categorical, independent groups (Little, 2013). These assumptions were met for position played, education, and occupation. Given that other variables such a years played, age, and premorbid functioning violated the above assumption as they were measured on a scaled level, comparison of means analyses and or analyses of variances were run to determine whether there were significant differences among the participants based on position played and the previously stated variables.

Research Question 1a. When retired NFL athletes are grouped by playing position are there statistically significant differences in levels of education?

A chi-square test of independence was conducted between position played and level of education. Results shown in Table 4-1 were interpreted using a .05 level of significance. There was a statistically significant association between position played and level of education, $\chi 2(24) = 39.34$, $p = .025$. The association was moderately strong (Cohen, 1988), Cramer's V=.303.

Table 4- 1. Crosstabulation of Position Played and Education Level

	Education Level			
Position Played	Associates Degree	3-5 years of college, but no degree	Bachelor's Degree	Post-Bachelor's or master's degree
Quarter Back	1 (4.8)	1 (-.07)	4 (.05)	0 (-1.0)
Running Back	0 (-.04)	4 (-0.9)	13 (0.8)	3 (0.2)
Wide Receiver	0 (-0.4)	10 (1.6)	10 (-1.7)	4 (.4)
Tight End	0 (-0.2)	1 (-1.0)	5 (0.3)	2 (0.9)
Offensive Lineman	0 (-0.4)	3 (-1.3)	11 (0.1)	5 (1.7)
Defensive Lineman	0 (-0.4)	7 (0.7)	10 (0.7)	3 (0.2)
Linebacker	0 (0.4)	4 (-0.3)	11 (1.0)	1 (-0.9)
Defensive Back	0 (-0.5)	11 (1.4)	16 (0)	1 (-1.8)
Special Teams	0 (-0.1)	0 (-0.9)	1 (-0.2)	1 (1.5)

Note. Adjusted residuals appear in parentheses below observed frequencies

Research Question 1b. When retired NFL athletes are grouped by playing position are there statistically significant differences in mean age group?

A one-way analysis of variance (ANOVA) was conducted to determine if there was a statistically significant difference in age based on the various positions played in the NFL. Results, shown in Table 4-2, were interpreted using a .05 level of significance. There was homogeneity of variance, as assessed by Levene's test of homogeneity of variances (p=.276). Quarterbacks had the highest mean age (M=58.67, SD=12.19), followed by Offensive Linemen (M=53.00, SD=12.78), Running Backs (M=51.10, SD= 9.63), Defensive Linemen (M = 51.05; SD=10.18), Special Teams (M=50.50, SD=2.12), Linebackers (M=48.25, SD= 9.43), Wide Receivers (M=47.54, SD= 8.62), Tight Ends (M=47.50, SD=15.76), and Defensive Back with the lowest mean age (M=42.71, SD= 8.02). Age was statistically significant between different positions played, $F(8,134)$ =2.67, p= .009.

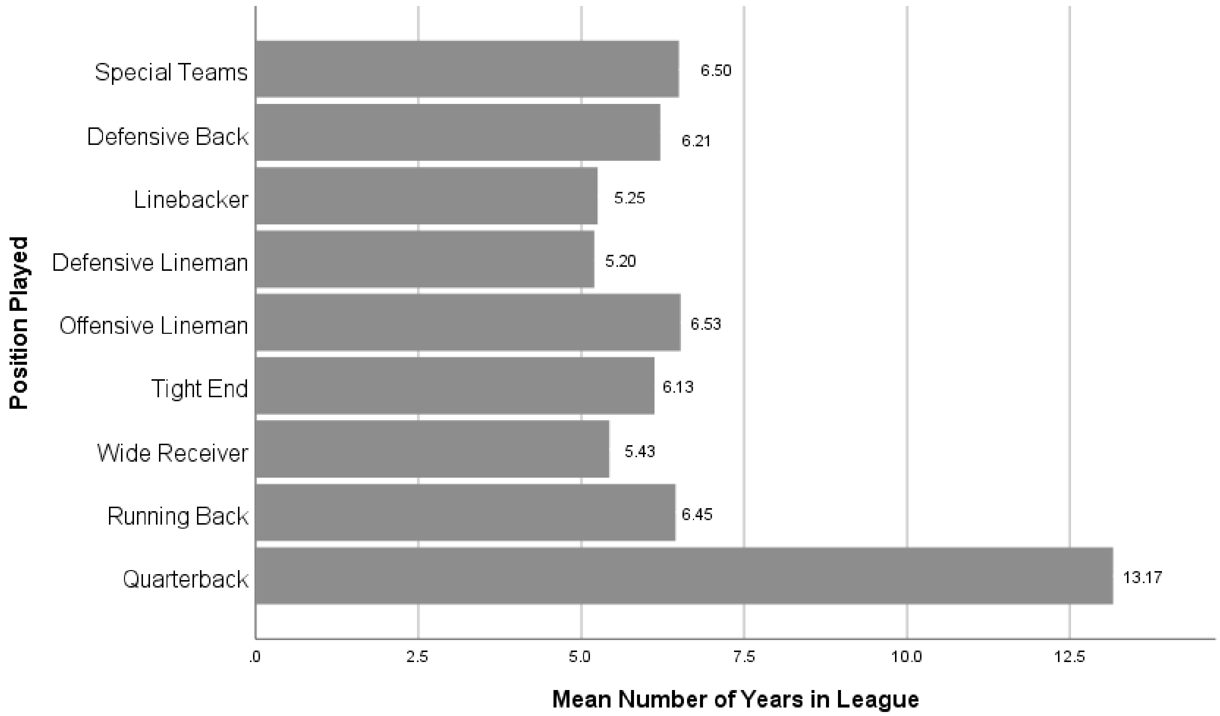
Table 4- 2. ANOVA Summary Table for Position Played and Age

	SS	*df*	MS	F	p
Between Groups	2224.171	8	278.021	2.673	.009
Within Groups	13935.256	134	103.994		
Total	16159.427	142			

Research Question 1c. When retired NFL athletes are grouped by playing position are there statistically significant differences in number of years played in the NFL?

A one-way Welch ANOVA was conducted to determine if the number of years played in the NFL was different for the various positions. There were no outliers, as assessed by boxplot; data was normally distributed for each group. There was heterogeneity of variances, as assessed by Levene's test of homogeneity of variances (p=.049). For the overall sample, the average number of years played at the professional level was 6.20. Years played based on player position type, shown in Figure 4-1, were: Quarterbacks (M=13.17, SD=7.03), Offensive Linemen (M=6.53, SD=3.12), Special Teams (M=6.50, SD=2.12), Running Backs (M=6.45, SD= 2.93), Defensive Back (M=6.21, SD= 3.60), Tight Ends (M=6.13, SD=3.00), Wide Receivers (M=5.43, SD= 3.33), Linebackers (M=5.25, SD=2.91), and Defensive Linemen (M = 5.20; SD=2.59) in that order, but the differences between these position groups was not statistically significant, Welch's $F(8, 17.916) = 1.093$, $p = .412$.

Figure 4- 1. Average Playing Career Length in the NFL based on Position Played



Research Question 1d. When retired NFL athletes are grouped by playing position are there statistically significant differences in racial identity?

A chi-square test of independence was conducted between position played and racial identity. Results shown in Table 4-3 revealed a statistically significant association between position played and racial identity, $\chi 2(8) = 50.071$, $p = .000$. The association was large (Cohen, 1988), Cramer's V=.592.

Table 4- 3. Crosstabulation of Position Played and Racial Identity.

Position Played	Racial Identity: White	Racial Identity: Black
Quarter Back	5 (3.4)	1 (-3.4)
Running Back	1 (-2.2)	19 (2.2)
Wide Receiver	3 (-1.5)	21 (1.5)
Tight End	2 (0)	6 (0)
Offensive Lineman	13 (4.8)	6 (-4.8)
Defensive Lineman	4 (-0.5)	16 (0.5)
Linebacker	1 (0.1)	12 (-0.1)
Defensive Back	1 (-2.9)	27 (2.9)
Special Teams	2 (2.5)	0 (-2.5)

Note. Adjusted residuals appear in parentheses below observed frequencies

Research Question 1e. When retired NFL athletes are grouped by playing position are there statistically significant differences in premorbid levels of functioning?

A Kruskal-Wallis H test was run to determine if there were differences in the test of premorbid functioning (wordlist) scores between the different positions. Distributions of TOPF scores were not similar for all groups, as assessed by visual inspection of a boxplot. The distributions of TOPF scores were statistically significantly between groups, $\chi2(8) = 18.806$, $p = .016$. Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values were used to determine significance with a criterion significance level at .05. The post hoc analysis did not reveal any statistically significant differences in TOPF scores among the position played group after using this adjustment. Means and standard deviations of positioned played and TOPF can be found in Table 4-4.

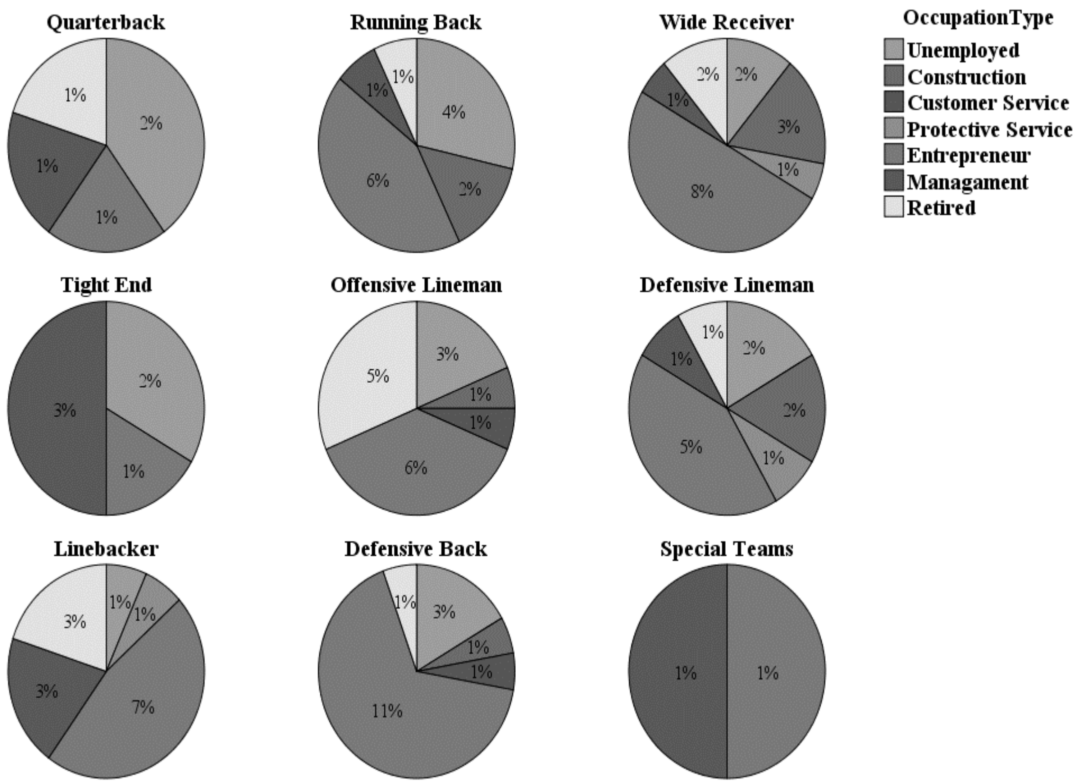
Table 4- 4. Means and Standard Deviations of Position Played and TOPF.

Position Played	N	M (SD)
Quarter Back	6	48.83 (8.89)
Running Back	20	46.20 (6.88)
Wide Receiver	24	42.71 (7.09)
Tight End	8	41.00 (5.73)
Offensive Lineman	19	43.95 (7.83)
Defensive Lineman	20	43.4 (8.64)
Defensive Back	27	44.93 (8.04)
Special Teams	2	56.5 (0.71)

Research Question 1f. When retired NFL athletes are grouped by playing position are there statistically significant differences in occupation type after retiring from the NFL?

A chi-square test of independence was conducted between position played and occupation which was broken down into several categories, shown in Figure 4-2: Unemployed, Construction, Customer service, Protective Service, Entrepreneur, Management occupations, Administrative, and Retired. 37 participants did not provided responses to this question. There was no statistically significant association between position played and occupation, $\chi 2(48) = 48.199$, $p = .465$. The association was small (Cohen, 1988), Cramer's V=.275.

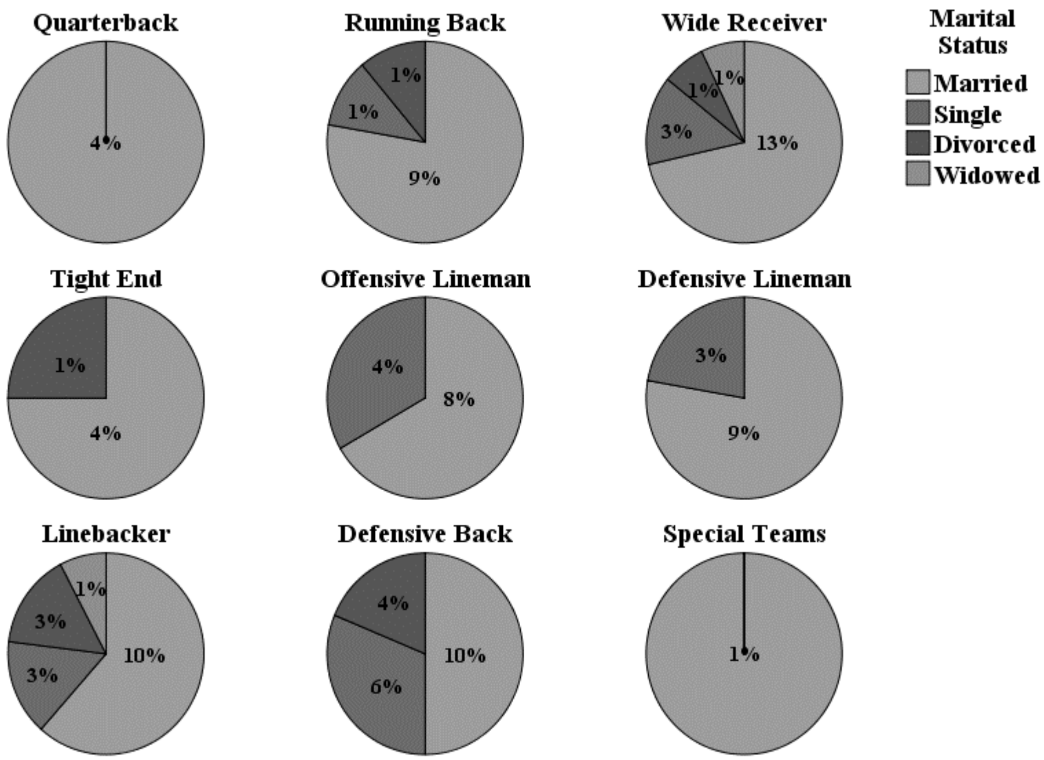
Figure 4- 2. Careers after NFL retirement based on Position Played.



Research Question 1g. When retired NFL athletes are grouped by playing position are there statistically significant differences in marital status?

A chi-square test of independence was conducted between position played and marital status, which was broken down into married, single, divorced, and widowed, shown in Figure 4-3. 65 participants did not provide responses to this question. There were no statistically significant association between position played and occupation, $\chi2(24) = 14.541$, $p = .933$. The association was small (Cohen, 1988), Cramer's V=.249.

Figure 4- 3. Marital Status based on Position Played



Specific Aim 2: Explore Whether Position Played in the NFL Determines Levels of Cognitive Impairment Across the Domains of Complex Attention/Processing Speed, Learning and Memory, Language, Visuo-spatial and Executive Function after Controlling for Covariates.

Assumption analyses were run for each analysis type and included boxplots of all dependent variables to assess for outliers. For each dependent variable there was homogeneity of variances, as assessed by Levene's test for equality of variances.

Research Question 2a. After controlling for covariates, are there differences on complex attention and processing speed measures by former NFL playing position?

A multivariate analysis of covariance (MANCOVA) was run to determine the effect of position played across the six measures of complex attention and processing speed (i.e. digit span, arithmetic, coding, symbol search, letter-number sequencing, and cancellation). Means and adjusted means were not very dissimilar (see Table 4-5) and scores showed a general trend to be lower for offensive and defensive linemen. There was homogeneity of regression slopes, as assessed by the interaction between position played and the following covariates: age, education, racial identity, and premorbid level of functioning. There was homogeneity of covariances as assessed by Box's M test, $p > .05$. The one way MANCOVA showed that there was no statistically significant difference among player position on the combined dependent variables after controlling for the covariates, $F(48, 574.83) = .928$, $p = .613$, Wilk's $\Lambda = .693$, partial $\eta 2 = .059$.

On the overall measure of complex attention and processing speed level of impairment, participants were classified into four impairment criteria levels: No impairment (N=97), Level 1 Impairment (N=7), Level 1.5 impairment (N=14), and Level

2 impairment (N=25). A chi-square test of independence showed that there was not a statistically significant association between position played and overall impairment level on measures of complex attention and processing speed, $\chi 2(24) = 26.061$, $p = .350$. Means and standard deviations of positioned played and overall LOI for complex attention/processing speed can be found in Table 4-6.

Table 4- 5. Means, Adjusted Means, Standard Deviations and Standard Errors for Each Playing Position for Complex Attention/Processing Speed Variables.

	Complex Attention and Processing Speed Measures											
	Digit Span		Arithmetic		LN		SS		CD		CN	
Position Played	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)
Quarterback	44.00 (12.00)	39.48 (5.13)	44.60 (12.48)	38.39 (4.45)	46.00 (11.79)	46.32 (3.92)	48.00 (16.11)	43.47 (5.43)	38.00 (10.46)	35.69 (4.46)	42.80 (14.81)	38.29 (5.17)
Running Back	45.84 (8.66)	46.89 (2.55)	41.84 (7.11)	43.50 (2.21)	45.26 (4.24)	43.92 (1.95)	44.84 (9.41)	46.50 (2.70)	43.37 (8.47)	44.60 (2.22)	48.00 (10.83)	49.73 (2.57)
Wide Receiver	42.14 (8.95)	43.07 (2.38)	40.62 (9.82)	42.05 (2.06)	43.24 (7.17)	42.56 (1.81)	38.67 (13.65)	39.75 (2.51)	39.90 (10.78)	40.57 (2.07)	39.95 (8.69)	41.02 (2.40)
Tight End	44.86 (14.67)	45.51 (4.11)	45.00 (8.45)	45.90 (3.56)	42.29 (7.27)	40.85 (3.14)	48.00 (20.93)	48.10 (4.35)	44.57 (11.43)	44.13 (3.57)	43.71 (15.47)	43.90 (4.14)
Offensive Linemen	44.88 (11.84)	41.05 (2.87)	43.94 (10.16)	38.94 (2.49)	43.59 (8.88)	43.22 (2.19)	42.53 (8.70)	38.08 (3.03)	38.47 (8.83)	35.32 (2.49)	41.29 (7.75)	37.37 (2.89)
Defensive Linemen	41.42 (12.50)	41.97 (2.57)	40.32 (11.61)	40.45 (2.23)	42.68 (7.59)	47.55 (1.96)	35.52 (9.70)	36.29 (2.72)	36.26 (9.47)	37.05 (2.24)	38.00 (12.36)	38.53 (2.60)
Linebacker	44.50 (8.88)	44.32 (2.69)	44.06 (8.74)	43.81 (2.33)	47.69 (9.50)	45.16 (2.05)	44.44 (9.86)	44.29 (2.85)	42.63 (9.58)	42.60 (2.34)	45.56 (11.00)	45.39 (2.71)
Defensive Back	43.86 (12.23)	45.64 (2.16)	40.54 (11.15)	42.99 (1.87)	44.14 (10.24)	43.13 (1.65)	40.43 (12.28)	42.17 (2.29)	39.36 (9.81)	40.42 (1.88)	40.14 (12.26)	41.60 (2.18)
Special Teams	41.5 (12.02)	34.73 (7.96)	48.5 (12.02)	39.00 (6.90)	48.00 (7.07)	46.32 (6.07)	43.00 (0)	34.25 (8.42)	45.00 (7.07)	38.22 (6.92)	42.00 (7.07)	34.40 (8.02)

Table 4- 6. Crosstabulation of Position Played and Overall LOI for Complex Attention/Processing Speed Overall

Position Played	Complex Attention/Processing Speed Overall LOI			
	No Impairment	Level 1 Impairment	Level 1.5 Impairment	Level 2 Impairment
Quarter Back	5 (0.8)	0 (-0.6)	0 (-0.8)	1 (-0.1)
Running Back	15 (0.7)	2 (1.1)	3 (-0.8)	0 (-2.2)
Wide Receiver	17 (0.3)	1 (-0.2)	2 (-0.3)	4 (-0.1)
Tight End	6 (0.4)	0 (-0.7)	0 (-1.0)	2 (-0.6)
Offensive Lineman	13 (0.1)	0 (-1.1)	4 (1.8)	2 (-0.9)
Defensive Lineman	10 (-1.8)	0 (-1.1)	4 (1.7)	6 (1.6)
Linebacker	12 (0.7)	2 (1.5)	0 (-1.4)	2 (-0.6)
Defensive Back	17 (-0.9)	2 (0.6)	1 (-1.2)	8 (1.7)
Special Teams	2 (1.0)	0 (-0.3)	0 (-0.5)	0 (-0.7)

Research Question 2b. After controlling for covariates, are there differences on learning and memory measures by former NFL playing position?

A multivariate analysis of covariance (MANCOVA) was run to determine the effect of position played on six measures of learning and memory (i.e. LMI, LMII, VPAI, VPAII, VRI, VRII). Means and adjusted means were not very dissimilar (see Table 4-7). There was homogeneity of regression slopes, as assessed by the interaction between position played and the following covariates: age, education, racial identity, and premorbid level of functioning. The one way MANCOVA showed that there was no statistically significant difference among player position on the combined dependent variables after controlling for the covariates, $F(48, 604.35)=.687$, $p = .947$, Wilk's $\Lambda =$ .770, partial $\eta 2 = .043$.

On the overall measure of learning and memory level of impairment, participants were classified into four impairment criteria levels: No impairment (N=97), Level 1 Impairment (N=11), Level 1.5 impairment (N=11), and Level 2 impairment (N=24). A chi-square test of independence showed that there was not a statistically significant association between position played and measures of learning and memory, $\chi 2(24) =21.38$, p =.616. Means and standard deviations of positioned played and overall LOI for learning and memory can be found in Table 4-8.

Table 4- 7. Means, Adjusted Means, Standard Deviations and Standard Errors for Each Playing Position for Each Learning and Memory Variable.

	Learning and Memory Measures											
	LM I		LMII		VPA I		VPA II		VR I		VR II	
Position Played	M *(SD)*	M_{adj} (SE)	M *(SD)*	M_{adj} (SE)	M *(SD)*	M_{adj} (SE)	M *(SD)*	M_{adj} (SE)	M *(SD)*	M_{adj} (SE)	M *(SD)*	M_{adj} (SE)
Quarterback	38.83 (17.30)	35.51 (4.60)	36.17 (9.56)	31.84 (4.23)	39.33 5.54)	37.07 (3.68)	40.67 (6.25)	38.52 (3.97)	45.00 (4.65)	41.01 (4.81)	49.00 (2.45)	48.40 (4.42)
Running Back	39.60 (9.18)	41.05 (2.42)	39.45 (9.21)	41.19 (2.22)	42.20 (6.60)	42.65 (1.94)	40.5 (5.97)	41.07 (2.08)	43.65 (10.40)	45.35 (2.53)	46.90 (7.56)	47.48 (2.33)
Wide Receiver	36.45 (8.43)	37.30 (2.26)	36.36 (6.90)	37.56 (2.08)	40.00 (6.97)	40.38 (1.81)	42.05 (10.41)	42.55 (1.95)	43.41 (10.49)	44.58 (2.37)	47.68 (10.41)	47.87 (2.18)
Tight End	40.00 (12.17)	39.75 (3.71)	31.13 (9.09)	36.74 (3.41)	43.6 (5.01)	43.44 (2.97)	42.75 (5.09)	43.58 (3.20)	45.13 (10.38)	44.88 (3.88)	48.50 (11.80)	48.32 (3.57)
Offensive Linemen	40.26 (10.31)	37.32 (2.67)	39.79 (12.00)	35.88 (2.45)	43.42 (11.82)	41.37 (2.13)	41.53 (8.70)	39.62 (2.30)	42.32 (9.84)	38.95 (2.79)	45.68 (8.85)	44.87 (2.57)
Defensive Linemen	38.53 (10.86)	39.37 (2.28)	36.89 (10.32)	37.69 (2.28)	7.96) (7.59)	39.55 (1.98)	39.58 (9.25)	40.01 (2.14)	41.58 (11.84)	41.96 (2.59)	45.42 (10.80)	45.92 (2.38)
Linebacker	38.56 (8.73)	38.47 (2.61)	38.38 (9.80)	38.32 (2.40)	40.94 (8.32)	40.97 (2.08)	42.38 (8.97)	42.40 (2.25)	43.06 (13.57)	42.98 (2.73	44.69 (9.90)	44.63 (2.51)
Defensive Back	36.42 (11.77)	37.36 (2.10)	36.25 (11.11)	37.76 (1.93)	38.89 (9.57)	39.79 (1.68)	39.39 (9.17)	40.30 (1.81)	39.68 (11.68)	41.00 (2.20)	45.79 (11.17)	45.77 (2.02)
Special Teams	42.00 (7.07)	36.88 (7.69)	37.00 (0)	30.06 (7.06)	43.00 (0)	40.32 (6.15)	48.00 (7.07)	45.02 (6.63)	43.00 (14.12)	36.70 (8.04)	50.00 (14.14)	48.34 (7.40)

Table 4- 8. Crosstabulation of Position Played and Learning and Memory.

Position Played	Learning and Memory Overall LOI: No Impairment	Level 1 Impairment	Level 1.5 Impairment	Level 2 Impairment
Quarter Back	3 (-1.0)	2 (2.4)	0 (-0.7)	1 (0)
Running Back	16 (1.3)	1 (-0.5)	2 (0.4)	1 (-1.5)
Wide Receiver	17 (0.3)	2 (0.1)	2 (0.1)	3 (-0.6)
Tight End	7 (1.2)	0 (-0.8)	0 (-0.8)	1 (-0.3)
Offensive Lineman	11 (-1.0)	1 (-0.4)	3 (1.4)	4 (0.5)
Defensive Lineman	14 (0.2)	2 (0.4)	0 (-1.4)	4 (0.4)
Linebacker	10 (-0.5)	1 (-0.2)	3 (1.8)	2 (-0.5)
Defensive Back	17 (-0.9)	2 (-0.1)	1 (-0.9)	8 (1.9)
Special Teams	2 (1.0)	0 (-0.4)	0 (-0.4)	0 (-0.6)

Research Question 2c. After controlling for covariates, are there differences on visuo-spatial measures by former NFL playing position?

A multivariate analysis of covariance (MANCOVA) was run to determine the effect of position played on three measures of visual spatial (i.e. block design, matrix reasoning, visual puzzles). Means and adjusted means were not very dissimilar as shown in Table 4-9. There was homogeneity of regression slopes, as assessed by the interaction between position played and the following covariates: age, education, racial identity, and premorbid level of functioning. The one way MANCOVA showed that there was no statistically significant difference among player position on the combined dependent variables after controlling for the covariates, $F(24, 366.04)=.855$, $p = .665$, Wilk's $\Lambda = .854$, partial $\eta 2 = .051$.

On the overall measure of visual perceptual level of impairment, participants were classified into four impairment criteria levels: No impairment (N=121), Level 1 Impairment (N=2), Level 1.5 impairment (N=1), and Level 2 impairment (N=19). A chi-square test of independence showed that there was not a statistically significant association between position played and measures of visual spatial, $\chi 2(24) =22.509$ p =.549.

Table 4- 9. Means, Adjusted Means, Standard Deviations and Standard Errors for Each Playing Position for Each Visual Perceptual Variable.

	Visual Perceptual Measures					
	Block Design		Matrix Reasoning		Visual Puzzles	
Position Played	*M(SD)*	M_{adj} (SE)	*M (SD)*	M_{adj} (SE)	*M (SD)*	M_{adj} (SE)
Quarterback	46.67 (9.48)	45.11 (3.59)	45.00 (9.02)	43.80 (4.77)	45.50 (9.85)	43.93 (4.26)
Running Back	46.05 (8.51)	46.24 (1.91)	47.15 (7.30)	47.39 (2.53)	44.00 (7.04)	44.52 (2.26)
Wide Receiver	42.00 (9.13)	42.27 (1.80)	43.41 (12.15)	43.64 (2.39)	44.18 (9.54)	44.29 (2.13)
Tight End	44.50 (8.57)	44.03 (3.00)	47.75 (16.61)	47.22 (3.98)	46.75 (13.99)	46.61 (3.56)
Offensive Linemen	46.79 (7.06)	44.70 (2.04)	51.79 (12.20)	49.84 (2.71)	47.68 (10.07)	46.16 (2.42)
Defensive Linemen	39.68 (10.64)	40.75 (2.00)	46.89 (14.05)	48.00 (2.66)	42.89 (10.05)	44.20 (2.37)
Linebacker	44.69 (8.65)	44.81 (2.11)	45.00 (10.83)	45.10 (2.80)	45.31 (13.72)	45.27 (2.50)
Defensive Back	40.39 (7.85)	41.35 (1.67)	43.57 (9.07)	44.34 (2.21)	41.21 (8.73)	41.44 (1.98)
Special Teams	58.00 (7.07)	55.21 (6.04)	55.00 (7.07)	52.25 (8.01)	53.50 (9.19)	51.79 (7.15)

Research Question 2d. After controlling for covariates, are there differences on executive functioning measures by former NFL playing position?

A multivariate analysis of covariance (MANCOVA) was run to determine the effect of position played on four measures of executive functioning (i.e. verbal fluency, similarities, trails B, category). Means and adjusted means, as shown in Table 4-10, were not very dissimilar. There was homogeneity of regression slopes, as assessed by the interaction between position played and the following covariates: age, education, racial identity, and premorbid level of functioning. The one way MANCOVA showed that there was no statistically significant difference among player position on the combined dependent variables after controlling for the covariates, $F(32, 462.572)=.878$, $p = .662$, Wilk's $\Lambda = .805$, partial $\eta 2 = .053$.

On the overall measure of executive functioning level of impairment, participants were classified into four impairment criteria levels: No impairment (N=106), Level 1 Impairment (N=17), Level 1.5 impairment (N=6), and Level 2 impairment (N=14). A chi-square test of independence showed that there was not a statistically significant association between position played and measures of executive functioning, $\chi 2(24) =15.017$ $p =.920$.

Table 4- 10. Means, Adjusted Means, Standard Deviations and Standard Errors for Each Playing Position for Each Executive Functioning Variable.

	Executive Functioning Measures							
	Verbal Fluency		Similarities		Trails B		Category	
Position Played	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)	*M* *(SD)*	M_{adj} (SE)
Quarterback	44.83 (8.47)	46.71 (4.88)	42.83 (8.21)	41.77 (3.85)	45.67 (11.34)	44.92 (4.63)	47.33 (7.97)	47.41 (4.54)
Running Back	45.65 (9.13)	46.01 (2.59)	47.35 (8.80)	47.54 (2.04)	47.25 (10.87)	47.69 (2.46)	40.45 (9.14)	40.43 (2.41)
Wide Receiver	41.82 (10.48)	41.63 (2.45)	43.41 (7.73)	43.63 (1.93)	43.77 (12.87)	43.66 (2.32)	41.95 (9.34)	41.93 (2.28)
Tight End	40.50 (16.79)	39.96 (4.08)	45.00 (11.65)	44.47 (3.21)	47.00 (12.00)	47.40 (3.87)	39.75 (7.25)	39.82 (3.79)
Offensive Linemen	42.74 (12.40)	43.02 (2.78)	49.16 (10.88)	47.32 (2.19)	39.68 (10.83)	39.82 (2.63)	38.95 (10.35)	39.15 (2.58)
Defensive Linemen	37.58 (10.02)	38.17 (2.72)	41.37 (10.99)	42.37 (2.14)	38.89 (11.41)	39.44 (2.58)	36.00 (12.70)	35.89 (2.53)
Linebacker	42.56 (13.91)	42.51 (2.87)	46.69 (6.74)	46.80 (2.26)	46.25 (8.98)	46.07 (2.72)	40.31 (9.08)	40.30 (2.67)
Defensive Back	45.07 (11.36)	44.20 (2.27)	44.86 (8.70)	45.62 (1.79)	45.21 (9.13)	44.62 (2.15)	40.11 (12.69)	40.03 (2.11)
Special Teams	47.00 (11.31)	46.39 (8.21)	50.00 (4.24)	47.35 (6.47)	39.00 (9.90)	39.78 (7.78)	45.50 (0.71)	45.81 (7.63)

Research Question 2e. After controlling for covariates, are there differences on language measures by former NFL playing position?

A multivariate analysis of covariance was run to determine the effect of position played on three measures of language (i.e. BNT, Semantic Fluency, BDAE-CIM). Means and adjusted means were not very dissimilar, as shown in Table 4-11. There was homogeneity of regression slopes, as assessed by the interaction between position played and the following covariates: age, education, racial identity, and premorbid level of functioning. The one way MANCOVA showed that there was no statistically significant difference among player position on the combined dependent variables after controlling for the covariates, $F(24, 363.139)=.979$, $p = .494$, Wilk's $\Lambda = .834$, partial $\eta 2 = .059$.

On the overall measure of language level of impairment, participants were classified into four impairment criteria levels: No impairment (N=76), Level 1 Impairment (N=5), Level 1.5 impairment (N=4), and Level 2 impairment (N=58). A chi-square test of independence showed that there was not a statistically significant association between position played and measures of language, $\chi 2(24) =123.754$ p =.476

Table 4- 11. Means, Adjusted Means, Standard Deviations and Standard Errors for Each Playing Position for Each Language Variable.

	Language Measures					
	BNT		Semantic Fluency		BDAE-CIM	
Position Played	*M(SD)*	M_{adj} (SE)	*M (SD)*	M_{adj} (SE)	*M (SD)*	M_{adj} (SE)
Quarterback	43.00 (11.52)	42.37 (4.20)	44.33 (9.20)	44,52 (5.57)	34.33 (20.75)	31.44 (7.51)
Running Back	37.85 (8.82)	37.30 (2.23)	44.25 (10.81)	44.13 (2.96)	28.65 (16.47)	28.90 (3.98)
Wide Receiver	32.27 (9.81)	34.48 (2.11)	36.50 (13.8)	36.49 (2.80)	31.27 (17.33)	31.36 (3.77)
Tight End	36.00 (11.96)	36.10 (3.51)	35.88 (10.36)	35.96 (4.66)	33.13 (19.37)	34.00 (6.27)
Offensive Linemen	41.16 (11.99)	40.97 (2.39)	36.89 (16.10)	37.22 (3.17)	33.47 (17.59)	32.97 (4.27)
Defensive Linemen	36.79 (8.98)	35.98 (2.34)	36.42 (14.79)	36.12 (3.10)	32.32 (16.95)	32.65 (4.18)
Linebacker	34.19 (7.67)	34.36 (2.47)	40.88 (10.16)	40.88 (3.27)	32.13 (16.81)	34.98 (4.41)
Defensive Back	34.52 (10.04)	35.47 (1.99)	40.70 (12.68)	40.68 (2.64)	28.04 (18.45)	28.30 (3.55)
Special Teams	38.00 (1.41)	37.98 (7.06)	39.50 (3.53)	39.95 (9.37)	49.50 (7.79)	50.30 (12.62)

Specific Aim 3: To Examine Whether Racial Identity Determines Level of Cognitive Performance Within a Retired NFL Population after Controlling for Covariates.

Before conducting the multivariate general linear models, the sample was evaluated to verify that all of the assumptions of a one-way multivariate analysis of covariance (MANCOVA) were met. This includes linearity, homogeneity of regression slopes, homogeneity of covariances, as assessed by Box's M test, univariate or multivariate outliers, as assessed by no standardized residuals greater than ± 3 or Mahalanobis distance values greater than a specific cut-off point (p > .001), respectively, outliers and normal distribution. Assumptions were satisfied.

Research Question 3. After controlling for covariates, are there differences across multiple cognitive domains based on racial identity/group?

Five separate multivariate General Linear Models were performed to examine the racial identity differences on neurocognitive variables. All analyses controlled for age, education, and premorbid level of functioning. As shown in Table 4-12, there were several statistically significant differences in cognitive performance based on racial identity.

On the combined measures of complex attention/processing speed, there was a statistically significant difference between the racial identity groups, $F(6, 126)=3.240$, $p = .005$, Wilk's $\Lambda = .866$, partial $\eta 2 = .134$. Follow-up univariate one-way ANOCOVAs were performed. A Bonferroni adjustment was made such that statistical significance was accepted when $p<.0083$. There were statistically significant differences in adjusted means for WAIS-IV Arithmetic T-scores ($F(1, 131)=14.83$, $p =<.001$, partial $\eta 2 = .102$), but not for digit span ($F(1, 131)=2.54$, $p = .113$, partial $\eta 2 = .018$), LN sequencing (F(1, 131)=3.68, *p* =.057, partial η2 = .027), Symbol Search (*F*(1, 131)=7.09, *p* =.009, partial η2 = .051), Coding (*F*(1, 131)=2.23, *p* =138, partial η2 = .017), or cancellation (*F*(1, 131)=4.70, *p* =0.32, partial η2 = .035). Pairwise comparisons were run. Black former athletes had statistically significantly lower adjusted mean arithmetic scores compared to white former athletes, an adjusted mean difference of 7.38, 95% CI [3.59, 11.16].

On the combined measures of learning and memory, there was a statistically significant difference between the racial identity groups, *F*(6, 132)=2.17, *p* = .049, Wilk's Λ = .910, partial η2 = .090. Follow-up univariate one-way ANOCOVAs and a Bonferroni adjustment was made such that statistical significance was accepted when p<.0083. There were no statistically significant differences in adjusted means for the individual learning and memory tests.

On the combined measures of visual-spatial skills, there was a statistically significant difference between the racial identity groups, *F*(3, 135)=11.294, *p* < .001, Wilk's Λ = .799, partial η2 = .201. Follow-up univariate one-way ANOCOVAs were performed. A Bonferroni adjustment was made such that statistical significance was accepted when p<.0167. There were statistically significant differences in adjusted means for WAIS-IV block design T-scores (*F*(1, 137)=16.36, *p* =<.001, partial η2 = .107), and visual puzzles (*F*(1, 137)=28.87, *p* <.001, partial η2 = .174), but not for matrix reasoning (*F*(1, 137)=1.10, *p* =.297. Pairwise comparisons were run. Black former athletes had statistically significantly lower adjusted mean block design and visual puzzles scores compared to white former athletes, an adjusted mean difference of 6.92, 95% CI [3.53, 10.30] and 10.40, 95% CI [6.58, 14.23] respectively.

On the combined measures of language, there was no statistically significant difference between the racial identity groups, $F(3, 133)=1.20$, $p = .312$, Wilk's $\Lambda = .974$, partial $\eta 2 = .0.26$, Similarly on the combined measures of executive functioning, after controlling for age, education and premorbid functioning, there was no significant difference between black and white former athletes, $F(4, 134)=1.29$, $p = .276$, Wilk's $\Lambda = .963$, partial $\eta 2 = .0.37$. In terms of overall LOI based on stated classification system, only the visuo-spatial domain showed a significant association with racial identity, $\chi 2(3) = 8.04$, $p =.045$.

Table 4- 12. Pairwise Contrasts for Adjusted Mean Differences for all subtests for each racial group

	Racial Identity (White vs. Black former Athletes)	
Cognitive Measures	M_{adj} (SE)	95% Confidence Interval
Digit Span	3.53 (2.22)	[-0.85, 7.91]
Arithmetic	7.38 (1.92)$^{+}$	[3.59, 11.16]
Letter Number Sequencing	3.20 (1.67)	[-0.10, 6.50]
Symbol Search	6.67 (2.51)	[1.71, 11.63]
Coding	3.05 (2.04)	[-0.99, 7.08]
Cancellation	5.20 (2.40)	[0.45, 9.94]
Logical Memory I	4.51 (2.15)	[0.26, 8.76]
Logical Memory II	5.12 (2.01)	[1.15, 9.09]
Verbal Paired Associates I	1.29 (1.71)	[-2.15, 4.73]
Verbal Paired Associates II	2.31 (1.93)	[-1.50, 6.12]
Visual Reproduction I	5.54 (2.30)	[0.98, 10.09]
Visual Reproduction II	1.03 (2.07)	[-3.06, 5.11]
Block Design	6.92 (1.71)*	[3.54, 10.30]
Matrix Reasoning	2.43 (2.33)	[-2.17, 7.03]
Visual Puzzles	10.40 (1.94)*	[6.58, 14.23]

Note. *=statistically significant difference ($p<.0167$) and + ($p<0.0083$) based on Bonferroni adjustment, 95% confidence interval (CI) is simultaneous confidence interval based on Bonferroni adjustment, all scores are measured in T-scores (M=50, SD=10).

Specific Aim 4: To Determine if Racial Identity and Position Played in the NFL Serve as Better Predictors of Cognitive Performance Compared to Demographic Variables and Premorbid Functioning.

Before conducting the hierarchical multiple regressions included in specific aim 4, the sample was evaluated to verify that all of the assumptions of hierarchical multiple regression (i.e. independence of residuals as assessed by a Durbin-Watson statistic, linearity, homoscedasticity, multicollinearity, outliers, high leverage points or highly influential points) were satisfied and all assumptions were met.

Research Question 4a: How much variation in complex attention and processing speed is explained by racial identity and player position group?

Given the known impact of demographic and neuropsychiatric variables such as age, education, premorbid functioning, social relationships, contact-sport playing history, and comorbid psychiatric and neurological diagnosis on cognition, a hierarchical multiple regression was run to determine if the addition of racial identity and player position, when grouped by nonspeed positions (N=39) and speed positions (N=102)) using Lehman et al. (2012) classifications within a retired NFL population, improved the prediction of complex attention and processing speed averaged performance over and above characteristics (i.e. age, education, marital status, years played, premorbid functioning, diagnosis). See Table 4-13 for full details on each regression model. A criterion for significance of $p < .05$ was used. In the first model, demographic characteristics of age, education, marital status, years played, premorbid functioning, and neuropsychiatric diagnosis significantly contributed to the regression model, $F(6, 66)=3.873$, $p=.002$ and accounted for 26% of the variation in complex attention and processing speed performance. Introducing racial identity to the model explained an additional 4.3% of the variation and this change in R^2 was significant, $F(1, 65) = .4.023$, p =.049. Adding position group to the regression model explained an additional 5.9% of the variation in complex attention and processing speed scores and this change R^2 was also significant, $F(1, 64) = 5.878$, p=.018. The full model of age, education, marital status, years played, premorbid functioning, neuropsychiatric diagnosis, racial identity and position group to predict complex attention and processing speed performance (Model 3) was statistically significant, $R^2 = .362$, $F(8, 64) = 4.541$, $p < .001$, however age, education, years played and neuropsychiatric diagnosis did not significantly predict complex attention and processing speed scores. The most important predictor of this measure was TOPF, which uniquely explained 14.5% of the variance in complex attention and processing speed performance. Marital status accounted for 5.5%. Taken together the 8 individual variables accounted for 36.2% of the variance in complex attention and processing speed performance.

Table 4- 13. Hierarchical Multiple Regression Predicting Complex Attention and Processing Speed Performance from Age, Education, TOPF, Neuropsychiatric Diagnosis, Years Played in NFL, Marital Status, Racial Identity and Player Position Group.

	Complex Attention & Processing Speed					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	57.267**		74.298**		72.355**	
Age	.074	.070	.026	.025	.053	.051
Education	-2.411	-.199	-2.626	-.217	-2.642	-.218
Marital Status	-1.887	-.213	-1.876	-.212	-2.251**	-.254
Years Played	-.184	-.076	-.232	-.096	-.286	-.119
TOPF	.539***	.435	.481**	.389	.492***	.397
Diagnosis	-1.902	-.105	-1.425	-.079	-.902	-.050
Racial Identity			-4.869**	-.225	-6.644**	-.307
Position Group					5.604**	.264
R^2	0.260		0.304		0.362	
F	3.873**		4.047**		4.541***	
ΔR^2	0.260		0.043		0.059	
Δ F	3.873**		4.023**		5.878**	

Note. **p*<.05, ***p*<.001

Research Question 4b: How much variation in learning and memory performance is explained by player position and race?

A hierarchical multiple regression was run to determine if the addition of racial identity and then of player position within a retired NFL population improved the prediction of learning and memory averaged performance over and above demographic characteristics (i.e. age, education, marital status, years played, premorbid functioning, and diagnosis). See Table 4-14 for full details on each regression model. In the first model, demographic characteristics of age, education, marital status, years played, premorbid functioning, and neuropsychiatric diagnosis significantly contributed to the regression model, $F(6,69)=3.902$, p=.002 and accounted for 25.3% of the variation in learning and memory performance. Introducing racial identity explained an additional 6.9 % of the variation and this change in R^2 was significant, $F(1, 68) = 6.969$, $p =.010$. Adding position group to the regression model only explained an additional 0.1% of the variation in learning and memory scores and this change R^2 was not significant, $F(1, 67) = .119$, $p=.731$. The full model of age, education, marital status, years played, premorbid functioning, neuropsychiatric diagnosis, racial identity and position group to predict learning and memory performance (Model 3) was statistically significant, $R^2 = .324$, $F(8, 67) = 4.013$, $p=.001$, however age, education, marital status, neuropsychiatric diagnosis and player position group did not significantly predict learning and memory scores in the full model. The most important predictor of this measure was TOPF, which uniquely explained 8.9% of the variance in learning and memory performance, followed by number of years played in the league which explained 6.3% of the variance in learning and memory performance. Taken together the 8 individual variables accounted for 32.4% of the variance in learning and memory average performance.

Table 4- 14. Hierarchical Multiple Regression Predicting Learning and Memory Performance from Age, Education, TOPF, Neuropsychiatric Diagnosis, Years Played in NFL, Marital Status, Racial Identity and Player Position Group.

	Learning and Memory					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	38.304**		60.710**		61.030**	
Age	.178**	.229	.118	.152	.116	.150
Education	-1.263	-.131	-1.679	-.174	-1.681	-.175
Marital Status	-.278	-.028	-.219	.022	.265	.027
Years Played	-.513**	-.242	-.570**	-.270	-.565**	-.267
TOPF	.406**	.388	.338**	.323	.336**	.320
Diagnosis	-3.131	-.199	-2.683	-.170	-2.731	-.174
Racial Identity			-5.409**	-.295	-5.196**	-.283
Position Group					-.6971	-.038
R^2	0.253		0.323		0.324	
F	3.902**		4.629***		4.013***	
ΔR^2	0.253		0.069		0.001	
Δ F	3.902 **		6.969**		0.119	

Note. *p<.05, **p<.001

Research Question 4c: How much variation in visuo-spatial performance is explained by player position and race?

A hierarchical multiple regression was run to determine if the addition of racial identity and then of player position within a retired NFL population improved the prediction of visuo-spatial averaged performance over and above demographic (i.e. age, education, marital status, years played, premorbid functioning, and diagnosis). See Table 4-15 for full details on each regression model. In the first model, demographic characteristics of age, education, marital status, years played, premorbid functioning, and neuropsychiatric diagnosis significantly contributed to the regression model, $F(6,69)=4.122$, p=.001 and accounted for 26.4% of the variation in visuo-spatial performance. Introducing racial identity explained an additional 10.3% of the variation and this change in R^2 was significant, $F(1, 68) = 11.005$, $p = .001$. Adding position group to the regression model only accounted for an additional .5% of the variation in visuo-spatial scores and this change R^2 was not significant, $F(1, 67) = .558$, $p=.458$. While, the full model of age, education, marital status, years played, premorbid functioning, neuropsychiatric diagnosis, racial identity and position group to predict visuo-spatial performance (Model 3) was statistically significant, $R^2 = .372$, $F(8, 67) = 4.953$, $p<.001$, age, education, marital status, years played, neuropsychiatric diagnosis, and player position group did not significantly predict visuo-spatial scores in the full model. The most important predictor of this measure was TOPF which uniquely explained 12.5% of the variance in visuo-spatial performance, followed by racial identity which explained 10.3% of the variance. Taken together the 8 individual variables accounted for 37.2% of the variance in visuo-spatial performance.

Table 4- 15. Hierarchical Multiple Regression Predicting Visuo-spatial Performance from Age, Education, TOPF, Neuropsychiatric Diagnosis, Years Played in NFL, Marital Status, Racial Identity and Player Position Group.

	Visuo-spatial					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	36.104		68.126**		67.750**	
Age	.187	.197	.097	.102	.101	.106
Education	-1.394	-.119	-1.959	-.167	-1.983	-.169
Marital Status	-1.419	-.155	-1.341	-.146	-1.463	-.159
Years Played	-.271	-.105	-.348	-.135	-.360	-.140
TOPF	.569***	.446	.470**	.369	.479**	.376
Diagnosis	-1.127	-.059	-.501	-.026	-.351	-.018
Racial Identity			-8.002**	-.358	-8.533**	-.382
Position Group					1.766	.079
R^2	0.264		0.366		0.372	
F	4.122**		5.617***		4.953***	
ΔR^2	0.264		0.103		0.005	
Δ F	4.122**		11.005**		0.558	

Note.*p<.05, **p<.001

Research Question 4d: How much variation in language performance is explained by player position and race?

A hierarchical multiple regression was run to determine if the addition of racial identity and then of player position within a retired NFL population improved the prediction of language averaged performance over and above demographic factors (i.e. age, education, marital status, years played, premorbid functioning, and diagnosis). See Table 4-16 for full details on each regression model. In the first model, demographic characteristics of age, education, marital status, years played, premorbid functioning, and neuropsychiatric diagnosis significantly contributed to the regression model, $F(6,68)=5.180$, $p<.001$ and accounted for 25.3% of the variation in language performance. Introducing racial identity explained an additional .6% of the variation and this change in R^2 was not significant, $F(1, 67) = .582$, $p = .448$. Similarly, adding position group to the regression model only explained an additional .3% of the variation in language scores and this change R^2 was not significant, $F(1, 66) = .290$, $p=.592$. The full model of age, education, marital status, years played, premorbid functioning, neuropsychiatric diagnosis, racial identity and position group to predict language performance (Model 3) was statistically significant, $R^2 = .323$, $F(8, 66) = 3.929$, $p = .001$, however, marital status, years played, neuropsychiatric diagnosis, racial identity and player position group did not significantly predict language scores in the full model. The most important predictor of this measure was education which uniquely explained 14.9% of the variance in language performance, followed by age which explained 8.6% of the variance and TOPF which explained 7.6%. Taken together the 8 individual variables accounted for 32.3% of the variance in language performance.

Table 4- 16. Hierarchical Multiple Regression Predicting Language Performance from Age, Education, TOPF, Neuropsychiatric Diagnosis, Years Played in NFL, Marital Status, Racial Identity and Player Position Group.

	Language					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	90.728***		98.556***		98.891***	
Age	.334**	.351	.313**	.329	.310**	.327
Education	-5.256***	-.449	-5.399***	-.462	-5.383***	-.460
Marital Status	-2.016**	-.220	-2.002**	-.218	-1.912	-.209
Years Played	-.446	-.174	-.465	-.181	-.457	-.178
TOPF	.409**	.319	.384**	.299	.377**	.294
Diagnosis	-1.261	-.066	-1.092	-.057	-1.199	-.062
Racial Identity			-1.926	-.086	-1.531	-.068
Position Group					-1.330	-.060
R^2	0.314		0.320		0.323	
F	5.180***		4.496***		3.929**	
ΔR^2	0.314		0.006		0.003	
Δ F	5.180***		0.582		0.290	

Note. *p<.05, **p<.001

Research Question 4e: How much variation in executive functioning performance is explained by player position and race?

A hierarchical multiple regression was run to determine if the addition of racial identity and then of player position within a retired NFL population improved the prediction of executive functioning averaged performance over and above demographic factors (i.e. age, education, marital status, years played, premorbid functioning, and diagnosis). See Table 4-17 for full details on each regression model. In the first model, demographic characteristics of age, education, marital status, years played, premorbid functioning, and neuropsychiatric diagnosis significantly contributed to the regression model, $F(6,69)=4.519$, p=.001 and accounted for 28.2% of the variation in executive functioning performance. Introducing racial identity explained an additional .6% of the variation and this change in R^2 was not significant, $F(1, 68) = .603$, $p = .440$. However, when position group was added to the regression model there was a significant R^2 change, $F(1, 67) = 5.451$, $p = .023$, which explained 5.4 % of the variance in executive functioning scores. The full model of age, education, marital status, years played, premorbid functioning, neuropsychiatric diagnosis, racial identity and position group to predict executive functioning performance (Model 3) was statistically significant, $R^2 = .342$, $F(8, 67) = 4.353$, $p < .001$. Age, years played, neuropsychiatric diagnosis, and racial identity did not significantly predict executive functioning scores in this model. The most important predictor of executive functioning performance within this sample was TOPF, which uniquely explained 19.5% of the variance, followed by education explained 8.6% of the variance and player position group, which explained 5.3%. Interestingly, marital status accounted for 4.4% of the variance above other variables in the model. Taken together the 8 individual variables accounted for 34.2% of the variance in executive functioning performance.

Table 4- 17. Hierarchical Multiple Regression Predicting Executive Functioning Performance from Age, Education, TOPF, Neuropsychiatric Diagnosis, Years Played in NFL, Marital Status, Racial Identity and Player Position Group.

	Executive Functioning					
	Model 1		Model 2		Model 3	
Variable	B	β	B	β	B	β
Constant	71.581***		77.957***		76.994***	
Age	.043	.057	.025	.034	.035	.046
Education	-3.098**	-.330	-3.210**	-.342	-3.272**	-.348
Marital Status	-1.388	-.189	-1.373	-.187	-1.685**	-.229
Years Played	-.058	-.028	-.073	-.035	-.103	-.050
TOPF	.480***	.469	.460***	.450	.482***	.471
Diagnosis	-.959	-.062	-.835	-.054	-.450	-.029
Racial Identity			-1.593	-.089	-2.958	-.165
Position Group					4.533**	.253
R^2	0.282		0.288		0.342	
F	4.519**		3.938**		4.353***	
ΔR^2	0.282		0.006		0.054	
Δ F	4.519**		0.603		5.451	

Note. *p<.05, **p<.001

CHAPTER V: DISCUSSION

To date, limited research has been conducted on cognitive functioning utilizing a comprehensive neuropsychological battery in a diverse retired NFL population. As such, the purpose of the current dissertation study is to extend the body of research on factors relevant to cognitive health in diverse retired NFL players. There were four primary aims of the current investigation: (1) Explore whether position played in the NFL yielded statistically significant differences across various psychosocial variables in retired NFL athletes, (2) Explore whether position played in the NFL determines levels of cognitive impairment across the domains of complex attention/processing speed, learning and memory, language, visuospatial and executive function after controlling for covariates, (3) To determine whether racial identification plays a role on cognitive performance within the sample of retired NFL players and (4) To determine whether racial identity or former NFL position serve as a better predictors of cognitive performance over demographic variables.

Primary Outcomes

The first aim of the current study was to explore whether there were differences in psychosocial variables based on position played in the NFL. It was predicted that there would be differences in psychosocial factors among player positions based on prior research which shows individual variability amongst player positions in professional sports on the basis of race, and by proxy, quality of education, socioeconomic status, and pay discrimination (Ducking et al., 2015). However, results only partially support this hypothesis, as there were statistically significant differences among the various positions played on factors of racial identity, premorbid levels of functioning, education, and age but not for average years played, occupation after retirement and marital status. These findings suggest that when examining cognitive performance in former NFL players' psychosocial factors that may increase or reduce the risk of acute and chronic long-standing cognitive decline, should not be excluded.

The significant findings on racial differences among position groups in this sample, are consistent with previous research that show Black players tend to be overrepresented in running back, wide receiver and defensive back positions, while being disproportionately represented in quarterback, centers, guards and kicking specialists positions (Ducking, 2015; Lehman et al., 2012; Pitts & Yost, 2012). Specifically, in the current sample there were a greater number of retired Back athletes that accounted for speeded positions (i.e., running backs, defense backs, wide receivers, and tight ends) compared to white retired players, while White former players accounted for a greater number of quarterback and special team (i.e. kickers, punters) positions compared to Black former players. One explanation for these positional differences based on race may be rooted in the historical hiring practices of professional teams (Scully, 1973). The NFL hired its first black player in 1946 and by 1966, 25% of players were black (Scully, 1973). That percentage has more than doubled in the 21st century. Historically, Black football players have been unequally represented in the aforementioned positions since the 1960s (Scully, 1973). Loy & McElvogue (1970) as cited in Smith and Seff (1989) suggested that this positional discrimination may be explained by prejudicial and socialization factors that existed in excluding Black players from central roles that involved decision-making and leadership such as the quarterback positions. Another explanation for these positional disparities is based on the pattern of residential segregation that excluded Black youth from quality and or certain training opportunities compared to White youth (Scully, 1973). Although current personal prejudice and segregation are unlikely explanations for the disparities, today, it is possible that the disparities seen are a reflection of the aftereffects or remnants of the historical underpinnings of positional segregation in professional sports. Notably, at the collegiate level, Black athletes who were high school quarterbacks and white athletes who were running backs in high school are more likely to switch positions with their racial counterparts (Pitts & Yost, 2012), which provide some evidence for the continued racial segregation between these two positions. The negative effects of this continued positional disparity are of concern given documented differences in physical expenditure, injury, health, career length and potential earnings by position.

In additional to racial disparity amongst player positions, there were significant differences noted in age within this sample, such that, on average quarterbacks represented the highest mean age compared to other positions and similarly were shown to average the longest career lengths compared to other positions, though there was not a significant difference noted across the positions in years played in the NFL. While there are notable qualitative differences in age of retirement, length of retirement, number of games played and time in which the evaluation was complete[7]amongst the sample, it is possible that the differences noted in age are due to the nature of data collection methods. In line with prior research, performance variables and positions demands may account for the differences seen in age and career length in the NFL and speeded positions such as

[7] These variables were collected as part of the large data set but considered beyond the scope of the initial research questions and thus not included in this study.

running backs, who average the shortest career length and are known for their running speed and agility which often result in colliding at full speed/force into larger defensive players (Career trend, 2018; Pitts &Yost, 2012). Kickers and punters typically enjoy longer careers and are generally not expected to tackle or block other players (Career trend, 2018; Pitts &Yost, 2012). It is also not uncommon for positions to change throughout a player's career that may impact these factors (e.g. George Blanda, who played for 26 seasons, started as a quarterback, and ended as a kicker, Casey, 2020). There was a wide age range in the sample that may reflect varied experiences with concussion management, which will provide valuable future research on determining rate of decline over time within this population.

The differences in neuropsychological outcomes due to educational quality, attainment, and access and by proxy racial identity, have been well documented and are supported within these findings. Though few studies have explored differences in quality of education, literacy levels and socioeconomic status of retired football players (Allison, et al., 2016), this study found that education and premorbid estimates yielded significant differences in player position, with more defensive backs having completed a bachelor's degree, followed by running backs. With regards to measures of premorbid function, special teams, and quarterbacks, which consisted of a greater number of retired White athletes, had the highest rates of premorbid functioning. While the expectation for differences in years of education was low given the draft requirements of the NFL for educational attainment, premorbid functioning was anticipated to yield differences amongst player position given the disproportionate distribution of race among positions within our sample. Though socioeconomic status or education quality were not directly studied, the differences in premorbid functioning are likely related to the disparity in educational experiences of former Black and White American football players, as described above. Evidence on modifiable risk factors for cognitive decline and dementia has listed years of formal education and greater literacy rates as protective factors (Baumgart et al., 2015). Thus, if some players are already at a greater risk for the development of cognitive decline based on years and quality of education (amongst other factors), then the interaction that comes from player position physical demands or risk of injury may account for some of the differences in better or worse outcomes following repetitive head impacts.

After retiring from the NFL, approximately 15% of the sample pursued bachelors or master's degree. Additionally, retired NFL players had a range of occupations following their retirement, though no differences amongst player position were noted. Discriminant analysis of employment status amongst individuals with TBIs can be predicted based on level of education, pre-injury productivity condition, and functional status following injury (Gollaher et al., 1998). Careers after football may be influenced by several factors, such as perceived importance in preparing for an occupation after NFL retirement, fewer marketable skills to occupations outside of sports, neurobehavioral changes following head injuries, psychological factors (e.g. adjustment, depression; Barnes, 1990; Titkemeyer, 2015). For this sample, there was an endorsement of a wide range of occupations after the NFL, with few participants who reported unemployment. Occupational/employment outcomes for retired NFL players remains an underexplored risk/protective factor for cognitive decline and dementia later in life, as is marital status.

There were no significant differences on the basis of player position found with regards to marital status, but of the 54% of participants who provided information on relationship status, 64.1% reported being married, 10.3% divorced, and 2.6% widowed. Single and cohabitating status made up 19.2%, and 3.8%, respectively. Being married is associated with greater access to sociopsychological (e.g. social engagement, support) and economic resources, while being unmarried in adults and older adults has been shown to increase the risk of dementia onset and death (Drefahl, 2012; Johnson et al, 2000; Liu, et al., 2019). Given established differences in marital status, the lack of significant differences between player positions in the current study may indicate no relationship is present or the fact that half of the participants did not provide data on marital status. As such future inquiry to establish and better understand the relationship between marital status and player position is needed.

Playing Position and Cognition

The second aim of the study focused on determining whether there were significant cognitive differences across the various positions played in the NFL while controlling for group differences. Given the documented differences in the sample noted above, steps were taken to account for these covariates, such as racial identity, level of education, premorbid functioning, and age. It was hypothesized that the individual speed positions would show greater impairments across cognitive domains when compared to non-speed positions. The obtained findings did not satisfy this hypothesis as cognitive performance across the domains of complex attention/processing speed, learning and memory, visual perceptual, executive functioning and language was not mitigated by individual player position. The lack of significance observed suggests that there may be more important differences between the individual positions, such as position group, mechanism of injury (including magnitude and location), incidence of concussion history, and recovery periods between head injuries. Several studies have shown that the magnitude and frequency of injury varies for position, for example offensive backs are 1.24 and 1.52 times more likely to encounter an impact that exceeds peak linear acceleration than linemen positions (Crisco et al., 2010; Kerr et al., 2015; Register-Mihalik et al., 2017). Other positions may tend to experience greater frequency than magnitude of hits, yielding more localized damage based on the location of contact.

Racial Identity

The third aim of the study was to determine the role of racial identity on cognitive performance of retired NFL players. It was predicted that retired Black athletes would produce lower cognitive scores compared to retired White athletes across all cognitive domains. Given the known impact education can have on neuropsychological outcomes, and the group differences noted in this sample, it is important to note that there were still significant differences across cognitive domains even after controlling for education, premorbid functioning and age. Results showed that there were significant differences on the basis of racial identity of retired NFL players on combined measures of complex attention/processing speed, learning and memory and visual-spatial performance. No significant differences were noted for language and executive functioning measures.

These findings are consistent with previous research on racial differences in neurocognitive performance, which found that Black athletes had lower memory and processing speed scores when compared to their White counterparts, even at baseline testing (Houck et al., 2018). Moreover, several studies have provided explanations for the disparities seen among athletes on the basis of race. For instance, demographic and neurodevelopmental factors such as parental social economic status (SES) and football player's intelligence quotient (IQ) scores may serve as risk factors of acute and chronic long-term cognitive deficits in the context of a history of repetitive mTBIs (Andersson et al., 1996). Black athletes, particularly those from a low SES upbringing, have disproportionate access to quality education compared to White athletes (Darling-Hammond, 2004; Dotson et al., 2008). When literacy or overall quality of education is measured by reading level, there is a greater degree of variability observed in neurocognitive performance among racial groups (Dotson et al., 2009; Manly et al., 2004). In the current study, retired White athletes had higher estimates of premorbid functioning based on simple demographic characteristics and a word reading test, than retired Black athletes. Thus, the quality of early and secondary education amongst the sample may explain in part, the differences seen in cognitive performance.

Predictors of Cognitive Performance

The fourth objective of this study included determining whether racial identity and position group served as better predictors of cognitive performance compared to psychosocial variables within retired NFL players. The findings revealed the strongest predictor of cognitive performance as the combination of psychosocial variables (e.g. age, education, marital status, years played, premorbid functioning, and diagnosis (i.e. psychiatric and neurological)). Taken in total the established psychosocial variables when combined with racial identity and player position accounted for roughly 30-40% of the variance in cognition (i.e. learning and memory (32.4%), language (32.3%), executive functioning (34.2%), complex attention/processing speed (36.2%), visual-spatial performance (37.2%) pointing to the importance of increased understanding of these factors. In looking at the impact of race over and above known psychosocial factors, race uniquely explained 0.6%-10.3% of the variance within these models (i.e. language (0.6%), executive functioning (0.6%), complex attention/processing speed (4.3%), learning and memory (6.9%), visual-spatial performance (10.3%) indicating that the relationship between well-established demographic variables (Gary et al., 2009; Iverson et al., 2013) across cognitive domains, were indirectly affected by racial identity. Moreover, on measures of attention/processing speed and visuospatial performance, TOPF was a significant predictor of performance on its own. When the effect of racial identity was included, TOPF remained a significant predictor of performance, but was reduced. This suggested that although these measures were directly affected by premorbid estimates of functioning, this was also due to the indirect effects of TOPF on racial identity. In the learning and memory domain, when race was added, years played, and TOPF remained significant predictors of performance, but age did not. In the language domain, age, education, marital status and TOPF remained significant predictors of performance and were all changed by the inclusion of race. On executive functioning measures, both education and TOPF remained significant predictors of performance and were changed by the inclusion of racial identity, though racial identity was not a significant predictor in this domain.

When player position was grouped between speed and non-speed positions, player position uniquely explained 0.1%-5.9% of the variance within these models (i.e. language (0.3%), executive functioning (5.4%), complex attention/processing speed (5.9%), learning and memory (0.1%), visual-spatial performance (0.5%) indicating the mediating effect of player position across some cognitive domains, particularly with complex attention/speed and executive functioning, two domains primarily impacted by brain injury (Fork et al., 2005; Mathias & Wheaton, 2007). As with racial identity, the inclusion of position group showed significant changes in predictive value of psychosocial variables, but particularly its inclusion in complex attention/processing speed and executive measures led to significant increases in the predictive value of performance based on marital status, lending support to findings that marital status is an important area of research regarding protective factors of cognitive outcomes (Johnson et al., 2000; Liu et al., 2019). Of note, beyond the unique variance of these factors, the addition of both race and position into the model yielded some interesting interaction effects, which should be examined through future research. Consistently, across the cognitive domains, there was a negative relationship between each cognitive domain and years played, education, marital status, diagnosis, and racial identity, while there were positive relationships with age and premorbid functioning.

Consistent with previous findings, baseline and subsequent performance on neuropsychological testing may be significantly influenced by history of comorbid conditions, age, race, and premorbid functioning and/or education (length & quality) beyond repeated exposure to brain injury and thus are important factors to consider in interpreting variability in cognitive performance of retired NFL players (Asken et al., 2016). Particularly, the fact remains that some players are more vulnerable to the interaction effects of these factors and accurate evaluation of these factors are crucial in understanding what factors may modify risk and specific change across individuals. Thus, causal models that focus solely on the presence of a history of repetitive concussions in the onset of chronic degenerative conditions such as dementia or CTE, captures only part of the picture, and thus need to be expanded to a broader framework of exploration.

Limitations

While the present study serves the potential to add to current scientific literature, the study contains a number of limitations that need to be considered. Participants were recruited from convenience sampling rather than random selection which may limit the generalizability of the results. The sample also consisted of individuals who voluntarily participated in a neuropsychological evaluation due to their involvement in a concussion litigation settlement with the NFL. As such, performance validity measures were administered, but this study did not exclude participants who failed the majority of effort measures due to the exploratory nature of this study and the need to maintain an adequate sample size. Therefore, future studies are needed to examine these results using more stringent exclusion criteria as more participants are recruited. Within such a sample, individual variability in cognitive reserve, demographic factors, pre-existing medical factors, and concussion history have the potential to influence results in significant ways. Additionally, the cross-sectional nature of the study, and brief history obtained limits temporal precedence of the variables. Demographic and background information, including concussion history, were based on athlete self-report. Our sample included participants who spanned careers up to more than 20 years. Many retired athletes' career timelines fell within a period when little to no attention was given to the management of concussions. However, concussion management and protocols have significantly changed and improved over the last few decades. It is likely these results would look very different in a population with retirement from the NFL within the last three years. By the same token, there are several comorbid factors that may increase over time or during retirement from the NFL that include issues related to substance abuse, health problems, changes in financial status, and psychosocial pressures. Many participants gave rough estimates of likely number of concussions they experienced whether recognized or not from their national teams at the time. Given the arbitrary nature of this information, concussion history and number of concussions were not included in this study analyses. Additionally, while efforts were taken to capture estimates of premorbid functioning in the absence of baseline cognitive and developmental history, there are limitations in accounting for pre-existing learning or neurodevelopmental conditions that may have impacted neurocognitive performance. Given the likely interaction effects of concussion history, mechanisms of injury to player position and racial identity, and comorbid psychological or neurodevelopmental disorders, absence of this data limits the findings of this study. While the sample size was moderately adequate, there was a disproportionate sample size of Black and White athletes, as well as uneven dispersion of participants by playing position history, notably special teams, and fullbacks, which also limits this study's findings.

Future Directions

Future research should aim to collect a wider range of demographic information including SES, and history beyond game variables such as concussion history and age of first exposure to contact-sports. Given the significant variability noted amongst athletes, with particular focus on racial identity, access to quality of education, a neurobiopsychosocial approach could be adopted to interpreting cognitive data within this population. While recent studies have acknowledged the association between traumatic brain injuries (TBIs) and CTE affecting a broader population outside of contact sports athletes or military combat officers, little is known about how TBIs affect the rate of cognitive decline across individuals (Hof et al., 1991; Gavett et al., 2011). As such, studies should increase focus on improving baseline recording of players cognitive and psychosocial functioning and follow-up testing. Future studies should also focus on confirming the current study's findings and further identifying the factors that moderate the presence or degree of cognitive changes for professional athletes. Given that Black athletes are overrepresented in this particular population, particular attention should be placed on increasing inclusivity in studies on acute and chronic effects of mTBIs in the NFL. Given the unique relationships and interactions observed within the studied variables, future efforts should be devoted in part to determining the structural relationship of these variables with latent constructs.

Conclusions

The results of this study provide evidence consistent with previous research on the influence of various factors in interpreting the variability in cognitive performance seen among former professional football players. Specifically, this dissertation study found that retired Black athletes had lower performances on complex attention/processing speed, learning and memory and visual-spatial measures after controlling for education, premorbid intellectual functioning, and age. The study also found that there were demographic differences on the basis of individual player position, but not cognitive differences. However, when position was classified based on performance group, there were significant predictions for complex attention/processing speed and executive functioning performance. The lack of expected cognitive differences across individual playing positions might be due to the sample size, differences between positions, or latent factors not explored within this study. The differences discovered by this study highlight the importance of exploring contextual biopsychosocial factors (e.g. age, race, player position) within a lifecourse perspective to better understand the pathways by which repetitive brain injury can develop into long-standing neurocognitive deficits leading to CTE and AD in some athletes but not others.

While this study focused on retired NFL players, it is important to highlight that professional football players begin their "playing careers" before the age of puberty. The earlier a child becomes involved in contact sports the more experienced the athlete becomes but the more vulnerable the brain will be given the larger number of opportunities for injury exposure. Thus, parents and lawmakers have a duty to protect children from harm, and efforts focused on reducing the incidence of head trauma in contact-related sports should take precedence. While traumatic brain injuries can occur in any circumstance that causes trauma to the brain, such as a fall or car accidents, there are situations in which we can advocate for increased safety, prevention, and education. According to Dr. Bennet Omalu, "There is no reason whatsoever that any child under the age of 18 should play the high-impact, high-contact sports" (Pawlowski, 2019). While controversial, Dr. Omalu's statement is reflective of the documented incidence of cognitive and behavioral changes, as well as potential health and economic impacts that can occur as a result of contact sport related concussions (Aubry et al., 2002; Cherry et al., 2016; Giza & Hovda, 2001; Stern et al., 2013). Thus, these impacts should be carefully weighed against the documented positive benefits of team-sports for physical, social, and psychological health (Eime et al, 2013a; Eime et al., 2013b). Furthermore, sports for many symbolize an economic boost in the form of academic scholarships and careers that attract substantial revenue. As such, the issue becomes how to better understand the lifecourse impact of these events in order to intentionally design rules of play to ensure the safety of players by allowing time for the brain to recover and thus decreasing the risk of chronic brain damage. Overall, continued pursuit of inclusive, diverse lifecourse perspective research into concussion management will help to identify factors that could modify cognitive impairment and improve protective and rehabilitative efforts.

APPENDIX A

US DEPARTMENT OF VETERANS AFFAIRS, DEPARTMENT OF DEFENSE MEMORANDUM FROM THE ASSISTANT SECRETARY OF DEFENSE. TRAUMATIC BRAIN INJURY: UPDATED DEFINITION AND REPORTING

DEFINITION OF TRAUMATIC BRAIN INJURY

A traumatically induced structural injury or physiological disruption of brain function, as a result of an external force, that is indicated by new onset or worsening of at least one of the following clinical signs immediately following the event:

- Any alteration in mental status (e.g., confusion, disorientation, slowed thinking, etc.).
- Any loss of memory for events immediately before or after the injury.
- Any period of loss of or a decreased level of consciousness, observed or self-reported.

External forces may include any of the following events: the head being struck by an object, the head striking an object, the brain undergoing an acceleration/deceleration movement without direct external trauma to the head, or forces generated from events such as a blast or explosion, including penetrating injuries.

The above criteria define a TBI. Sequelae of TBI may resolve quickly, within minutes to hours after the neurological event, or they may persist. Some sequelae of TBI may be permanent. Most signs and symptoms will manifest immediately following the event. However, other signs and symptoms may be delayed from days to months (e.g., headaches, subdural hematoma, seizures, hydrocephalus, spasticity, etc.). Signs and symptoms may occur alone or in varying combinations and may result in a functional impairment. These signs and symptoms are not better explained by pre-existing conditions or other acute medical, neurological, or psychological causes, but may be a case of an exacerbation of a pre-existing condition. The signs and symptoms generally fall into one or more of the following three categories:

- <u>Physical</u>: Headache, nausea, vomiting, dizziness, sleep disturbance, weakness, paresis/plegia, sensory loss including hearing loss, visual loss, loss/alteration of taste or smell, tinnitus, spasticity, aphasia, dysphagia, dysarthria, balance disorders, disorders of coordination, seizure disorder.
- <u>Cognitive</u>: Deficits in attention, concentration, memory, speed of processing, new learning, planning, reasoning, judgment, executive control, self-awareness, language, abstract thinking.
- <u>Behavioral/emotional</u>: Feelings of depression or anxiety, agitation, irritability, impulsivity, aggression. Note: The signs and symptoms listed above are typical of each category but are not an exhaustive list of all possible signs and symptoms.

Note: The signs and symptoms listed above are typical of each category but are not an exhaustive list of all possible signs and symptoms.

SEVERITY OF BRAIN INJURY STRATIFICATION:

Not all individuals exposed to an external force will sustain a TBI. TBI varies in severity, traditionally described as concussion/mild, moderate, or severe. These categories are based on the presence and duration of the immediate, injury-induced alteration of consciousness; loss of consciousness; or posttraumatic amnesia.

Injury severity (i.e., concussion/mild, moderate, severe) is determined at the time of the injury, but this severity level, while having some prognostic value, does not necessarily reflect the patient's ultimate level of functioning. It is recognized that serial assessments of the patient's cognitive, emotional, behavioral, and social functioning are required. Current anatomic and functional imaging technology is only an adjunct to the diagnosis of TBI.

- TBI is classified as concussion/mild, moderate, or severe if it meets any of the criteria below within a particular severity level. If a patient meets criteria in more than one category of severity, the higher severity level is assigned. The trauma may cause structural damage and intracranial hemorrhage requiring immediate surgical intervention, or may produce subtle, non-structural damage indicated by altered brain function and a normal Computed Tomography (CT) scan.

- If it is not clinically possible to determine the level of severity because of medical interventions (e.g., sedation, pharmacologic paralysis, etc.), other severity markers may be required, such as a CT scan.

- It is emphasized that the majority (more than 80 percent) of those with a concussion, which is the most common type of TBI, will have a full, spontaneous recovery within a few days or weeks. Guidance on concussion evaluation and treatment can be found in the Concussion Management Algorithms located on the Defense and Veterans Brain Injury Center (DVBIC) website

Table: Classification of TBI Severity (If a patient meets criteria in more than one category of severity, the higher severity level is assigned)

Criteria	Mild/Concussion	Moderate	Severe
Structural Imaging	Normal	Normal or abnormal	Normal or abnormal
Loss of Consciousness (LOC)	0-30 mins *	> 30 minutes and <24 hours	> 24 hours
Alteration of Consciousness (AOC)	Up to 24 hours	> 24 hours; Severity based on other criteria	
Posttraumatic Amnesia (PTA)	0-1 day	>1 and <7 days	>7 days

Source: US Department of Veterans Affairs, Department of Defense

*It is recognized that there are published ICD-9-CM and ICD-10-CM codes for concussion with LOC ~ 1 minutes; however, these codes should not be used because LOC > 30 minutes is not classified as a concussion within the DoD.

In addition to a uniform definition for the diagnosis of TBI within the DoD and VA, there is an agreed upon set of ICD-9-CM and/or ICD-10-CM codes that should be used when screening for or treating TBI in the Military Health System.

TBI is only one of the causes for post-concussion symptoms. The presence of these symptoms alone is not sufficient for a diagnosis of TBI.

APPENDIX B: DIAGNOSTIC STATISTICAL MANUAL OF MENTAL DISORDERS 5th EDITION DIAGNOSIS OF TBI CRITERA

Major or Mild Neurocognitive Disorder Due to Traumatic Brain Injury

A. The criteria are met for major or mild neurocognitive disorder.
B. There is evidence of a traumatic brain injury - that is, an impact to the head or other mechanisms of rapid movement or displacement of the brain within the skull, with one or more of the following:

    a. Loss of consciousness
    b. Posttraumatic amnesia
    c. Disorientation and confusion
    d. Neurological signs (e.g., neuroimaging demonstrating injury; a new onset of seizures; a marked worsening of a preexisting seizure disorder; visual field cuts; anosmia; hemiparesis).

C. The neurocognitive disorder presents immediately after the occurrence of the traumatic brain injury or immediately after recovery of consciousness and persists past the acute post-injury period.

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BIOGRAPHICAL SKETCH

Kimberly's interest in neurocognitive changes and deficits began during her undergraduate studies in the late Dr. Robert Glassman's brain-behavior lab at Lake Forest College. Her research interests led her to obtain an undergraduate summer research fellowship in the department of cellular and molecular pharmacology at the Rosalind Franklin School of Medicine and Science in the lab of Dr. Kuei Tseng, studying the cellular mechanisms underlying age-dependent modulation of cortical activity in neuropsychiatric conditions using animal models. Her foundations in neuroscience research propelled further when she accepted a post-baccalaureate research fellowship at the Max Planck Florida Institute for Neuroscience in Dr. David Fitzpatrick's Functional Architecture and Development of Cerebral Cortex lab. During her graduate school training, she honed her research experiences in completing several projects on neuropsychological assessments in understanding various neurological and neuropsychiatric conditions that were accepted as poster presentations at various local and national conferences. Her graduate training began under the mentorship of Dr. Charles Golden in his Neuropsychology Assessment Clinic, where she continued to foster her skills as a clinician, researcher, teacher, and mentor. Her specialized interest in concussion and TBI related research grew during training in a Sports Concussion Clinic and working with current and retired professional athletes. As a Jamaican immigrant, she was cognizant of the racial disparities that exist in conducting neuropsychological assessment and research with this population and was compelled to exploring this further in her dissertation. While her research experiences and interests have been broad, they have all focused on brain-behavior relationships. Kimberly has recently gained mentorship from Dr. Ashley Stripling and expanded her interests in exploring and distinguishing age-related changes from the influence of neurological injury and disease process within a neurobiopsychosocial framework.