A Comparison Study of Executive Functioning Abilities in Individuals who Play Contact Sports

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Abstract

Executive functioning (EF) impairments are common amongst contact sports players, particularly due to the risk of concussions. Past studies have investigated the EF abilities of athletes, with particular emphasis on comparisons between contact and non-contact sport players, and on comparisons between athletes who have history of frequent head impact in sport versus those who do not. Evidence on EF abilities of athletes remains an evolving topic in research world-wide, and there is also a lacuna in local studies. The present study investigated and compared EF abilities in a local sample of individuals who play sports, using a quantitative data collection method. This was carried out by examining group differences on tests of EF between a CONTACT group (*n* = 43) and a NON-CONTACT group (*n* = 17). Further analysis was then carried out to examine group differences within the CONTACT group. The sample comprised of 60 adults over the age of 18 (females, *n* = 19; males, *n* = 41). Each participant completed five performance-based measures and one self-report measure of EF, along with a demographic questionnaire. Data was then analysed through independent samples t-tests. The results showed that, in comparison to contact sport players who did not have a history of head injury in sports, contact sport players who had a history of head injury in sports showed worse scores on a test of inhibitory control. Although not statistically significant, the findings also suggested that contact sport players self-reported more behavioural difficulties than the non-contact sport players. No other significant findings were revealed on the remaining tests of EF. Future studies are recommended to examine EF in sport in a larger sample of local athletes. The study findings also highlight the importance of neuropsychological testing for individuals who have sustained a head injury in sport.

Key words: executive functioning, contact sport, traumatic brain injury, neuropsychological testing.

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List of Acronyms

TBI	Traumatic Brain Injury
EF	Executive Functioning
mTBI	Mild Traumatic Brain Injury
PCS	Post-Concussion Syndrome
SIS	Second Impact Syndrome
CTE	Chronic Traumatic Encephalopathy
SRC	Sport-Related Concussion
LOC	Loss of Consciousness
GCS	Glasgow Coma Scale
PTA	Post Traumatic Amnesia
DEX	Dysexecutive Questionnaire
DS	Digit Span
DSF	Digit Span Forwards
DSB	Digit Span Backwards
KS	Key Search
RSC	Rule Shift Cards
TMT	Trail Making Test
CWIT	Colour Word Interference Test
BADS	Behavioural Assessment of the Dysexecutive Syndrome
WAIS-IV	Wechsler Adult Intelligence Scale (Fourth Edition)
D-KEFS	Delis-Kaplan Executive Function System

Chapter 1: Introduction

Preamble

The introductory chapter provides a brief overview of the different sections of the study. A background to the study will be introduced and the rationale for the study will be outlined. The chosen methodology and the expected contributions to the field will then be presented, followed by an overview of each chapter of the study.

Traumatic Brain Injury in Sport

Despite the benefits of participating in sports and other related recreational activities, the risk of sport-related traumatic brain injuries is well documented (Theadom et al., 2020). Concerns have also been raised regarding the high-speed contact across multiple sports (Tierney, 2021). When considering the different types of sports, contact sport players are at a greater risk of sustaining a traumatic brain injury (TBI) due to experiencing physical force on each other (National Collegiate Athletic Association [NCAA] Sports Medicine Handbook, 2014). Contact sport players are therefore at an increased risk of head-trauma (Ling et al., 2015), specifically repetitive head impacts (Zetterberg et al., 2018). Repetitive head trauma has been classified as any form of brain trauma, including mild trauma that does not necessarily show any observable manifestations and signs of a concussion (Gavett et al., 2011; McKee et al., 2009; Spiotta et al., 2011; Stern et al., 2011).

The severity of an injury in sport is often dependent on a variety of factors, including the type of sport and the precautions taken (Cantu, 1996). Therefore, certain sports such as rugby and football are classified as significantly more dangerous than others (eg. tennis). Across contact sports, concussions (also referred to as mild TBIs) have been reported to be the most common type of TBI (Ling et al., 2015). Concerns about potential long-term cognitive consequences from repetitive mild head injuries in sports have also been raised

(Saigal & Berger, 2014). Nonetheless, studies have also shown that severe head injuries are indeed widespread amongst contact sports (Mizobuchi & Nagahiro, 2016).

Neuropsychological Outcomes of TBI in Sports

Generally, neuropsychological outcomes of TBIs do not solely depend on the severity of the injury itself, but also rely on the interplay of other factors, such as the type and extent of underlying structural damage, and the person's premorbid functioning (Baxendale et al., 2019). Since the frontal lobes are positioned at the front of the brain, a blow to the head may put these areas at high risk of damage (Nel & Govender, 2018). Thus, the location of the frontal lobes is vulnerable to injury across individuals who play contact sports. Furthermore, marked changes in the frontal lobes have shown an association with resulting neurocognitive deficits following a mild TBI (mTBI) (Lipton et al., 2009). Although existing research regarding the long-term cognitive deficits following mTBI are inconsistent (Gaines et al., 2016), deficits in executive functioning (EF) remain the most common neurobehavioural consequence of all TBIs (Ghawami et al., 2017). Additional to the risk of EF deficits following any head injury in sport, the presence of repetitive head trauma in sport can also lead to chronic traumatic encephalopathy (CTE) (Baugh et al., 2012). Even though the most common cases of CTE in sport have been observed in American football players and boxers, athletes who practice other contact sports such as rugby and soccer[1] are also at risk (McKee et al., 2014). Amongst other consequences of CTE, executive dysfunction is usually one of the initial cognitive symptoms that arises (Baugh et al., 2012).

Past studies have also concluded that contact sport players show poorer performance on tests of EF in comparison to individuals who play non-contact sports (eg. Hume et al., 2017). A recent systematic review by Gallo and colleagues (2020) was conducted to gather

[1] Throughout all the chapters of this study, the words 'soccer' and 'football' have been mentioned according to how they are presented in the cited literature.

an understanding of the current evidence regarding the association between sport-related concussion (SRC) and long-term impairments in cognitive functioning. Similar to many other studies, the results indeed pointed towards an association between concussions in sport and long-term cognitive functioning (Gallo et al., 2020).

Executive Functioning in Sport-Related TBIs

Although EF is a growing field of interest in sport research, a concrete definition and operational understanding of the EF construct remains imprecise (Ball, 2022). An overview of the multiple definitions of EF will be further explored in the following chapter.

Furthermore, ongoing research continues to highlight the implications of possible EF difficulties deriving from head injuries in sport. Apart from the everyday difficulties that executive dysfunction can lead to, it is also common that injured athletes may experience EF difficulties during the sport itself, such as a slowed response to the fast-paced and changing environment of the game (Tapper et al., 2016).

Rationale for the Study

Stillman et al. (2016) discuss the positive effects that physical activity may have on overall cognitive functioning. On the other hand, the risk of sustaining a head injury, particularly in contact sports, remains a growing concern.

The purpose of this study is to investigate and compare EF abilities in individuals who play contact or non-contact sports. Furthermore, this study will also examine EF abilities in individuals who play contact sports and have a history of head injury/concussion in sport, and/or play the contact sport at a professional level. Several neuropsychological measures that are often used to assess EF, such as the Tower of London (Shallice, 1982) test and the Wisconsin Card Sorting test (Berg, 1948; Grant & Berg, 1948) lack ecological validity, therefore indicating that findings from such tests are not essentially representative of everyday functioning. In order to capture a more accurate understanding of EF abilities in day-to-day functioning, the ecological validity of assessments is crucial (Burgess et al., 2006). Thus, in comparison to solely using objective tests of EF, using tests which yield generalisation to the real world would therefore offer a better understanding of day-to-day EF in individuals who play sports.

In order to guide this study, a primary research question and three secondary hypotheses were developed. The primary research question informing the study was:

- What are the EF abilities of people who play contact sports?

The secondary hypotheses that developed from the primary research question of this study were as follows;

- H_1: There is an association between contact sports and EF deficits.
- H_2: Individuals who play contact sports and have a history of concussion/head injury in sport are more likely to perform significantly poorer on EF tests in comparison to contact sport players who do not.
- H_3: Individuals who play contact sports at a professional level are more likely to perform significantly poorer on EF tests in comparison to individuals who do not.

To investigate the primary research question and to test the emerging hypotheses, the study adopted a quantitative approach to gather a larger and more generalisable study sample. A non-probability sampling method was adopted, and through convenience sampling, any interested candidate who was eligible for the study was recruited. Inclusion criteria required participants to be at least 18 years of age and currently practicing a sport.

The aims of the study were investigated through standardised performance-based and report-based measures of EF. A demographic questionnaire was also used to evaluate any associations related to variables such as gender, age, history of head injury/concussion in sport and level of sport. In total, 60 participants were recruited and were required to complete five tests of EF, a demographic questionnaire, and self-report measure of EF.

Following the data collection process, the recruited participants were split into two groups according to the information provided in the demographic questionnaire regarding the type of sport practiced. The two groups were classified as contact sports (CONTACT) and non-contact sports (NON-CONTACT), and the findings obtained from all measures were analysed according to the groups using the latest version of Statistical Package for the Social Sciences (SPSS) Version 28.0.

Research Contributions

The study aims to contribute to a better understanding of EF in contact sport players in comparison to EF abilities in non-contact sport players within the local context. A previous study has investigated EF in a sample of local rugby players, however, to the author's knowledge, no others studies investigating and comparing EF in contact and non-contact sports has been conducted within the Maltese population. Additionally, this study may set the ground for a larger local study, in which different assessment measures may be used to further explore a variety of cognitive domains in athletes who practice different types of sport.

Clinical Contributions

By assessing EF abilities in a sample of individuals who play sports, this study may provide a better understanding of identifying cognitive symptoms that are commonly observed as a consequence of head trauma in sport. Furthermore, the study aims to increase awareness about the importance of neuropsychological testing for individuals who have sustained a head injury in sport.

Overview of Chapters

Chapter one aimed to provide a background of the topic in study by introducing relevant literature in line with the primary research question, as well as presenting an overview of the study. Chapter two will present a more detailed account of the relevant literature, whilst Chapter three will present a detailed outline of the methodology used. This will include an explanation of the inclusion and exclusion criteria, the sample, the data collection measures used, the hypotheses and the chosen statistical tests. Chapter four will then present the findings of the study, highlighting any associations between variables, whilst Chapter five will discuss the study findings with reference to relevant literature. The study will then be concluded in Chapter six, where the primary findings will be presented, the strengths, limitations and implications of the study will be discussed, and suggestions for future research will be proposed.

Chapter 2: Literature Review

Chapter Overview

This chapter provides an introduction to traumatic brain injuries (TBIs) and the presence of such injuries in sport. The first part of the chapter will distinguish between the different mechanisms and pathophysiology of TBIs, followed by an overview of the severity, aetiology and prevalence. The second part of the chapter will explore TBI in the context of sport and will present past studies that have investigated the association between neuropsychological functioning and type of sport. The functional and cognitive outcomes of TBI will then be discussed, with a particular emphasis on executive functioning (EF) as the focus of this study. Lastly, a discussion on the current models of EF will be presented, followed by an overview of some of the widely used neuropsychological measures of EF, with a specific focus on the measures which are commonly used within the local context.

Introducing Traumatic Brain Injury

Traumatic Brain Injury (TBI) is defined as a disruption in either brain function, structure or both, and is characterized by a sudden injury to the brain as a result of an external mechanical force (Corrigan et al., 2018; Jamjoom et al., 2021; Bozkurt et al., 2022). Globally, the incidence of TBIs is a worldwide health concern, with all TBIs accounting for five million deaths each year (Negida et al., 2021).

TBIs are primarily grouped into two broad categories, including penetrating and non-penetrating (closed-head) injuries. A penetrating injury occurs when an object penetrates the skull, such as a bullet, whilst a non-penetrating injury occurs when the skull remains intact despite the rapid force to the head (Ginsburg & Huff, 2022). When determining the type and extent of a primary brain injury, various factors are considered, such as the nature of the impact, the site of impact and the type of force (Prasetyo, 2020). Furthermore, there are several types of mechanical forces that can result in brain trauma, such as rotational forces, linear forces, and blast injuries amongst others (McKee & Daneshvar, 2015).

Following any penetrating or non-penetrating injury, the resulting cell-damage can be categorised into two groups, namely primary and secondary injuries (Prasetyo, 2020). The following sections will discuss the pathology of the primary and secondary phases of injury, followed by a discussion related to the severity continuum and clinical presentation of TBI.

Primary Brain Injuries

A primary brain injury occurs at the moment of impact and results in a physical disruption of intracranial compositions (Sande & West, 2010), so it is therefore considered to be the instant result of an external mechanical force (McKee & Deneshvar, 2015). Since there are various types of forces to the head that can result in TBI, the pathology of a primary injury is considered to be heterogeneous (Keating & Cullen, 2021).

All head injuries resulting from an external force are usually categorised as focal or diffuse injuries (Vincent et al., 2014). Focal injuries are generally the result of a direct blow to the head such as a gunshot, whilst diffuse injuries are widespread and involve the shearing of axons throughout the brain, often seen in acceleration/deceleration injuries such as in road-traffic accidents (Vincent et al., 2014). Therefore, whilst focal injuries are confined to one area of the brain, diffuse injuries affect different areas of the brain.

Moreover, although primary injuries may be prevented to a certain extent, such as by wearing a helmet whilst riding a motorbike, the resulting impact to the functional tissue of the brain that may occur in such injuries is irreversible (Ng & Lee, 2019).

Secondary Brain Injuries

Apart from the instant disruption that may occur, primary brain injuries and the resulting cascades of biochemical mechanisms may also lead to secondary injuries which generally show a more prolonged presentation (Prasetyo, 2020). Secondary brain injuries are defined as a consequence of the biological and physiological changes which occur during the initial trauma (Ponsford et al., 1995). By contrast to an immediate primary injury, a secondary injury can also develop within minutes to several months after the impact, progressively increasing the chances of neurological impairments (Jassam et al., 2017).

There are various neurochemical and neurometabolic changes that can arise as a consequence of the primary insult, and some examples include, cerebral oedema which refers to the swelling of the brain (Zusman et al., 2020), alterations to the blood-brain barrier (Thapa et al., 2021), and the degeneration of neurons and other supporting cells in the brain (Jarrahi et al., 2020). Mitochondrial impairment is also a hallmark event in secondary injuries, and may lead to changes in metabolic and physiological functions that can eventually result in apoptosis, a process which is characterised as programmed cell death (Thapa et al., 2021).

Therefore, since secondary brain injuries are typically observable physiological responses as result of the pathological changes from an impact (Pinsky et al., 2016), they can be considered to be a delayed clinical presentation that is superimposed by the primary brain injury (Ponsford et al., 1995). Due to the delayed presentation, it is well documented that therapeutic interventions can only prevent additional secondary brain damage to a certain extent (Prasetyo, 2020). Examples of such interventions include; monitoring body temperature due to the possibility of infections and hyperthermia, mechanical ventilation to support breathing in the cases of hypoxia and hypercarbia, and anti-epileptic medication as a means of seizure control for individuals who suffered a seizure as a result of the injury (Wiles et al., 2023).

TBI Severity

The Glasgow Coma Scale (GCS) was introduced by Teasdale and Jennett in 1974 and is often used by clinicians as a form of assessment of consciousness and severity. Initially, the GCS was used for patients who had sustained a head injury, however it is now most often used to assess acute patients in general (Mehta & Chinthapalli, 2019). As a clinical scale, the GCS is an objective measure which is used to assess an individual's levels of consciousness based on the individual's responses (Gardner and Zafonte, 2016). The GCS assesses eye-opening responses (scored from one to four), motor responses (scored from one to six) and verbal responses (scored from one to five), and the final GCS classification is based on the total score of the three types of responses (Teasdale & Jennett, 1974). Total scores of 13-15 are classified as mild TBI (mTBI), scores of nine to 12 as moderate TBI, and scores of eight and below classify the TBI as severe (Teasdale & Jennett, 1974).

Moreover, the Post Traumatic Amnesia (PTA) duration is also noted to provide an estimate of the TBI severity based on altered consciousness. The duration of PTA refers to the period after a brain injury when an individual presents as disoriented and shows impairment in the acquisition of novel information (Forrester et al., 1994), whereby the longer the duration, the greater the severity. The interpretation of PTA duration has been reported as problematic since studies investigating the reliability and reproducibility of measures of PTA are scarce (Tenovuo et al., 2021). However, it can be assumed that the end of PTA duration is at the point of return to full awareness and intact memory of new information (Parker et al., 2022).

The following sections will explore and distinguish between mild, moderate and severe TBIs as classified by the GCS.

Mild TBI

Mild TBIs (mTBI) are the most common TBIs worldwide, representing between 70% and 90% of all sustained TBIs (Iaccarino et al., 2021). Traditionally, many studies have documented that a GCS score ranging between 13-15 beginning at 30 minute post-injury is used as the cut-off point to define a mTBI (eg. Joseph et al., 2015; Kaufman et al., 2019).

In general, mTBIs are characterised by sudden physiological changes which are better understood as complex neurometabolic cascades, in which the affected cells typically go into recovery, whilst other cells may also degenerate and lead to cell death (Iverson, 2005). The term ‘complicated mTBI’ is a more recent term which has also been proposed to refer to all mTBIs that are coupled with visible intracranial abnormalities on brains scans, such as magnetic resonance imaging (MRI) and computed tomography (CT) (Karr et al., 2020; Lefevre-Dognin et al., 2021).

The prevalence of mTBIs in general is considered to be high, globally affecting approximately 42 million people each year (Gardner & Yaffe, 2015). Despite this, it is still challenging to obtain a thorough understanding of the clinical consequences, and it is somewhat difficult to provide an accurate diagnosis of such injuries (Katz et al., 2015).

In most cases, but not all, the presence of cognitive and/or neurobehavioral consequences from a mTBI are usually self-limiting and follow a predictable course regardless of age (Iverson, 2005). Although recovery for the majority of mTBI cases is usually expected within a maximum of three months (Rabinowitz et al., 2015), mTBI symptoms can also linger and lead to long-term consequences and impairments (Iverson & Lange, 2011). Nonetheless, it is incorrect to assume that mTBIs generally do lead to persistent brain damage, however it cannot be assumed that mTBIs cannot lead to indefinite brain damage (Iverson & Lange, 2011). Thus, this indicates that although the severity of mTBIs is considered to be relatively less than other moderate and severe brain injuries, it is not always the case.

Concussions. Concussions are also a type of mTBI, and the terms ‘concussion’ and ‘mild TBI’ (mTBI) are commonly used interchangeably (eg. Gardner & Yaffe, 2015; Choe, 2016). For the purpose of this literature review, the terms mTBI and concussion have been used interchangeably according to how they are referred to in the literature.

Concussions refer to traumatically short-lived disturbances of brain functioning which occur as a result of an external force that causes acceleration-deceleration movement of the brain (McCrory et al., 2017). Despite this, Sussman et al. (2018) postulate that a lack of accurate definitions for both concussion and mTBI still remains, and this commonly results in uncertainty about the accurate diagnosis and confusion in terms of treatment. It is also somewhat confusing for a clinician to determine a clearcut distinction between a mTBI and a concussion (Sharp & Jenkins, 2015). This is suggested as the symptoms of a concussion are similar to symptoms of a TBI, such as headaches, disrupted sleep and loss of consciousness (LOC) (Sharp & Jenkins, 2015). Furthermore, due to the absence of a distinction between the symptoms of concussions and other TBIs, it is common for a neurologist to assume that any post-TBI symptoms are likely to be benign and simply ‘post concussive’ in nature (Sharp & Jenkins, 2015). This may result in inappropriate reassurance to patients that symptoms may quickly resolve, and may possibly lead to insufficient treatment and a lack of thorough investigation (Sharp & Jenkins, 2015).

Moderate and Severe TBIs

Based on the Glasgow Coma Scale (GCS) that was previously discussed (Teasdale & Jennett, 1974), a total score between nine to 12 is considered to indicate a moderate TBI, whilst a total score below eight is considered to indicate a severe TBI. Whilst LOC in mTBIs often lasts for a few seconds to a maximum of 30 minutes, LOC in moderate TBIs can vary between 30 minutes to 24 hours, whilst the most severe group of TBIs can present with LOC for over 24 hours (eg. O’Neil et al., 2013). Amongst others, Watanitanon et al. (2018) postulate that limited attention has been given to the moderate TBIs, therefore highlighting a lack of guidelines for the moderate TBI severity group in comparison to the mTBI and severe TBI groups. To the author’s knowledge, research on the moderate-severe group appears to be more widespread in comparison to a focus on moderate TBI as a group in itself. To illustrate this, moderate TBIs have also been referred to as a grey area in neurotrauma (Godoy et al., 2016).

Despite this gap in the research, Lezak et al. (2012) have previously defined moderate TBIs as brain insults which impact both the grey and white matter of the brain. Individuals who have sustained a moderate TBI are likely to be responsive to commands upon arrival to the emergency department (ED), unlike individuals who have sustained a severe TBI (DeCuypere & Klimo, 2012). Due to the likelihood of abnormalities upon neuroimaging, all individuals who have sustained a moderate or severe TBI are assessed through brain scans upon admission to ED (DeCuypere & Klimo, 2012). Apart from intracranial complications (within the skull), neuroimaging has shown that moderate and severe TBIs are also often associated with multiple extracranial disruptions (external to the skull) (Gundappa, 2019). Furthermore, individuals who have sustained a moderate or severe head injury are often faced with other simultaneous injuries, such as internal damage to the limbs, lungs or the spinal cord (Rajajee et al., 2019).

Due to the similarities between moderate and severe brain injuries, moderate TBIs have also been referred to as 'potentially severe' TBIs (Godoy et al., 2016; Godoy et al., 2020).

Neuroimaging and TBI Severity

A computerized tomography (CT) scan is the preferred imaging modality in the acute stage of head injuries (Rajajee et al., 2019). Especially in cases of moderate and severe TBIs, it is recommended that a CT scan is carried out as soon as possible (Rajajee et al., 2019). Such scans may detect and identify particular lesions in the brain which could require neurosurgical interventions (Rajajee et al., 2019). A non-contrast CT is used to detect any skull fractures, swelling of the brain and intracranial hematomas amongst others (Rajajee et al., 2019). CT scanning is also recommended during the follow-up stages of the injury in order to monitor for any further clinical deteriorations (Rajajee et al., 2019).

Diffusion tensor imaging (DTI) is another relatively modern magnetic resonance imaging (MRI) modality that provides insight about the axonal tracts, thus moving closer to providing an enhanced identification of the extent of the TBI severity (Smith et al., 2019).

Aetiology and Prevalence of TBI

TBI remains a significant cause of hospital admissions and deaths in Europe (Majdan et al., 2016). Majdan et al. (2016) investigated the epidemiology of TBI in Europe through a cross-section analysis across 25 European countries, and concluded that a higher percentage of males (61%) were hospitalised due to a TBI in comparison to females (39%). They also concluded that the majority (55%) of individuals who sustained a TBI were younger than 44 years of age (zero to 44 years old), whilst 29% were over 65 years of age (Majdan et al., 2016). Across the 25 European countries, 33,415 deaths due to TBI were identified, and the majority (68%) of deaths were identified in males (Majdan et al., 2016).

In 2017, 2.5 million cases of TBI were reported in the European Union, with the vast majority being mTBIs (90%) (Foks et al., 2017). Furthermore, a recent systematic review conducted by Brazinova et al. (2021) concluded that the most frequent mechanisms of TBIs in Europe were traffic accidents and falls.

Moreover, although TBI is a global health concern, low-income (LI) and middle-income (MI) countries are faced with the largest burden of TBI (Smith et al., 2022), with over 70% of trauma-related fatalities occurring in LI and MI countries (Tropeano et al., 2019). Iaccarino et al. (2021) also report other common findings across a number of population-based studies. Their findings indicated a global increased incidence of TBI in early childhood (zero to four years old), in late adolescence (ages 15-19) and in the elderly population aged 75+ (Iaccarino et al., 2021). Moreover, they also concluded that the elderly population are accounting for the highest rates of hospital admissions and subsequent deaths (Iaccarino et al., 2021).

TBI in Sport

Most injuries in sport occur when players come into contact with one another (Khurana & Kaye, 2012), and typically result from a direct force to the face, head or neck, or an indirect and impulsive blow to another part of an athlete's body (Iverson, 2010). For example, by definition, a 'knockout' in boxing is associated with loss of consciousness (LOC) and concussion (Ling et al., 2015). Another example could be in soccer, where the two most frequent causes of concussion are in heading manoeuvres where the head is used to intentionally hit the ball, and in collisions between players, against a goalpost or to the ground (Ling et al., 2015).

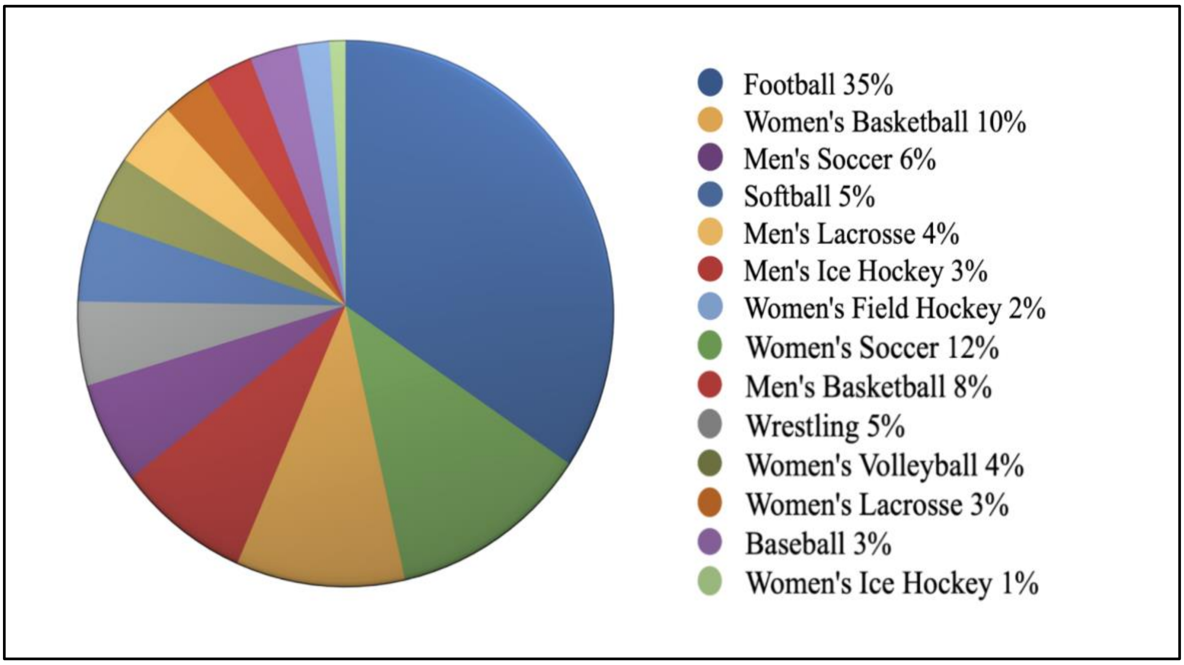
Concussions are reported to be the most common type of acute TBI in contact sports, particularly in high-impact sports such as football (Ling et al., 2015). The epidemiology of sport-related concussions (SRC) have been mentioned across multiple studies that make reference to the National Collegiate Athletic Association [NCAA] statistics (eg. Daneshvar et al., 2011; Covassin & Elbin, 2011; Ma et al., 2012). Figure 1 overleaf presents the United States of America's annual estimate of concussions across 14 NCAA sports as presented in the most recent online version of the NCAA Sports Medicine Handbook (2014). To the author's knowledge, this is the most recent online available handbook published by the NCAA.

When analysing the pie chart depicted in Figure 1, it is evident that the incidence of concussion is highest in football. Baugh et al. (2015) also note that SRCs are less common during practice and training, and more common during games, such as during an official football game.

It can therefore be understood that contact sport players are at a higher risk of sustaining a concussion compared to non-contact sports players.

Figure 1

National Annual Estimate of Concussions in 14 NCAA sports



Note: This pie chart depicts the percentage of concussions in practice and competition across 14 selected NCAA Sports as adapted from a pie chart that is included in the NCAA Sports Medicine Handbook (2014). The data presented reflects data that was gathered between 2009-2014.

The following sub-section introduces the different sport-categories, followed by an overview of sports within the local context, and a detailed explanation of common TBIs in sport.

Sport Categorisation

To the author's knowledge, the NCAA appears to be a well-established association that is commonly referred to across several studies. The 24th edition of the NCAA Sports Medicine Handbook (NCAA, 2014) categorises sports into three categories, namely contact sports, limited contact sports and non-contact sports. In contact sports, such as football and rugby, players intentionally come into forceful physical contact with other objects or players in the team, and thus are at a higher risk of experiencing a head injury. In comparison to contact sports, limited contact sports involve infrequent and weak contact between players, whilst non-contact sports involve no contact between players, such as when playing golf. Unlike previous versions, the latest NCAA Sport Medicine Handbook (2014) lists sports such as tennis and golf as 'limited contact' sports rather than non-contact on the basis that athletes still remain at risk of sustaining a concussion during sport.

For the purpose of this study, the author has categorised sports into two primary categories, being contact and non-contact sports.

Sports in Malta

According to a recent article by Owen (2022), football, horse racing and boules were listed as the three top sports in Malta. Other commonly practised sports are also accompanied by their respective registered federations and associations, such as the Malta Football Association, Malta Boxing Organisation and Malta Handball Association. Despite the top three sports in Malta, football has remained the most popular sport (Borg, 2022; Busuttil, 2023), with the first football game being in the late 19th century (Busuttil, 2023). Rugby is also a local popular sport, with its popularity beginning during its revival in 1982 (Malta Rugby Football Union, 2020). Apart from the common sports, there are plenty of other sports practiced in Malta, such as scuba-diving, which are relatively less competitive than the popular and competitive sports such as football and rugby (Air Malta, 2021).

With regards to specific contact and non-contact sports, a couple of popular local sports can be listed. These include boxing, rugby, football and waterpolo as examples of contact sport, and tennis, gymnastics, padel and golf as examples of non-contact sports. However these are just some examples of an abundance of sports that are played within the local context.

Expanding on TBI in Sport

Trauma to the head is common across several contact sports (Ling et al., 2015). The following sub-sections will present an explanation of the commonly reported TBIs in sport.

mTBI/Concussion. Sport-related concussions (SRC) occur when a biomechanical force to the head or body causes acceleration, deceleration and rotational forces to the brain during sport (Hallock et al., 2023). As previously stated earlier on in this chapter, concussions are defined as the most common type of brain injury in athletes (Ianof et al., 2014). When considering the common occurrence of mild TBIs (mTBI) in sport, most studies have solely focused on cases which were hospitalised, most likely resulting in inaccurate study findings, and therefore suggesting that mTBI cases in sport are being missed (Theadom et al., 2016). Furthermore, multiple mTBI cases in sport can also be missed as sport-players may not realise that they have sustained a TBI (Theadom et al., 2016). It is also possible that the TBI itself can be overshadowed by other injuries which require immediate intervention (Theadom et al., 2016), such as leg fractures and anterior cruciate ligament (ACL) injuries.

Post-Concussion Syndrome. The term Post-Concussion Syndrome (PCS) is commonly used to refer to a group of symptoms, including behavioural, cognitive, emotional and physical symptoms, which linger and persist for longer than three months following a concussion (Permenter et al., 2022). Although the symptoms of a concussion usually disappear within days to weeks, some individuals with PCS continue to experience persistent symptoms for months, and even possibly years post-injury (Dwyer & Katz, 2018). Individuals who return to play during PCS are often at risk of developing Second Impact Syndrome (SIS) which can potentially be fatal (Nzuva, 2019). SIS will be explored in detail in the next section.

Furthermore, it is understood that the period of time of symptom persistence is what distinguishes post-concussion symptoms from the more prolonged Post-Concussion Syndrome (PCS) (Jotwani & Harmon, 2010).

Table 1 below presents some examples of symptoms of PCS as outlined by Jotwani and Harmon in 2010.

Table 1

Examples of symptoms of PCS

	Symptoms of PCS	
Cognitive	**Physical**	**Emotional**
Slowed response speed	Headache	Depression
Mental fogginess	Nausea	Anxiety
Poor concentration	Vision changes	Panic attacks
Distractibility	Sensitivity to light	Irritability
Difficulty with learning	Tinnitus	Personality changes
Memory difficulty	Dizziness	Apathy
Disorganisation	Trouble with balance	Lowered frustration tolerance
Difficulty with problem-solving	Fatigue	Increased emotionality

Second Impact Syndrome. In 1984, Saunders and Harbaugh reported a case study about a football player who returned to the playing field after an initial head injury. On returning to play, he then collapsed and died after what was presumed to be a second head injury (Saunders & Harbaugh, 1984). Therefore, sustaining an additional injury whilst still recovering from the initial injury can result in Second Impact Syndrome (SIS). The term SIS is used to refer to diffuse cerebral swelling (Hobbs et al., 2016), which can present itself with or without acute bleeding inside the skull (Giza et al., 2017). In the severe cases, SIS can indeed result in significant disability (Laker, 2015), and possibly even death (Enam et al., 2021).

Repetitive Head Injury and Chronic Traumatic Encephalopathy. In the 1920s, ‘punch-drunk syndrome’ was proposed in relation to boxers who presented with neuropsychiatric long-term symptoms associated with mild repetitive head trauma (Martland, 1928; Munakomi & Puckett, 2022). The long-term and irreversible damage of repetitive head impacts in boxers has been well documented for almost a century, and is now commonly referred to as chronic traumatic encephalopathy (CTE) (Ling et al., 2015). CTE involves diffuse axonal injury, the deposition of tau protein in the brain, and a loss of brain cells (neurons) and connections between cells (i.e synapses) (Hallock et al., 2023).

A case series study conducted by Mez et al. (2017) sought to investigate the neuropathological and clinical characteristics in a sample of deceased American football players whose brains were donated as a contribution to the research. Findings concluded that CTE was diagnosed in the majority of the sample (*n*=177 of *n*=202), therefore suggesting that a large percentage of the sample showed a relation between previous participation in football and neuropathological signs of CTE.

Moreover, VanItallie (2019) also noted an association between the risk of being diagnosed with CTE and the number of years participating in football, noting that the longer time spent devoted to football, the higher the chances of developing CTE.

Outcomes of TBI

Apart from immediate symptoms of TBI, such as headaches, disturbed sleep, nausea and unrestrained drowsiness which usually recover over time, studies have also highlighted other long-term sequalae of TBI (Sahler & Greenwald, 2012; Van Gils et al., 2020; Yamamoto et al., 2018). Across all severities, TBIs can cause deficits across several cognitive domains, and the most frequently impacted domains are attention, executive functioning (EF), memory (Pavlovic et al., 2019) and processing speed (Stocchetti & Zanier, 2016). A scoping review in 2017 concluded that a large number of individuals who sustain a mild TBI (mTBI) will continue experiencing a considerable amount of cognitive impairments across the domains of attention, executive functioning, learning and memory, language and processing speed (McInnes et al., 2017). Therefore, it is understood that these cognitive deficits are not solely observed in the more severe TBIs.

Various studies have examined the cognitive symptoms and long-term consequences of TBI amongst athletes. However, past studies that have investigated neuropsychological profiles of athletes participating in different sports have demonstrated inconsistent findings (Tsushima et al. 2016). A recent systematic review also reported that concrete evidence of poorer cognitive functioning amongst former athletes who have been exposed to head trauma and concussions is still evolving (Cunningham et al., 2020). A more in-depth analysis of the neuropsychological profiles of contact and non-contact sport players will be presented further on in this chapter.

The following subsections will present a discussion on the cognitive domains which may be impaired as a result of a TBI, followed by an overview of functional outcomes and recovery of TBI.

Attention and Speed of Information Processing

Attention deficits and mental slowness are frequent symptoms post-TBI (Azouvi et al., 2017). In 1980, William James defined attention as ‘the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought’ (James, 1890, p. 403-404). Since this definition, multiple attempts have been made to provide a more accurate definition of attention (Lindsay, 2020). However, in its generic form, attention is described as a state of alertness and the ability to take in information from surroundings (Lindsay, 2020).

Several studies have reported significant difficulties related to attention control in individuals who have sustained a moderate to severe TBI (eg. Finnanger et al., 2015). Finnanger et al. (2015) concluded that individuals who sustained a moderate or severe TBI had experienced attention control difficulties during the five years following the injury in comparison to controls of same age, sex and education (eg. Finnanger et al., 2015).

An association between attention and processing speed has been well-documented (eg. Asloun et al., 2008; Bate et al., 2001). However, although not all difficulties related to attention may be attributed to slowed processing speed, deficits in the areas of divided (i.e. attending to multiple stimuli) and focused attention (i.e. attending to a specific stimulus) may be a result of slowed processing speed (eg.Asloun et al., 2008; Bate et al., 2001). Considering that both attention (eg. Cohen et al., 1993) and processing speed (eg. Calvillo & Irimia, 2020) are core cognitive processes due to the influence they hold on all other cognitive domains, deficits in these areas of functioning as a result of TBI can indeed impact daily living.

Other studies have also reported an association between post traumatic amnesia (PTA) duration and processing speed abilities one-year post TBI, demonstrating that as the PTA duration increases, processing speed abilities decrease (eg. Sigurdardottir et al., 2015).

Memory

Memory is often the first cognitive domain to be particularly impaired after sustaining a TBI, and one of the last to be regained during TBI recovery (eg. Barman et al., 2016). Memory is considered to be a dynamic cognitive function which is characterized by three individual cognitive processes, including encoding, maintenance and retrieval (Tulving, 1985). Although several studies have reported deficits in memory following TBI, it is unclear whether any of these three processes are significantly impacted in comparison to the other two processes (Paterno et al., 2017).

The hippocampus, prefrontal cortex (PFC) and their connecting tracts are the main areas of the brain which are involved in memory (Polich et al., 2019). Since both the hippocampus (Weston et al., 2021) and PFC (Hoskison et al., 2009; Wood & Worthington, 2017) are vulnerable to TBI, individuals who sustain a TBI are therefore at risk of developing difficulties related to learning and remembering.

Executive Functioning

Certain higher-order skills have been considered as 'executive' due to their association with the frontal lobes of the brain which are theoretically believed to function in an 'executive' (Pribram, 1973) or 'supervisory' (Shallice, 1988) manner. Since the frontal lobes are positioned at the front of the brain, a blow to the head may put these areas at high risk of damage (Nel & Govender, 2018). However, although deficits in executive function related behaviours are often present secondary to frontal lobe damage, damage to other brain structures can also lead to similar difficulties (Baddeley et al., 1997; Lezak, 1995). Recent definitions of EF steer towards defining the function of EF rather than the brain structure assumed to be responsible for the skill. A recent definition of EF by Cristofori (2019) depicts that EF includes the higher-order cognitive functions which enable goal achievement, and allow an individual to adapt to novel situations and maintain social interactions.

Moreover, apart from the cognitive functions, behavioural functions are also part of EF, and both cognitive and behavioural functions can be impacted by TBI (Rabinowitz & Levin, 2015). Some of these functions are displayed in Table 2 overleaf.

Table 2

Examples of Cognitive and Behavioural Executive Functions

Executive Functions	
Cognitive Functions	**Behavioural Functions**
Memory Acquisition and Retrieval	Motivation
Top-down Control of Attention	Impulsivity
Planning	Emotions
Judgement	
Decision Making	

Note: This table was adopted from Rabinowitz and Levin (2015). These are just some examples of many functions which fall under the umbrella term of executive functioning. Specific executive functions will be explored in depth in the last part of this chapter.

Functional Outcome and Recovery

Most individuals who have sustained a mild TBI (mTBI) often recover within weeks to months post-TBI, however the remaining subgroup of individuals experience long-term symptoms such as forgetfulness and difficulty concentrating (Cassidy et al., 2014). Predicting long-term deficits across cognitive domains in TBI also depends on other factors such as premorbid functioning and injury-related factors, and these factors may influence the trajectory of the extent of cognitive dysfunction and overall recovery (Svingos et al., 2019).

Most often, the majority of recovery of moderate to severe TBIs occurs during the first year post-injury (Iverson & Lange, 2011). The 12 month duration following a severe TBI is considered to be a crucial phase for recovery, and it is during this stage that TBI patients and their families are often faced with notable emotional and personal difficulties (Elbourn et al., 2018). Better functional outcomes have been associated with the onset of rehabilitation, where patients who receive rehabilitation at an earlier stage post-injury have a more favourable functional outcome in comparison to patients who receive later rehabilitation care (Andelic et al., 2012).

Moreover, the overall long-term recovery of moderate and severe TBIs is also dependent on other factors such as the patient's resilience, and the ability and willingness to adapt to any changes (Sandhaug et al., 2015). Other studies have also shown that additional recovery can be observed during the second year following injury, however further recovery following this stage is somewhat unrealistic (eg. Iverson & Lange, 2011). Furthermore, compensatory techniques to compensate for an impaired cognitive function can also reflect an improvement in functioning over the years ensuing the TBI (Iverson & Lange, 2011).

Neuropsychological Profiles of Contact and Non-Contact Sport Players

To link the aforementioned cognitive outcomes of TBI more specifically to sports, this section will present a closer look at the cognitive presentations of individuals who play sports.

Tsushima et al. (2019) conducted a study using the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) battery to assess neurocognitive functioning in a group of high-school athletes. ImPACT is a computerised neuropsychological measure used to assess an array of cognitive domains including verbal memory, visual memory and motor speed, impulse control and reaction time (Tsushima et al., 2019). As part of the ImPACT measure, a total symptom score is also obtained from a scale that lists post-concussion symptoms that are commonly reported, such as dizziness and headaches (Tsushima et al., 2019). The recruited athletes were categorized into three groups according to the risk of concussion in sport. These groups were listed as high contact (eg. football), moderate contact (eg. basketball) and low contact (eg. tennis) (Tsushima et al., 2019). Overall, the results showed that the high contact group had poorer performance than the two remaining groups, and this was also the case in the absence of a sport-related concussion (Tsushima et al., 2019). More specifically, lower scores in the high-contact group were revealed on tests of impulse control, visual memory and motor speed (Tsushima et al., 2019), and poorer results on the symptom scale were also shown in the high contact group (Tsushima et al., 2019). Furthermore, the high contact group showed poorer reaction time scores in comparison to the remaining two groups (Tsushima et al., 2019). When comparing the performance between the moderate contact and low contact groups, no significant differences were noted (Tsushima et al., 2019). This suggests that, apart from the high contact group, all contact sports included in the low and moderate contact groups of the study had shown similar performance on the tests.

Although the study did reveal that the high contact group had poorer scores, Tsushima and colleagues (2019) contend that the significant differences were not large enough to reflect actual clinical group differences. A limitation of the study suggested that the modest association between type of contact sport (high, moderate or low) and performance on neuropsychological tests may be a result of the psychometric properties of the testing instruments which were used (Tsushima et al., 2019). Nonetheless, previous studies by Tsushima and colleagues, one of which being a replication study, (Tsushima et al., 2016; Tsushima et al., 2018) also yielded results that have raised concerns about the risk of reduced neuropsychological functioning in young athletes who are exposed to high contact sports.

Furthermore, Hume et al. (2017) conducted a comparison study to compare cognitive functioning in former rugby players with former non-contact sport players (cricket and field hockey). They also sought to investigate for any association between a history of concussion and overall cognitive function. Hume et al. (2017) used a computerised neuropsychological test battery called CNS Vital Signs, and findings indicated that the contact sport players showed lowered performance across tests measuring complex attention, executive functioning (EF), processing speed and cognitive flexibility. They also concluded an association between history of concussion and any neurocognitive deficits (Hume et al., 2017).

Another study by Prien et al. (2020) sought to compare cognitive performance and mental health in retired elite football players and a group of retired non-contact sport players (Prien et al., 2020). Through their study, they also examined whether any of the findings were associated with a history of concussion or exposure to headings in football. Unlike the aforementioned studies that focused on computerized tests of neuropsychological functioning, Prien and colleagues (2020) also used a combination of other types of tests. A mix of computerised tools, paper-pen tasks, questionnaires and a symptom checklist were used (Prien et al., 2020). Results demonstrated that the contact sport and non-contact sport subjects achieved similar results on most of the tests. However, the contact sport players showed poorer performance on verbal memory and verbal fluency tasks, and such differences are assumed to be associated with a history of concussions and repeated headings in football (Prien et al., 2020). Moreover, the findings also suggested an association between the frequency of headings in sports, and depression, anxiety and overall mental health (Prien et al., 2020).

Thus, the aforementioned studies highlight the evolving research about the consequences of head injury on cognitive functioning in contact sport players.

Expanding on Executive Functioning

Due to the supervisory role of EF and its influences on all other cognitive domains, EF was chosen as the area of focus of this study. Furthermore, as mentioned in the previous section of this chapter, EF difficulties appear to have been highlighted in several studies which have investigated cognitive functioning in contact-sport players.

The following section presents an overview of the historical and current considerations in the study of EF, followed by a description of the role of executive functions in sport. Lastly, the specific executive functions which will be explored in this study will be presented, and an overview of neuropsychological tests of EF will be discussed.

Constructs of Executive Function

Research on EF dates back to Pribram's initial use of the term 'executive' to describe prefrontal functioning (Pribram, 1973), and the terms 'executive function tasks' and 'frontal tasks' have also often been used interchangeably (Keil & Kaszniak, 2002). Evidence of the association between the two terms originated from the case of Phineas gage who survived left frontal lobe damage and exhibited secondary impairments in executive functions, including altered behaviour and personality changes (Ratiu et al., 2004).

More recent studies have used advanced neuroimaging techniques, including functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans to investigate brain regions associated with EF. They have suggested that deficits in executive function are not solely associated with frontal lobe deficits, but are also associated with other connections between the frontal lobe and other areas of the brain (Bonelli & Cummings 2007; Stuss, 2011; Chung et al. 2014).

Since the 1970s, the concept of EF has been driven and defined by a number of different constructs, and it is difficult to conclude a universal and accurate term. However, a common belief amongst most researchers is that executive processes in general act as part of a supervisory and directive system, responsible for regulating other specific neuropsychological functions.

Over the years, several studies have discussed the unitary and diversity of the various executive functions (eg. Friedman & Miyake, 2017). Many of these studies have examined common executive processes which Miyake and colleagues (2000) classified as the three main executive functions, namely inhibition, shifting and updating. An association between EF and working memory (WM) was also suggested, implying that, to some extent, all executive functions are dependent on WM (Miyake et al., 2000).

Among all higher-order processes, inhibition, shifting and updating still remain the three core executive processes (Rodríguez-Nieto et al., 2022), and while they do not exclusively capture EF to the core, they illustrate the central domains that have been presented across several different paradigms of EF (Miyake et al., 2000; Miyake & Friedman, 2012).

The executive process of inhibition refers to the suppression of inappropriate responses (Rodríguez-Nieto et al., 2022), and this executive function is usually measured using interference control tests, requiring the individual to ignore any information that is not relevant to the task (Friedman & Miyake, 2004). Shifting involves redirecting one's attention between multiple sets, and is often assessed using task-switching tests which require the individual to move back and forth between tasks, or using tests which require the individual to perform two tasks in a simultaneous manner (Koch et al., 2018). Lastly, updating refers to the ability to store and manage information (working memory), and to monitor any incoming information relevant to the task at hand (Baddeley, 2012; Baddeley & Hitch, 1994). Working memory is commonly assessed using tests that require the ability to memorise information and manipulate that information to produce a response.

Similar to Miyake's model, the Diamond model (Diamond 2006; 2013) proposed that EF is defined as a construct based on inhibition, working memory (WM) and cognitive flexibility. Through this model (Diamond 2006; 2013), it has been proposed that other higher-order executive functions have developed from the aforementioned three core executive functions (inhibition, WM and cognitive flexibility). 'Planning' is an example of a higher order executive function which requires an individual to think and evaluate a sequence of steps prior to executing them (Diamond, 2013). In neuropsychology, the ability to plan is often measured using tests such as the Tower-of-Hanoi which requires an individual to rearrange plates in accordance with the provided rules whilst ensuring the least possible moves (Sullivan et al., 2009).

Along with their similarities, a key contrast between the two models is that whilst Miyake et al. (2000) postulate a unitary construct of EF with three distinct yet related functions, the Diamond model (2006; 2013) does not suggest any unitary mechanism of EF and suggests that EF is a multidimensional construct. Due to the overlap between models and the similarities between executive functions of both models, a variety of tests covering working memory (updating), cognitive flexibility (shifting), inhibition and planning were chosen for the purpose of this study. Through these tests, these specific executive functions will be assessed in individuals who play sports. The tests which were used for this study will be presented and further discussed in Chapter three.

Dysexecutive Syndrome

Moving away from using the term ‘frontal deficits’, the term ‘dysexecutive syndrome’ was coined by Baddeley (1986) to mitigate any misleading specification that executive functioning (EF) deficits are based on localisation. In 1988, Baddeley and Wilson suggested the use of a functional definition to describe deficits arising from damage to the frontal lobe. The use of functional definitions are in fact preferred for most cognitive disorders, such as referring to difficulties with memory as ‘memory deficits’ instead of ‘temporal lobe deficits’, thus moving away from labelling syndromes in terms of localisation (Ardila et al., 2007). Therefore, since neurological deficits are rarely restricted to the frontal lobe, the term ‘dysexecutive syndrome’ is more often used to describe such EF deficits (Hanna-Pladdy, 2007).

As evidently illustrated in the case of Phineas Gage, patients with prefrontal pathology may show intellectual abnormalities, such as difficulty solving tasks, as well as marked changes in their emotions and behaviour (Ardila, 2013). These changes are associated to what seems to be two different, yes closely associated executive functions, namely ‘metacognitive executive functions’ and ‘emotional/motivational executive functions' (Ardila, 2013). When comparing the anatomical structures of the prefrontal cortex (PFC) that are associated with the two executive functions, the metacognitive executive functions are associated with the dorsolateral PFC, whilst the emotional/motivational executive functions are said to be associated with the orbito/medial PFC (Ardila, 2013).

Given the vast range of behavioural and cognitive deficits that are associated with the executive domain, the term ‘dysexecutive syndrome’ therefore holds clinical utility (Hanna-Pladdy, 2007).

EF in Sport

Successful performance in sport requires a set of cognitive skills and higher-order executive functions. Problem-solving and decision-making abilities are two examples of executive skills which are largely investigated in sport psychology (eg. Moore et al., 2019). Previous studies have indeed emphasized the role of higher-order executive functions across different sports (eg. Lundgren et al., 2016). For example, basketball players are required to remember the blocking techniques of the opposing team players, and to then use that information to plan and decide on their responsive attack (working memory). Performance in sport also requires inhibition (ignoring irrelevant stimuli) and cognitive flexibility (quickly adjusting to changes) skills (Koch & Krenn, 2021).

The specific higher-order executive functions which are investigated in this study will be explored in further detail in the following section.

Specific Executive Functions Explored in this Study

In light of the previously mentioned studies, the scope of this study is to investigate for any EF deficits experienced by contact sport players in comparison to non-contact sport players. Furthermore, this study aims to examine EF abilities in individuals who play contact sports at professional level, or have a history of concussion/head-injury in sport.

The following sections will delve into a deeper understanding of the specific executive functions which are explored in this study. The specific executive functions have been chosen with reference to the aforementioned EF models proposed by Miyake et al. (2000) and Diamond (2006; 2013), thus supporting both a unitary and multidimensional construct of EF.

Working Memory

Initially, Miller et al. (1960) coined the term 'working memory' (WM). The concept of WM was then adopted by Baddeley and Hitch in 1974 in their multicomponent model, providing a clear differentiation between WM and long-term memory. WM is considered to be the temporary storage and processing of information which is then used for problem solving and other tasks that are carried out over a limited period of time (Baddeley 1986; 2002). The problem-solving aspect of WM can be better explained as the manipulation of the stored information for complex cognitive tasks (Della Sala & Logie, 2002). In line with Baddeley's definition (Baddeley, 1986; 2002), Goldman-Rakic (1993) also defined the function of WM as the ability to hold information, internalise that information and use that information to guide behaviour without the support of any cues.

One of the most frequently used and simplest tests of WM is the Digit Span Backwards (DSB) from the Wechsler Adult Intelligence Scale assessment [WAIS] (Lezak et al., 2012; Wechsler, 2008). In the DSB test, the examinee is asked to remember a sequence of numbers, manipulate the number order, and produce a response of the numbers in reverse order.

Response Inhibition

The ability to inhibit a response is often defined as the capacity to withhold a predominant response (Stevens et al., 2007). Response inhibition is often measured with Go/No-Go tasks which require the examinee to produce manual responses to the rapidly changing auditory or visual cues (‘Go’ stimuli), but to restrain responses when provided an unlike cue (‘No-Go’ stimuli) (Stevens et al., 2007). Furthermore, the four different conditions of the Colour Word Interference test (CWIT) from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001) are widely used as a measure of response inhibition. In the CWIT, an examinee is required to complete tasks involving colour naming, word reading, inhibition (saying the ink colour and not reading the word), and switching between colour naming and word reading.

Therefore, response inhibition involves the ability to control and inhibit any inappropriate or irrelevant responses by means of appropriate and logical reasoning.

Cognitive Flexibility and Task Switching

Cañas et al. (2003) define cognitive flexibility as an individual’s ability to adapt learnt cognitive strategies to novel situations. In saying so, cognitive flexibility reflects a learning process which is developed through experience, and adapted according to unexpected changes in the environment (Cañas et al., 2006).

According to the Cognitive Flexibility Theory, individuals who have intact cognitive flexibility are able to quickly adapt and restructure their knowledge across multiple situational changes and demands (Spiro & Jehng, 1990). Detecting a change within an environment also requires a higher level of attentional control to primarily identify a new situation and act accordingly (Cañas et al., 2006). This ability to adapt is considered to be troublesome in situations where an individual cannot be flexible in noticing that an environment has changed (Cañas et al., 2006). The term ‘task switching’ is also used to describe the executive function that refers to the ability to adapt to a multi-tasking situation that requires shifting between two or more tasks which have no temporal overlap (Monsell, 2003; Kiesel et al., 2010).

Therefore, tasks which instruct the examinee to adapt, follow and switch between multiple instructions could assess such abilities. An example of a commonly used test to measure these abilities is the Trail Making Test [TMT] (D-KEFS) (Delis et al., 2001). This test is divided into five conditions, with conditions requiring the examinee to switch between two tasks. Condition one (visual scanning) requires the individual to mark all the target stimuli on the response booklet, whilst condition two (number sequencing) requires the individual to connect the numbers in sequential order. Condition three (letter sequencing) then requires the individual to join the letters in order, whilst condition four (number-letter switching) involves switching between numbers and letters in this fashion: 1-A-2-B-3-C. Lastly, condition five (motor speed) measures basic visuomotor speed.

Planning and Organisation

Executive functioning (EF) deficits may also present as poor planning skills and difficulties related to organisation (Lezak, 1982). Therefore, in the absence of such skills, an individual may experience difficulty to design a step-by-step plan and to execute that plan. An association between damage to the dorsolateral prefrontal cortex (DLPF) and impaired planning abilities and hypothesis generation have also been proposed (Royall et al., 2002). Other research also noted differences between performance that is assessed on a standard test of planning abilities, in comparison to the actual planning required to complete everyday tasks (Hanna-Pladdy, 2007). A frequently used ecologically valid test is the Key Search Test from the Behavioural Assessment of the Dysexecutive Syndrome [BADS] (Wilson et al., 1996). Intending to reflect a real-life scenario, the Key Search assess an individual’s ability to create and executive a search plan to find a key which was lost in a field.

Executive Deficits and Everyday Functioning

Real-life complex scenarios and overall daily functioning involve organisation skills and goal-oriented behaviours which rely on a vast number of cognitive resources (Burgess et al., 2000). For example, having the executive skills to devise a grocery list, to organise and cook a meal, or to maintain a full-time job. Most neuropsychological tests involve short trials and require the patient to tackle single explicit problems in which initiation is usually prompted by the assessor, and successful trial completion is distinguished (Shallice & Burgess, 1991). In light of this, patients with executive deficits may still perform well on neuropsychological assessment of executive function (Verdejo-García & Pérez-García, 2007). Therefore results must be interpreted with caution, and when possible, ecologically valid tests should be opted for.

Furthermore, it is often difficult to assess EF in patients with dysexecutive syndrome, as although the individual component skills of EF may be intact upon tasks like the building blocks tasks (eg. Block Design; Wechsler, 2008), patients may be unable to initiate EF skills in daily tasks, and will experience difficulties in everyday activities (Burgess and Alderman,1990). On the contrary to laboratory testing, many daily tasks require individuals to use their executive skills over a longer period of time in which they are usually presented with multiple competing tasks at the same time (Shallice & Burgess, 1991). In order to capture a better understanding of executive deficits in everyday functioning, self-report and informant-report questionnaires of EF such as the Dysexecutive Questionnaire (DEX; Wilson et al., 1996) are often used.

Neuropsychological Tools Measuring Executive Function

Walsh (1978) has emphasized that assessments of EF should be novel, complex and must involve an integration of information. However, Alexander and Stuss (2000) have stated that it is hard to generalise what is considered as novel and what is considered as overlearned, as what may be novel for one individual may not necessarily be novel and complex for another.

Emphasis has been made on the importance of measuring EF in more ecologically valid ways, thus moving closer to capturing an idea of real-life functioning and moving away from standard laboratory testing (Doebel, 2020). The Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson et al., 1996) was introduced in response to the need for more ecologically valid assessment tools to measure EF (Norris & Tate, 2000). As a measure to assess EF and to predict everyday problems of EF which may arise in daily life, the BADS includes a total of six subtests measuring cognitive flexibility, novel problem solving, planning, judgement and estimation, and behavioural regulations. The six subtests of the BADS include the Rule Shift Cards, Key Search, Zoo Map, Modified Six Elements, Action Programme and Temporal Judgement.

Furthermore, the BADS also includes the previously mentioned self-report questionnaire and an independent rater questionnaire as report-based measures of dysexecutive problems (DEX; Wilson et al., 1996). A study by Bennett et al. (2005) investigated the sensitivity of the Dysexecutive Questionnaire (DEX) to assess executive dysfunction. To do so, they used several measures including the DEX to assess 64 TBI individuals. The DEX was used by a clinical neuropsychologist and an occupational therapist for each of the 64 individuals who participated in the study. Only a few measures were sufficiently useful in predicting DEX scores, and results showed that using a mix of various tests from the BADS and other assessments may be essential in order to detect any signs of executive dysfunction within a clinical population (Bennett et al., 2005).

Another study by Azouvi et al. (2014) highlighted a strength of the DEX questionnaire. They noted that the DEX combines both emotional and cognitive features of an individual's behaviour, and provides a comprehensive picture and understanding of how the experienced difficulties could be impacting everyday life (Azouvi et al., 2014).

Along with the BADS, another widely used measure is the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). Being the very first assessment of its kind, the D-KEFS focuses solely on assessing EF (Latzman & Markon, 2010). It is defined to be a comprehensive assessment battery which provides normative and qualitative information about higher level cognitive skills, such as problem solving skills, reasoning abilities and planning skills amongst others (Shunk et al., 2006). The D-KEFS consists of nine stand-alone tests, namely the Trail Making Test, Design Fluency Test, Verbal Fluency Test, Sorting Test, Color-Word Interference Tests, Twenty Questions Test, Word Context Test, Tower Test, and Proverb Test (D-KEFS; Delis et al., 2001). A key strength of the D-KEFS is that each of the nine tests can be administered independently, each of which provides an overall performance score (Shunk et al., 2006).

Although the D-KEFS has also been documented as a well-designed measure of frontal lobe functioning measuring a vast range of neuropsychological abilities (Shunk et al., 2006), other academics in the field have stated that the nine tests of the D-KEFS are not representative of a comprehensive EF assessment (Baron, 2004).

Other research has also shown that the D-KEFS holds adequate levels of validity and reliability (Delis et al., 2004), as well as appropriate test-retest reliabilities (Homack et al., 2005). Considering that all tests can be administered individually, this allows the assessor to compare performance between tests, thus classifying the D-KEFS as an appropriate measure for structural studies and age-related changes (Latzman & Markon, 2010).

It is postulated that tests involving EF very often require the input of other cognitive domains, such as attention (Diamond, 2013). In saying so, performance on tests of EF are subject to error as detecting EF deficits may be inaccurate and not representative of current

EF due to the involvement of other areas of cognition (Diamond, 2013). Thus, when interpreting scores, it is important to note that errors on EF tests may also be attributed to possible deficits in other areas of cognitive functioning. Anderson (2002) also noted that when scoring assessments, situational and behavioural factors are not considered. Therefore, scoring heavily relies on quantitative test findings of EF performance that may limit the diagnostic utility of the tests. In order to overcome this limitation, an amalgamation of quantitative, qualitative and cognitive process methodologies for testing and interpretation is recommended (Anderson, 2002).

Due to the strong ecological validity of the BADS and the comprehensiveness of the D-KEFS, this study shall make use of subtests from both measures to assess the EF abilities of individuals who play sports. Together with these tests, the commonly used digit span test of working memory (WM) will be included in the study.

Other measures

Apart from the assessment measures mentioned in this chapter, there are other common neuropsychological assessments which are used to measure EF. Some of these include, but are not limited to the Iowa Gambling task (Bechara et al., 1994) the Wisconsin Card Sorting Test (Berg, 1948; Grant & Berg, 1948) and the Go/No-Go task (Gordon & Caramazza, 1982).

Overall, when considering the major role of EF in overall cognitive functioning, EF abilities are not only captured on the mentioned EF assessments. They can also be evaluated through clinical observations and further interpretation of the examinee’s performance on other subtests that measure different domains.

Conclusion

In conclusion, this chapter reviewed existing literature on traumatic brain injuries (TBI) with a particular focus on executive functioning (EF) in TBI. The pathophysiology of

TBIs and the clinical presentations of different severities of TBI were discussed, and the vulnerability of TBI in sport was explored. Studies which have investigated the neuropsychological profiles of athletes who participate in contact and non-contact sports were presented, and different executive functions and their applicability in everyday life were also considered. Lastly, commonly used neuropsychological measures of EF were discussed.

The following chapter will explore the methodology utilized for the purpose of this study to explore the EF abilities of people who participate in sports.

Chapter 3: Methodology

Introduction

This chapter describes the methodology that was adopted to explore the executive functioning (EF) abilities of individuals who play contact sports. The theoretical framework, research design and the study sample are first presented, followed by a review of the assessment tools used for data collection. The general procedures including the ethical considerations and research approval are then described. Lastly, the developed hypotheses of the study and the analytical tools used to analyse the findings and test the hypotheses are presented.

Introducing the Theoretical Framework

Stemming from positivism, the epistemology of quantitative research asserts that the researcher and the research participant are two separate entities, and that the researcher can investigate a phenomenon without affecting or being affected by the participant (Deshpande, 1983; Denzin & Lincoln, 1994; Sale et al., 2002). Considering the distinction between the researcher and the participant, this approach was termed as a dualist or objectivist approach (Smith, 1983). The quantitative positivist approach also posits that facts and values can be viewed independently, therefore achieving truth based on facts and the as-is (Slevitch, 2011).

Furthermore, the post-positivist approach emphasises the probability of an objective perspective of reality. Post-positivists believe that while it is impossible to find the truth, researchers can only aim to represent reality in a way that is influenced by subjectivity (Sukamolson, 2007).

With reference to the current study, the researcher believes that due to the susceptibility of inevitable errors in quantitative research and the imperfect extent of reality in the findings, the post-positivist paradigm is a suitable approach for investigating EF in individuals who play sports.

The Research Design

This study adopted a quantitative methodology for the data collection and analysis of results, allowing the researcher to gather a large sample of participants and to investigate any associations in a more generalisable manner within the local context. For the purpose of the assessment procedure of this study, the researcher chose a mix of performance-based tests of EF, together with a self-report measure of EF and a demographic questionnaire.

The performance-based tests were chosen from three different standardised assessments batteries, namely the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008), the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) and the Delis-Kaplan Executive Function System (DKEFS; Delis et al., 2001a). Considering that these assessment batteries include many different subtests measuring different areas of cognition, the researcher chose subtests which are commonly used in local clinical practice to measure the specific functions of EF that are investigated in this study. These include, working memory (Digit Span test), planning and performance monitoring (Key Search test), inhibitory control (Colour Word Interference test), cognitive flexibility (Rule Shift Cards test), task switching (Trail Making Test), as well as everyday problems of EF (Dysexecutive Questionnaire).

Moreover, considering that none of the aforementioned assessment batteries were standardised on a local population, the researcher ensured to choose subtests which were not necessarily culture specific. This was done by choosing tests that are not directly influenced by environmental factors that reflect a specific culture. Considering the large research sample, tests were also chosen based on the time of administration and the information that they provide. Therefore, when possible, subtests which are relatively quick to administer were chosen over the subtests which take a longer time to administer.

The following sections will explore the research methodology in further detail.

Participants

Participants were recruited by means of convenience sampling through internet platforms. Convenience sampling is a non-probability sampling method and is often used based on its convenience for the researcher (Acharya et al., 2013). Through social media platforms, the researcher was able to gather as many individuals as possible from the general population who fit the criteria of participation. Some participants were also recruited through participants who had already participated in the study, and others were also recruited through acquaintances who contacted and recommended eligible participants based on the inclusion criteria of the study.

The inclusion criteria for eligibility to participate in this study were as follows.

- Participants were required to be at least 18 years of age since the study aimed to investigate EF in an adult population who play sport.
- Participants were required to be practising a sport during the time of recruitment and participation in the study.
- Participants were required to have a good understanding and comprehension of the English language since the chosen EF tests for data collection were developed and standardised in English.

The exclusion criteria of this study included the following.

- Participants had difficulties related to colour blindness. This exclusion criterion was included as any difficulties related to colour blindness would have interfered with a specific task which was included in the data collection process (Colour-Word Interference test; CWIT). In order to assess for this, participants were asked to name out the colours of different blocks of colour which were printed on an A4 paper.

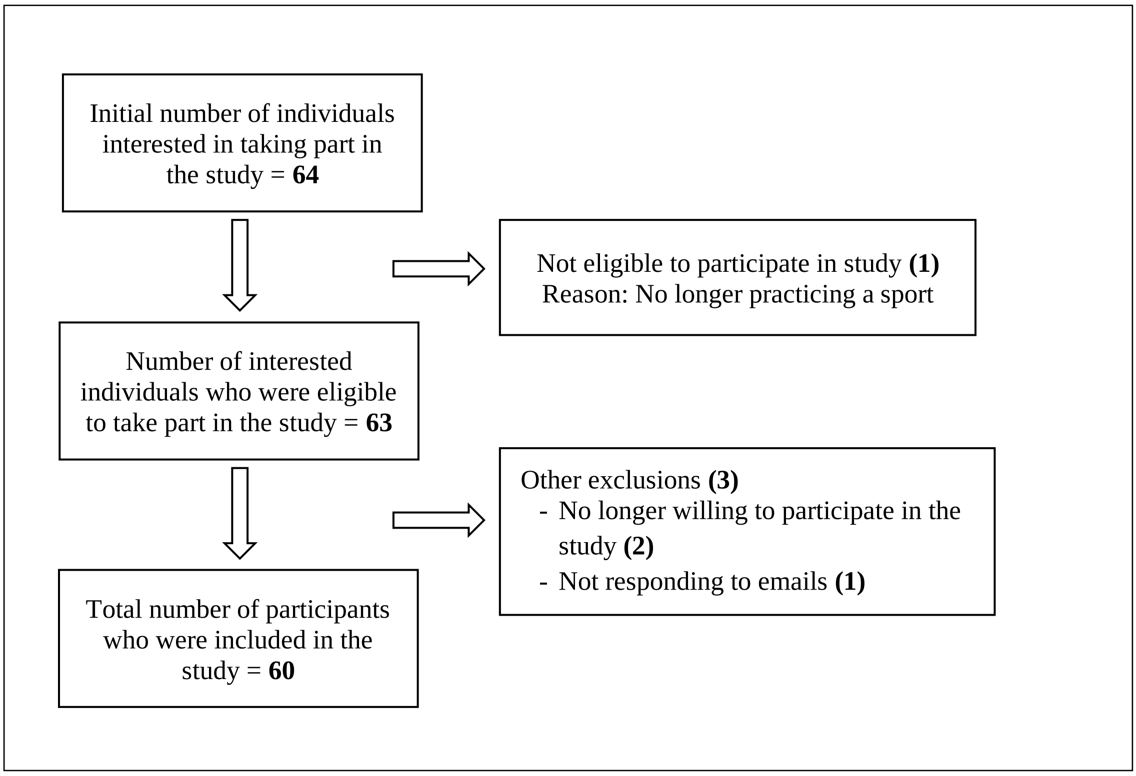
The Sample

As previously mentioned, this study adopted a convenience sampling technique. Thus, any individuals who fit the inclusion criteria were automatically eligible to participate. Initially, 64 potential participants showed an interest to participate in the study. Of these, one individual was excluded due to no longer practicing a sport, two individuals dropped out from the study as they were no longer willing to participate, and one individual was no longer responding to emails sent by the researcher. Following the exclusion of these individuals, the total sample size consisted of 60 participants. A total of 19 participants were female (*n*=19, 32%), and the remaining 41were male (*n*=41, 68%).

The recruitment process from initial interest to participation in study is illustrated in Figure 2 below.

Figure 2

Flowchart of the participant process from interest to inclusion in the study



Measures Used for Data Collection

The following subsections provide a detailed description of each measure which was used to gather relevant data for the purpose of this study.

Demographic Questionnaire

Participants' demographics were obtained using a demographics questionnaire which was produced by the researcher. This questionnaire consisted of a total of 11 questions, however completion of all questions was only required when applicable to the participant and in relation to previous responses on the questionnaire. The researcher ensured that only demographic information that could be relevant to the study was requested. Prior to filling in the demographic questionnaire, participants were informed that they could ask the researcher any questions should they have had difficulty understanding any of the questions.

Participants were required to indicate their gender and age for standardised scoring purposes. To support the researcher in classifying data during the analysis stage of the research, participants were asked to provide information regarding the type and name of sport they play. Participants were then asked how often they practice the sport and whether they practice the sport at a professional level or not, and if yes, for how long. TBI is more frequently seen in football players who play at a professional level due to the nature of the profession itself, and due to this, it has been termed to be an occupational disease (Vos et al., 2018). Such information may therefore allow the researcher to identify any group differences based on level of sport.

Participants were then asked whether they currently practiced any other sport, and whether they practiced any other sport in the past. If yes, they were asked to indicate which sport and whether they played at a professional level or not. Participants were also asked about any history of concussion and/or head injury in sport, and if yes, at what age, and how many. In the presence of a history of such injuries in sport, participants were required to indicate the severity of the injury ranging from mild, moderate or severe injury. The researcher deemed that such information was important to include since individuals with a history of concussion are at a significantly higher risk of sustaining further injury in sport in comparison to individuals that had never sustained a concussion (Reneker et al., 2019). Lastly, participants were asked to indicate whether they were ever hospitalised for such injuries.

Digit Span subtest from the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008)

The Digit Span (DS) is a subtest which is part of the most recent and widely used intelligence quotient test called the Wechsler Adult Intelligence Scale (Fourth Edition) (WAIS-IV; Wechsler, 2008). The DS test is often administered as part of the whole assessment battery or as an individualised subtest as a measure of working memory (WM) abilities. This subtest is divided into three parts, including Digit Span Forwards (DSF), Digit Span Backwards (DSB) and Digit Span Sequencing (DSS). For the purpose of this study, the researcher chose to administer the forwards (DSF) and backwards (DSB) tasks of this test, allowing comparison between immediate verbal memory and verbal WM.

The DSF part of the task required the participant to listen to different sequences of numbers read out by the researcher. Once the researcher finished reading each sequence, the participant was asked to repeat the numbers as they were read out by the researcher. This task had a total of eight items, each of which had two sequences of numbers. On the DSB task, the participant was required to repeat the sequence of numbers in reverse order. For this task, two sample unmarked trials were provided to ensure that the participants had understood the instructions well. For both the DSF and DSB, each correctly recalled sequence was allocated one point with a maximum of two points allocated per item. Both the DSF and DSB tasks were discontinued if the participant failed to correctly recall both sequences on an item. The maximum achievable total raw score is 16 for both tasks individually. Raw scores were then converted to scaled scores according to age range by using the conversion tables in the WAIS-IV manual. Scaled scores ranging between eight to 12 are considered to be average scores, whilst any scaled score below eight is considered to be below average and any score over 12 is considered to be above average for individuals the same age as the assessed.

A study by Fork et al. (2005) found that patients with Diffuse Axonal Injury (DAI) showed impaired performance on DSB tasks when compared to TBI patients that had normal computerised tomography (CT) scans. Despite the additional information which can be gathered from the sequencing task of this test, the researcher deemed that adequate information could be gathered from the DSF and DSB tasks of the digit span subtest.

Psychometric Properties. According to the WAIS-IV normative sample, the test-retest reliability of was .77 for the DSF and .71 for the DSB (Wechsler, 2008). Across age groups, mean internal consistency reliability of the DSF and DSB were reported to be adequate, at .81 and .82 respectively, and .93 for total DS (Wechsler, 2008). A test review by Climie and Rostad (2011) reported that most of the scoring of the WAIS-IV subtests is relatively straight forward (i.e. a response is either correct or incorrect), thus general interrater reliability of the test can be considered to be high. To test both the convergent and discriminant validity, subtests of the WAIS-IV have been co-normed with a variety of other assessments, and when comparing composite scores between the WAIS-IV and WAIS-III, the correlations between scores suggested high consistency (Climie & Rostad, 2011).

Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson et al., 1996)

As previously mentioned in Chapter two, the BADS (Wilson et al., 1996) is used to assess everyday problems resulting from EF deficits. As an assessment of EF, it emphasises on subdomains which are most often utilised in daily tasks, including planning, problem-solving and organisation skills amongst others (Wilson et al., 1996). For the purpose of this study, two performance-based subtests (Key Search and Rule Shift Cards) and a self-report measure (Dysexecutive Questionnaire; DEX) from the BADS were chosen and will be discussed in the following subsections.

Dysexecutive Questionnaire (DEX; Wilson et al., 1996). The DEX questionnaire is a report-based questionnaire which is used to assess for dysexecutive syndrome, and it is available in two versions. The Self-Rating form is filled in by the examinee, whilst the Independent-Rating form can be filled in by a family member or someone else who is knowledgeable about the examinee's behaviour and performance in everyday life (Wilson et al., 1996). Participants were asked to fill in the Self-Rating form of the DEX questionnaire as part of their participation in this study.

The DEX questionnaire consists of 20 items covering different aspects of EF. The participant was required to rate each statement on a five-point scale according to how much it applied to them. The five-point scale ranged from Never (0 points), Occasionally (1 point), Sometimes (2 points), Fairly Often (3 points) and Very Often (4 points). Total scores were obtained by adding the total scores of the items according to three factors, including Behaviour, Cognition and Emotion. Table 3 overleaf is adapted from the BADS manual and shows an overview of the three factors and their corresponding items of the questionnaire.

Table 3

Factor structure of the DEX

Factor	Items
Behaviour	2 - I act without thinking, doing the first thing that comes to mind. 7 - I have difficulty realising the extent of my problems and am unrealistic about the future. 9 - I do or say embarrassing things when in the company of others. 12 - I lose my temper at the slightest thing. 13 - I am unconcerned about how I should behave in certain situations. 15 - I tend to be restless, and 'can't sit still' for any length of time. 16 - I find it difficult to stop myself from doing something even if I know I shouldn't. 20 - I am unaware of, or unconcerned about, how others feel about my behaviour.
Cognition	3 - I sometimes talk about events or details that never actually happened, but I believe did happen. 6 - I get events mixed up with each other, and get confused about the correct order of events. 14 - I find it hard to stop repeating, saying or doing things once I've started. 18 - I find it difficult to keep my mind on something, and am easily distracted. 19 - I have trouble making decisions, or deciding what I want to do.
Emotion	5 - I sometimes get over excited about things and can be a bit 'over the top' at these times. 8 - I am lethargic, or unrealistic about things. 11 - I have difficulty showing emotion.

Key Search Test (Wilson et al., 1996). The Key Search test is used as a measure of planning abilities and performance monitoring (Wilson et al., 1996), and is relatively short and easy to administer. This subtest was included in the study as EF deficits may present as poor planning and organization abilities upon tasks (Lezak, 1982). Each participant was provided with an A4-sized white paper which had a 100 millimetres (mm) black bordered square in the middle of the paper and a small black dot 50mm beneath the square. Participants were told that the square represents a large field where they have lost their keys. Each participant was instructed to draw a line starting from the dot to show where they would walk to search the field with the aim of finding the lost keys. Although there was no time-limit for the task, participants were told that their performance would be timed and that they could take as long as needed to complete the search.

Scoring of this task is based on the following elements; entering the field, finishing the search, making a continuous line, making all parallel lines and making all vertical/horizontal lines. Further scoring is based on whether the participant made use of any pre-defined search patterns as presented in the BADS manual, whether the participant has made an obvious effort to cover all the ground of the field, and whether their chosen search pattern would provide a 95 percent certainty that they would find the keys.

Each element is scored according to the scoring criteria in the BADS manual, and a total raw score is obtained by adding the points from each element. The raw score was then converted into a profile score as present in Table 4 overleaf. If the participant took longer than 95 seconds to draw the route of their search pattern, one point was subtracted from the obtained profile score. Any profile score below 4 indicates difficulties in the measured abilities.

Table 4

Scoring of the Key Search Test

Raw Score	Profile Score
14-16	4
11-13	3
8-10	2
5-7	1
≤ 4	0

Rule Shift Cards Test (Wilson et al., 1996). The Rule Shift Cards test (Wilson et al., 1996) is broadly used to measure abilities related to cognitive flexibility and task switching, as well as the ability to follow a rule. This task consisted of a deck of 21 playing cards, some of which were red, and some of which were black. This task was divided into two trials, and each trial required the participant to follow a different rule. Both rules were printed on separate A4 papers, and the corresponding rule per trial was visible to the participant throughout each trial. By having the rules visible for the participant to refer to during the task, the chances of any memory constraints were reduced.

The rule of the first trial was to say, ‘yes’, whenever presented with a red playing card and to say, ‘no’, whenever presented with a black playing card. The second trial of the task followed a different rule, where the participant was required to say, ‘yes’ if the colour of the playing card was the same as the previous playing card shown, and if otherwise to say, ‘no’. The number of correct responses and the number of errors for each trial are totalled, however the first trial is not used to calculate the total profile score of this test. Scoring is only based on the total time taken and the number of errors on the second trial. The number of errors on trial two was converted to a profile score as presented in Table 5 overleaf. Should the time taken to complete trial two had been greater than 67 seconds, 1 point was removed from the profile score. Any profile score below 4 indicates difficulties in the measured abilities.

Table 5

Scoring of the Rule Shift Cards Test

Total Errors	Profile Score
0	4
1-3	3
4-6	2
7-9	1
≥ 10	0

Psychometric Properties. The BADS manual (Wilson et al., 1996) indicates adequate inter-rater reliability and concurrent validity. Test-retest reliability was reported to be highest in the Key Search, Action Program and Temporal Judgement tests, and lower in the remaining tests (Lezak et al., 2012). Considering that that novelty of EF tests is crucial, it is unlikely to expect overall high test-retest reliability since the tests will no longer be novel when re-administered (Wilson et al., 1996). The ecological validity of the test is also considered to be superior in comparison to other tests, classifying the BADS as a good measure of EF in daily functioning (Wilson et al., 1996). Comparable to other tests, the BADS has shown good construct validity in discriminating between neurological groups and group of individuals with no brain damage (Norris & Tate, 2000). Lezak et al. (2012) also report that several previous studies have examined the performance of TBI patients on the BADS, and the results demonstrated that TBI patients showed impairments on various subtests of the BADS.

Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001a)

The D-KEFS is another widely used laboratory-based assessment of EF (Delis et al., 2001a). The researcher chose subtests from this assessment due to the advantage of each of the nine included tests also being considered as stand-alone tests which are believed to assess the primary subdomains of EF that are associated with the frontal lobe (Delis et al., 2001a). The chosen subtests for this study (Colour-Word Interference Test and Trail Making Test) are designed to measure EF abilities related to response inhibition and task-switching (Delis at el., 2001).

Both chosen subtests were scored by converting raw scores (time taken) to scaled scores according to age. Any scaled score ranging from eight to 12 is considered to be within the average range of functioning, whilst any score below eight is considered as below the average and shows a level of impairment. Scaled scores above 12 indicate that the performance is above the expected ability of an individual the same age.

Colour-Word Interference Test (Delis et al., 2001a). The Colour-Word Interference Test (CWIT; Delis et al., 2001), more commonly known as the Stroop, is a measure used to broadly assess cognitive inhibition over four conditions (Scarpina & Tagini, 2017). This test is based on the Stroop test which was coined by Stroop in 1935. A study by Dimoska-Di Marco et al. (2011) supports the presence of response inhibition deficits subsequent to TBI, however they also note that there are other aspects such as fatigue and processing speed deficits which may influence poor performance on the Stroop task. However, although it can be argued that fatigue and processing speed deficits can influence performance on the Stroop, it is also possible that the presence of EF impairments can be the underlying cause of such deficits.

The conditions relevant for this study were the second (Word Reading), third (Inhibition) and fourth (Inhibition/Switching) conditions. The second condition required the participant to read the names of different colours which were printed in black ink. The third condition then required the participant to say the ink colour which the words were printed in and not to read the words. For example, if the word ‘red’ was printed in green ink, the correct response would be ‘green’, and not ‘red’. On the fourth condition, participants were required to switch between the rules on the two previous conditions. This was done by switching between saying the ink colour of the words that were not within a box, and reading the words that were within a box. Whilst the second condition is simply a word-reading task, the third and fourth conditions are those which require response inhibition and cognitive flexibility skills.

The duration to complete each condition was timed and any self-corrected and uncorrected errors were noted. Scoring was based on the completion time of each condition, and the time taken per condition was converted into a scaled score according to age using the respective conversion tables of the D-KEFS manual.

Trail Making Test (Delis et al., 2001a). Broadly, the Trail Making Test (TMT) is a measure of visual attention and visual search abilities, cognitive flexibility, spatial skills and task-switching ability. The TMT consists of a total of five conditions which measure different abilities (Delis et al., 2001a). With reference to the scope of this study, the researcher included the second condition (Number Sequencing) and the fourth condition (Number-Letter Switching) of the TMT. The second condition required the participants to join 16 numbers in sequential order, whilst the fourth condition required the participants to switch between numbers and letters in sequential order, starting in this manner: 1-A-2-B-3-C. Condition four is designed to assess higher-order cognitive skills including cognitive flexibility, attention, inhibition and interference control.

Both conditions were timed, and any errors were marked by the researcher by placing an X on the response booklet on the incorrect lines whilst the participant was completing the task. When generating a scaled score, the time taken was considered as the raw score which was then converted into a scaled score according to the respective age-bands as presented in the conversion tables of the D-KEFS manual.

Psychometric Properties. Since the tests included in the D-KEFS were modified from other pre-existing tools which had demonstrated validity, the validity of most of the tests in the D-KEFS was established (Delis et al., 2001b). A test review by Shunk et al. (2006) stated that relatively low positive correlations were indicated on validity tests, suggesting that the individual tests included in the D-KEFS are not interchangeable, and thus measure different executive functions. With reference to D-KEFS tests used for this study, internal consistency of both the TMT and the CWIT were relatively high, .57 to .81 and .62 to .86 respectively (Shunk et al., 2006). Test-retest reliability of the CWIT also showed relatively adequate results across conditions, ranging from .62 to .76 (Delis et al., 2001b). A study by Anderson et al. (2017) examined the criterion validity of the CWIT with 128 TBI outpatients and proved criterion validity of Condition 4 of the test (Inhibition/Switching). It was also suggested that the Inhibition/Switching subtest of the DKEFS adds clinical utility to the traditionally known Stroop test (Anderson et al., 2017).

With reference to the accuracy of the TMT, a study by Sánchez-Cubillo et al. (2009) has also suggested that the construct validity of the TMT can be proved, indicating that the test provides a clear indication of skills related to executive control.

General Procedures and Ethical Considerations

The research proposal for this study was accepted by the Department of Psychology on the 13th of April 2022, and the commencement of this study began following an acknowledgement of the research ethics application from Faculty Research Ethics Community (FREC) on the 5th of July 2022. Since this study involved a normative sample, no further ethical approval was required.

Each participant was provided with an Information Sheet (Appendix B) which was sent by the researcher via email, and this sheet contained further information regarding the study, participation and ethical considerations. Furthermore, participants were also offered the opportunity to ask any questions about the study. Participation was voluntary, therefore any eligible individual was able to participate in the study. Following voluntary choice to participate, all participants were provided with a consent form (Appendix B), and informed written consent was obtained electronically or by hand prior to the one-time assessment. A suitable date and time for the assessment was set between the participant and the researcher, and an effort was made to ensure that the setting of testing was held at a location where distractors were kept to a minimum. The length of testing was approximately between 30-40 minutes on average, however the total duration per participant was dependent on the amount of time that each participant took to understand and complete the tasks that were administered by the researcher. The data collection phase of the study took place between December 2022 and March 2023.

All participants had the right to accept, refuse or stop participation at any time in the research without needing to provide any reason and without any penalty. However, participants were informed that, in the event that a participant chooses to withdraw from the research, data from their assessment would only be erased as long as it was physically possible. Anonymity and confidentiality of participation was ensured by storing participant assessment scores in an anonymised form and separate from signed consent forms, and there were no specific risks to the participants.

In cases where participants asked for their individual assessment findings, scores were sent via email to their personal email address, and they were informed that such scores were not diagnostic and were solely administered for the purposes of this study.

Research Hypotheses and Method of Data Analysis

This study primarily aimed to examine EF in contact sport players and to compare EF in contact sport players to non-contact sport players. Following the data collection process, participants were divided into two groups according to whether they practice contact sports (CONTACT) or non-contact sports (NON-CONTACT) based on the information which they provided on the demographic questionnaire. The data collected was gathered and analysed using the most recent version of the Statistical Package for the Social Sciences (SPSS Version 28.0). The null hypothesis specifies that the distribution is normal and accepted if the *p*-value exceeds the 0.05 level of significance ($p > 0.05$). Moreover, the alternative hypothesis clearly specifies that the distribution is non-normal and accepted if the *p*-value is less than the 0.05 level of significance ($p < 0.05$).

This study sought to explore the relationship between EF and type of sport by exploring the primary research question. The primary research question informing this study was:

- What are the EF abilities of people who play contact sports?

The secondary hypotheses that branched out from the primary research question of this study were as follows:

- H_1: There is an association between contact sports and EF deficits.
- H_2: Individuals who play contact sports and have a history of concussion/head injury in sport are more likely to perform significantly poorer on EF tests in comparison to contact sport players who do not.
- H_3: Individuals who play contact sports at a professional level are more likely to perform significantly poorer on EF tests in comparison to individuals who do not.

Following evaluation of assumptions tests for violations and tests for outliers, parametric statistical tests were selected to analyse the collected data and to test the research hypotheses. In the presence of any assumption violations, equivalent non-parametric tests were also used as part of the analysis to ensure that such violations did not hold an influence on the findings. A snapshot of the statistical tests that were used are presented in Table 6 below.

Table 6

Outline of the statistical test used to analyse data

Statistical Test	**Purpose**
Analysis of Variance	- To examine the data for any group differences in variance of scores.
Chi-square test	- To examine the data for any differences between type of sport and the demographic variables.
Independent samples t-test	- To compare the performance of CONTACT and NON-CONTACT groups on different measures of EF.[1]
Mann-Whitney U test (equivalent of parametric independent samples t-test)	- To compare the performance of individuals with a history of concussion and without a history of concussion within the CONTACT group.[2] - To compare the performance of individuals who play CONTACT sports at a professional level and those that do not.[3]

Note. This table shows an outline of the statistical tests used to analyse the data and to test the branching hypotheses. Null hypotheses are rejected at a level of significance of 0.05 ($p <$ .05). Results for the non-parametric tests (Mann-Whitney U tests) were only reported if they indicated results that differed from those derived from the parametric tests (independent samples t-tests). [1] To investigate H_1. [2] To investigate H_2.[3] To investigate H_3 . ‘Performance’ relates to the results on the following tasks: Digit Span Forwards, Digit Span Backwards, Key Search Test, Rule Shift Cards Test, Colour Word Interference Test Conditions 2, 3 and 4 and Trail Making Test Conditions 2 and 4. EF = Executive Functioning.

Conclusion

This chapter provided an overview of the theoretical underpinnings, the research design and the procedures adopted for the purpose of this study. An overview of the sample was explained, and an outline of the research question, hypotheses and data analysis was provided. The next chapter will provide the findings of the normality of distribution and homogeneity of variance scores, coupled with a presentation of the results of the above-mentioned statistical tests.

Chapter 4: Results

Introduction

The purpose of this study was to primarily investigate executive functioning (EF) in individuals who play contact sports. This chapter presents the findings from statistical tests that were conducted to investigate the generated hypotheses of this study. The first part of the chapter presents the preliminary data considerations, including the inspection for outliers and any missing values, and the evaluation of the assumptions of normality and homogeneity of variance. This is followed by a description of the demographic information of the CONTACT and NON-CONTACT groups individually. The second part presents the findings derived from the Independent-samples *t*-tests regarding group differences in performance on EF measures. Lastly, further investigation for any demographic associations within the CONTACT group is then presented.

Preliminary Analyses

Checking for Data Errors, Missing Values and Outliers

Following visual examination of boxplots, all variable scores were within the possible range of scores, thus confirming that no errors in the data entry were made. Each variable included demographic information and scores of all the participants (n=60*)*, confirming that there were no missing values on the variables used for statistical analyses. Therefore, scores of the whole sample were used for the analyses of this study.

An inspection for outliers on both CONTACT and NON-CONTACT groups was also carried out due to the potential influence that outliers may hold on the statistical analyses of the data (Sullivan et al., 2021). In the presence of data values that are extremely distinct from other values in the sample, data may be compromised, leading to an analysis that is an inaccurate representation of the findings (Chambers et al., 2004). To ensure more accurate inspection, this was done through two methods, including graphical evaluation of box plots and the examination of z-scores.

Tabachnick and Fidell (2013) recommend that a z-score of 3.29 at ($p < 0.001$) should be used as the cut-off for determining outliers. In the case of outliers, conversion of scores to *z*-scores was used to confirm whether any suspected outlier is to be considered as a concern (Mowbray et al., 2019). The examination of box plots indicated multiple outliers across variables, however only the ones that beyond the cut off (*z*-score = 3.29) were considered as significant outliers. Although other extreme outliers (as marked with an asterisk) were marked on the box plots, they were not closely approaching the 3.29 cut off point and were therefore not identified as outliers. In total, three outliers (*z*-scores = -3.39, -3.43 and -4.405) were confirmed, including one outlier on the RSC test in the CONTACT group, and one outlier on each of the TMT conditions (conditions two and four) in the NON-CONTACT group.

The process of dealing with outliers should be done prior to the analysis of the data (Mowbray et al., 2019), and several strategies for managing outliers have been proposed. Tabachnick and Fidell (2013) recommend deletion, transformation or substitution, however no particular method was identified as a most suitable and preferred method. Although deletion can be considered as the 'safest' approach due to elimination of any extreme cases (Mowbray et al., 2019), the data set could be compromised. A commonly used substitution technique called Winsorization involves replacing an outlier with the closest non-outlier neighbouring value (Mowbray et al., 2019). Since this substitution technique is done without causing any changes in the sample size thus leaving the data set 'untouched', this technique was chosen as the preferred approach for this study.

Table 7 overleaf provides the outlier values before and after Winsorization according to the ± 3.29 cut off point.

Table 7

Identification of Outliers before and after Winsorization

Variable	Outliers				
	Group	Raw Score*	z-score	Winsorized Raw Score	Winsorized z-score
RSC	CONTACT	2	-3.39	**3**	**-1.58**
TMT Condition 2	NON-CONTACT	2	-3.43	**3**	**-3.13**
TMT Condition 4		1	-4.405	**4**	**-3.38**

Note: 'Raw score' refers to the scaled scores of the three outliers on two of the performance-based tests of EF, including the RSC and the TMT (Conditions 2 and 4). RSC = Rule Shift Cards, TMT = Trail Making Test.

Checking of Assumption of Normality and Homogeneity of Variance

In order to determine whether the assumptions required for parametric statistical methods were met, the data was examined using tests of normality (based on level of kurtosis and skewness) and homogeneity of variance.

Using tests of normality to determine whether data is 'normal' or 'not normal' is a fundamental process to be conducted prior to data analysis (Yap & Sim, 2010). If normality assumptions are violated, the use of non-parametric tests is recommended since they do not entirely rely on the normality of the data (Field, 2018). However, on the contrary to parametric testing, non-parametric testing is considered to be less powerful in detecting whether significant differences between groups exist (Hopkins et al., 2018). Nevertheless, using parametric tests for data which is not normality distributed may increase the chances of failing to detect a difference which actually exists (Hopkins et al., 2018).

Normality of Data Distribution. The normality of the data can be assessed through two main methods, including graphical and numerical (formal normality testing) procedures (Mishra et al., 2019). There are several methods which can be used to test for normality, some of which are considered appropriate based on sample size (eg. Shapiro-Wilk test for *n*<50 and Kolmogorov-Smirnov test for *n*≥50; Mishra et al., 2019). Another method which is used to assess for normality irrelevant of the sample size is through evaluation of the skewness (measure of asymmetry) and kurtosis (measure of the 'peakedness') (Kim, 2013). A value of zero for both skewness and kurtosis would indicate a perfectly normal distribution (Kim, 2013), however this is uncommon in the areas of education, health and the social sciences (Aslam, 2021).

For the purpose of this study, the data was assessed by examining the values of skewness and kurtosis within the CONTACT and NON-CONTACT groups. In total, 12 distributions per group were examined for the EF measures (report-based and performance-based), and all kurtosis and skewness values were converted into *z*-scores. When analysing data in a medium-sized sample (i.e. *n*>50 but *n*<300), it is suggested that an absolute *z*-score over 3.29 would reject the null hypothesis and thus consider the sample as non-normal (Kim, 2013).

As shown in Table 8 overleaf, there were two distributions (RSC and TMT condition two) that had significantly large values of skewness, and one distribution (TMT condition two) that had a significantly large value of kurtosis. Apart from these distributions which were in the NON-CONTACT group, all other distributions across both groups were within the range of the 3.29 critical value.

Table 8

Values of skewness and kurtosis on scales of the self-report measure and EF tests for the CONTACT and NON-CONTACT groups

		CONTACT *(n=43)*				NON-CONTACT *(n=17)*			
Measure	**Score**	**Skewness**	***Z***	**Kurtosis**	***Z***	**Skewness**	***Z***	**Kurtosis**	***Z***
DEX	Behaviour	.677	1.88	.714	1.00	.386	0.70	-.452	-0.43
	Cognition	-.027	-0.07	-.979	-1.38	.244	0.44	-.264	-0.25
	Emotion	-.062	-0.17	-.547	-0.77	-.635	-1.15	-.530	-0.50
DS	DSF	-.064	-0.18	-.284	-0.40	-.165	-0.3	-.219	-0.21
	DSB	.755	2.09	-.538	-0.76	.202	0.37	-.241	-0.23
KS	Profile Score	-.639	-1.77	-1.238	-1.75	-1.083	-1.97	-.467	-0.44
RSC	Profile Score	-1.160	-3.21	-.688	-0.97	**-1.866**	**-3.39**	1.655	1.57
CWIT	Condition 2	-.507	-1.40	.006	0.01	-.557	-1.01	2.204	2.07
	Condition 3	.647	-1.79	.633	0.89	-.134	-0.24	-1.067	-1.00
	Condition 4	-.879	-2.43	.929	1.31	-.124	0.23	-.351	0.33
TMT	Condition 2	-.963	-2.67	.691	0.97	**-1.948**	**-3.54**	**5.629**	**5.30**
	Condition 4	-.837	-2.32	.984	1.39	-1.363	-2.48	2.922	2.75

Note. The further away the skewness/kurtosis value is from zero, the higher the likelihood that the data is not normally distributed. Scores that have exceeded the critical value of 3.29 are highlighted in bold. This suggests that the variables having bold scores have violated the assumption of normality. DEX=Dysexecutive Questionnaire, DS= Digit Span, DSF=Digit Span Forward, DSB=Digit Span Backwards, KS=Key Search, RSC=Rule Shift Cards, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Homogeneity of Variance. Parametric tests assume that different groups have the same variability of scores. To test for this variance, Levene's test (Levene, 1960) is commonly used. Since all the *p*-values in Table 9 are larger than 0.05 ($p>0.05$), the assumption of homogeneity was not violated (Field, 2018), and the group variances between the CONTACT and NON-CONTACT groups were treated as equal.

Table 9

Results on Levene's test of homogeneity of variance

Measure	Score	*F* (df1, df2)*	*p*-value
DEX	Behaviour	0.85 (1,58)	.772
	Cognition	1.021 (1,58)	.316
	Emotion	2.044 (1,58)	.158
DS	DSF	.322 (1,58)	.567
	DSB	.419 (1,58)	.520
KS	Profile Score	.576 (1,58)	.451
RSC	Profile Score	.417 (1,58)	.521
CWIT	Condition 2	.659 (1,58)	.420
	Condition 3	3.676 (1,58)	.060
	Condition 4	1.156 (1,58)	.287
TMT	Condition 2	.025 (1,58)	.875
	Condition 4	.274 (1,58)	.602

Note. * The *F*(dfl, df2) and *p*-values reported were based on the median, since multiple authors have reported that the median is less biased by skewed distributions and outliers in comparison to the mean (Field, 2018; Pallant, 2016; Qualls et al., 2010). DEX=Dysexecutive Questionnaire, DS= Digit Span, DSF=Digit Span Forward, DSB=Digit Span Backwards, KS=Key Search, RSC=Rule Shift Cards, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Selecting between Parametric and Non-Parametric Tests

The above-mentioned tests revealed the presence of outliers. A small number of sizable values of skewness and kurtosis also indicated a few variables that were not normally distributed. As previously mentioned, this is to be expected, as identifying data which is not normally distributed is common in the social sciences (Field, 2018; Pallant, 2016).

Some authors also assert that most parametric methods are fairly robust and are able to tolerate slight violations of assumptions (Pallant, 2016). Based on the central limit theory, some statisticians also contend that normal distribution will be displayed irrespective of the shape of the sample (eg. Kim, 2015; Field, 2018), thus suggesting that parametric methods can still be chosen in cases where data that is not normally distributed. In line with this theory, the data in this study would therefore be appropriate for parametric methods.

However, to the author's knowledge, there is no established certainty about whether parametric testing can be used in the presence of data that is not normally distributed. For this reason, non-parametric testing was also conducted to examine whether any of the violations of assumptions had an influence on the findings.

Participant Demographics

The study sample consisted of 60 participants ranging from 20 to 50 years of age with a mean age of 28.11 years (*SD* = 6.12). Out of the total 60 participants 28.3% participants (*n*=17) were within the 18-25 age band, 66.7% (*n*=40) were within the 26-40 age band, and 5% (*n*=3) were within the 41-60 age band. In terms of gender, 31.7% were females (*n*=19) and 68.3% were males (*n*=41). With regards to level of sport, 30% (*n*=18) of the participants (*n*=60) played at a professional level, whilst 70% (*n*=42) did not. The majority (61.7%, *n*=37) of the whole sample *(n*=60) did not have a history of concussion/head injury in sport, whilst 38.3% did (*n*=23), and the most common type of TBI reported was mild TBI (mTBI) (*n*=18 of *n*=23). Furthermore, the majority (*n*=18) of participants who had a history of concussion/head injury reported not having sustained more than a total three concussions/head injuries in sport. In terms of hospitalisation, 16.7% (*n*=10) out of the total sample (*n*=60) had been hospitalised due to head injury/concussion in sport.

Participants were divided into two groups depending on whether they practiced a contact sport or a non-contact sport. The CONTACT group comprised of 71.7% (*n*=43) of the participants, and the remaining 28.3% (*n*=17) formed part of the NON-CONTACT group.

Chi-square tests were conducted to test for associations between type of sport and the following variables, including, gender, age, history of head injury/concussion in sport and level of sport. The *p*-values indicated statistically significant differences between gender and type of sport, $\chi^2(1) = 11.97$, $p=<.001$, and between history of head injury/concussion in sport and type of sport ($\chi^2(1) = 7.08$, $p=.008$). These results show that most males reported playing contact sports (contact sport *n*=35; non-contact sport *n*=6), whilst most females reported playing non-contact sports (non-contact sport *n*=11; contact sports *n*=8). Furthermore, the majority of participants who reported a history of concussion/head injury were within the CONTACT group (CONTACT *n=21;* NON-CONTACT *n*=2*)*.

Given that one range of the age variable had frequencies that were less than five (age range 41-60; *n* = 3), a Fisher's Exact test was run (Blalock, 1972). The test showed a *p*-value of .141 ($\chi^2(2) = 3.41$), therefore revealing that there is no statistically significant difference between age and type of sport since the *p*-value exceeded 0.05. Lastly, no statistically significant difference was noted on the level of sport variable as the *p*-value was above 0.05 (*p*=.189).

Table 10 overleaf presents the above mentioned demographic information for each of the CONTACT and NON-CONTACT groups individually.

Table 10

Demographic characteristics of CONTACT and NON-CONTACT groups

Variable	Descriptor	CONTACT (*n*=43)		NON-CONTACT (*n*=17)		Comparison		
		n	**%**	***n***	**%**	χ^2	***df***	***p***
Gender	Male	35	81.4	6	35.3	11.97	1	<.001
	Female	8	18.6	11	64.7			
Age	18-25	15	34.9	2	11.8	3.41	2	.141
	26-40	26	60.5	14	82.4			
	41-60	2	4.6	1	5.8			
Level of Sport	Professional	15	34.9	3	17.6	1.72	1	.189
	Not professional	28	65.1	14	82.4			
Head Injury/ Concussion in Sport	History	21	48.8	2	11.8	7.08	1	.008
	No history	22	51.2	15	88.2			

Comparisons between the CONTACT and NON-CONTACT group

The EF performance of the two groups of this study were compared on different measures of EF through independent-sample t-tests. Prior to running the tests, the results of the preliminary analyses were considered.

Table 11 presents the findings of the comparisons between the CONTACT (*n=43*) and NON-CONTACT (*n*=17) groups across the report-based and performance-based measures of EF which were used in this study. The mean values and standard deviations for each comparison are also presented in this table (Table 11).

Report-based measure of EF

Groups were compared on a self-report measure (DEX questionnaire) of EF. The scoring of this questionnaire is divided into three factors, including Behaviour, Cognition and Emotion, and the findings presented in Table 11 are according to the total scores of each of the three domains.

Results from the independent samples t-test indicated no significant difference between the CONTACT and NON-CONTACT groups on the areas of Cognition (*p*=.311) and Emotion (*p*=.088) as both values were above the 0.05 *p*-value. However, the .051 *p*-value of the Behaviour domain may suggest a possible group difference as it was approaching the *p*-value of significance. When evaluating the mean scores on the Behaviour factor, the CONTACT group had a higher mean score (*M*=10.47) in comparison to the NON-CONTACT group (*M*=7.76), indicating that the self-reported difficulties in the area of Behaviour were higher in the CONTACT group.

These findings indicate that the null hypothesis was accepted for all three factors of the DEX questionnaire (Behaviour, Cognition and Emotion domains), however results are suggestive of a possible association between Behaviour and type of sport.

Performance-based measures of EF

Groups were also compared on a series of performance-based tasks of EF across five measures using independent samples t-tests. Parametric tests were used for all measures, and Mann-Whitney tests (non-parametric equivalent of the independent samples t-test) were also run for the RSC and TMT condition two due to their large values of skewness and kurtosis.

On the DS tasks (DSF and DSB), no significant differences on the DSF (*p*=.854) and DSB (*p*=.956) were indicated as none of the values were above the 0.05 *p*-value. Similarly, no significant differences between groups were noted on the remaining measures, including the KS (*p*=.451), RSC (*p*=.521), CWIT (condition two *p*=.636, condition three *p*=.244 and condition four *p*=.703) and TMT (Condition two *p*= .521, Condition four *p*=.809). For the RSC and TMT condition two, Mann-Whitney tests were also carried out and yielded similar results, with *p*-values exceeding 0.05 (RSC *p*=.516, TMT condition two *p*=.269).

In sum, the findings of the independent samples t-tests demonstrated that both CONTACT and NON-CONTACT groups performed similarly across all the performance-based tests of EF. However, although not significant, the *p*-value of 0.051 on the Behaviour factor of the DEX questionnaire indicated a possible group difference.

Overall, the tests of group differences did not indicate any statistically significant group differences of EF abilities between contact sport players and non-contact sport players.

Table 11

Results of group comparisons between the CONTACT and NON-CONTACT individuals on EF measures

Measure	Variable	CONTACT *(n=43)*		NON-CONTACT *(n=17)*		Comparison				
		Mean	***SD***	***Mean***	***SD***	***t***	**df**	**Sig.**	**95% CI**	**Cohen's *d***
DEX	Behaviour	10.47	4.83	7.76	4.50	1.990	58	**.051**	[-.02, 5.42]	.570
	Cognition	6.09	3.27	5.18	2.74	1.022	58	.311	[-.88, 2.71]	.293
	Emotion	4.74	2.34	3.65	1.80	1.737	58	.088	[-.17, 2.36]	.498
DS	DSF	11.00	3.20	10.82	3.64	.185	58	.854	[-1.73, 2.09]	.053
	DSB	11.23	3.60	11.18	3.34	.055	58	.956	[-1.94, 2.05]	.016
KS	Profile Score	2.98	1.21	3.24	1.15	-.759	58	.451	[-.94, .42]	-.217
RSC	Profile Score	3.74	.441	3.82	.39	-.646	58	.521	[-.33, .17]	-.185
CWIT	Condition 2	12.28	1.64	12.06	1.56	.476	58	.636	[.71, 1.15]	.136
	Condition 3	12.02	1.81	11.35	2.40	1.178	58	.244	[-.47, 1.81]	.337
	Condition 4	11.02	2.04	11.24	1.60	-.383	58	.703	[-1.32. .90]	-.110
TMT	Condition 2	11.09	2.57	11.94	2.86	1.115	58	.269	[-2.37, .67]	-.320
	Condition 4	10.91	1.88	10.76	2.44	.243	58	.809	[-1.03, 1.32]	.070

Note. The bold score indicates a significant value. *SD* = Standard Deviation, df = degrees of freedom, DEX=Dysexecutive Questionnaire, DS= Digit Span, DSF=Digit Span Forward, DSB=Digit Span Backwards, KS=Key Search, RSC=Rule Shift Cards, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Comparisons within the CONTACT group

Following comparison of the CONTACT and NON-CONTACT groups, further analysis was also conducted to investigate EF within the CONTACT group (*n*=43). The below sections present the findings of the independent samples t-tests that were conducted. These analyses followed the same procedure as the above-mentioned tests, with non-parametric testing being run to examine whether any violations of assumptions posed an influence on the findings.

History of Head Injury/Concussion in Sport

The performance of the CONTACT group was further examined for any associations between history of head injury/concussion and performance on EF measures. Table 12 on the following page presents the findings of the comparison of CONTACT group individuals (*n*=43) who had a history of concussion/head injury (*n*=21) and those that did not (*n*=22).

A statistically significant difference on condition four of the Colour Word Interference Test (CWIT) was revealed, $t(41)=2.449$, $p=0.019$, $d=.747$. However, all other comparisons on the remaining tests did not reveal any significant group differences. Due to the large values of skewness and kurtosis, the Mann-Whitney tests were also conducted for the RSC and TMT condition two, showing similar *p*-values which exceeded 0.05 (RSC $p=.664$, TMT condition two $p=.902$).

These findings indicate that the only significant difference between individuals who had a history of concussion/head injury (*n*=21) and those that did not (*n*=22) was found on a task of inhibition/switching (CWIT condition four). Therefore, the null hypothesis was only rejected for condition four of the CWIT.

Table 12

Results of comparisons between history of concussion/head-injury and no history of concussion/head injury within the CONTACT group

Measure	Variable	CONTACT – HISTORY *(n=21)*		CONTACT - NO HISTORY *(n=22)*		Comparison				
		Mean	***SD***	***Mean***	***SD***	***t***	**df**	**Sig.**	**95% CI**	**Cohen's *d***
DEX	Behaviour	11.67	5.60	9.32	3.73	-1.626	41	.112	[-5.27, .569]	-.496
	Cognition	6.05	3.76	6.14	2.80	.088	41	.930	[-1.95, 2.12]	.027
	Emotion	4.52	2.66	4.95	2.04	.598	41	.553	[-1.02, 1.88]	.183
DS	DSF	11.71	3.32	10.32	3.00	-1.449	41	.155	[-3.34, .550]	-.442
	DSB	11.86	3.88	10.64	3.03	-1.113	41	.272	[-3.44, .994]	-.340
KS	Profile Score	3.14	1.20	2.82	1.22	-.881	41	.384	[-1.07, .420]	-.269
RSC	Profile Score	3.71	.463	3.77	.429	.430	41	.670	[-.216, .333]	.131
CWIT	Condition 2	12.29	1.71	12.27	1.61	-.026	41	.980	[1.03, 1.01]	-.008
	Condition 3	11.86	2.08	12.18	1.53	.585	41	.562	[-.797, 1.45]	.178
	Condition 4	10.29	2.28	11.73	1.52	2.449	41	**.019**	[.253, 2.63]	.747
TMT	Condition 2	11.10	2.63	11.09	2.58	-.005	41	.996	[-1.61, 1.60]	-.002
	Condition 4	11.10	1.61	10.73	2.12	-.639	41	.527	[1.53, .795]	-.195

Note. The bold score indicates a significant value. *SD* = Standard Deviation, df = degrees of freedom, DEX=Dysexecutive Questionnaire, DS= Digit Span, DSF=Digit Span Forward, DSB=Digit Span Backwards, KS=Key Search, RSC=Rule Shift Cards, CWIT=Colour Word Interference Test, TMT=Trail Making Test

Level of Sport

The performance of the 43 individuals in CONTACT group was further examined for any associations between level of sport (professional or non-professional) and EF abilities.

Table 13 overleaf presents the findings derived from CONTACT group according to level of sport. Overall, the findings did not reveal any significant differences as all *p*-values exceeded the 0.05 point. The Mann-Whitney tests were also conducted and showed similar results for the RSC and TMT condition two, with *p* values exceeding 0.05 (RSC p=.906, TMT condition two p=.122).

Therefore, there were no significant group differences in EF performance of individuals who play contact sports at a professional level (n=15) in comparison to those that do not (n=28).

Table 13

Results of comparisons between professional and non-professional level of sport within the CONTACT group

Measure	Variable	CONTACT - PROFESSIONAL *(n=15)*		CONTACT – NON-PROFESSIONAL *(n=28)*		Comparison				
		Mean	***SD***	***Mean***	***SD***	***t***	**df**	**Sig.**	**95% CI**	**Cohen's *d***
DEX	Behaviour	10.20	4.84	10.61	4.90	.261	41	.796	[-2.75, 3.56]	.083
	Cognition	5.93	3.35	6.18	3.28	.232	41	.818	[-1.89, 2.38]	.074
	Emotion	4.67	2.61	4.79	2.23	.157	41	.876	[-1.41, 1.65]	.050
DS	DSF	10.07	3.13	11.50	3.18	1.417	41	.164	[-.610, 3.48]	.453
	DSB	10.60	3.54	11.57	3.66	.839	41	.406	[-1.37, 3.31]	.269
KS	Profile Score	2.60	1.30	3.18	1.12	1.524	41	.135	[-.19, 1.35]	.488
RSC	Profile Score	3.73	.458	3.75	.441	.117	41	.908	[-.272, .305]	.037
CWIT	Condition 2	11.87	1.36	12.50	1.75	1.215	41	.231	[-.419, 1.69]	.389
	Condition 3	12.00	1.69	12.04	1.90	.061	41	.952	[-1.15, 1.22]	.020
	Condition 4	10.40	2.44	11.36	1.75	1.487	41	.145	[-.343, 2.26]	.476
TMT	Condition 2	10.40	2.50	11.46	2.58	1.304	41	.199	[-.583, 2.71]	.417
	Condition 4	10.27	2.05	11.25	1.71	1.674	41	.102	[-.203, 2.17]	.536

Note. SD = Standard Deviation, df = degrees of freedom, DEX=Dysexecutive Questionnaire, DS= Digit Span, DSF=Digit Span Forward, DSB=Digit Span Backwards, KS=Key Search, RSC=Rule Shift Cards, CWIT=Colour Word Interference Test, TMT=Trail Making Test

Conclusion

In sum, a significant difference on the CWIT condition four (p=0.019) was revealed when comparing EF performance between contact sport players who had a history of head injury/concussion in sport and those who did not. Comparisons between the CONTACT and NON-CONTACT groups did not indicate significant group differences on any of the tests of EF. However, the *p*-value of 0.051 on the Behaviour factor of the DEX was approaching the significant *p*-value of 0.05 that may suggest a possible group difference between the CONTACT and NON-CONTACT group.

Apart from these differences, no other significant findings were revealed. Therefore, this study only provided limited support to accept the alternative hypotheses.

Chapter 5: Discussion

Introduction

The aim of this study was to compare executive functioning (EF) abilities of contact and non-contact sport players, and to further explore EF abilities of individuals who play contact sports. In this chapter, the study findings which were presented in the previous chapter will be discussed critically with reference to the relevant literature on EF in individuals who play sports.

The first part of this chapter will provide a summary of results, followed by a discussion on the executive functions which were examined through the EF measures that were used in this study. Lastly, a discussion on specific EF differences within the CONTACT group will be presented.

Summary of Results

No significant group differences were shown between the CONTACT and NON-CONTACT groups. This means that both groups showed similar performance on the EF tests included in this study. Although not statistically significant, the 0.051 *p*-value between the two groups (CONTACT and NON-CONTACT) on the Behaviour factor of the self-report questionnaire (Dysexecutive Questionnaire; DEX) was near approaching the 0.05 *p*-value of significance. This indicates that the CONTACT group self-reported more behavioural difficulties.

Furthermore, the statistical tests showed a significant difference on the test of response inhibition (Colour Word Interference Test; CWIT) (condition four) between the CONTACT group participants who had a history of head injury/concussion in sport and those who did not. This indicated the individuals who had a history of head injury/concussion in sport performed worse on a test of inhibitory control.

Group Differences in Performance on Tests of Executive Functioning

Overview

It was hypothesised that performance on the EF tests would differ between the CONTACT and NON-CONTACT groups. Furthermore, it was anticipated that participants in the CONTACT would perform more poorly in comparison to the participants in the NON-CONTACT group on all tests in this study. Additionally, it was hypothesised that pronounced difficulties would be identified in the CONTACT group for participants who had a history of head injury/concussion in sport, and who practiced the contact sport at a professional level.

The following subsections will discuss the study findings according to the executive functions that were explored in this study, including; working memory (WM), response inhibition, cognitive flexibility and task switching, planning and organisation, as well as executive deficits in daily living. Each subsection will present a definition of the executive function, followed by the current findings with specific reference to the literature. Where relevant, suggestions for further research will be proposed.

Working Memory

The current study included working memory (WM) as a key function of EF to investigate for any differences between groups. The reason being that WM is considered to be one of the main executive functions (Diamond 2006, 2013), and is responsible for facilitating several skills such as planning and problem-solving. The importance of WM in the field of sport has been highlighted across several studies (eg. Furley & Memmert, 2010; Mayers et al., 2011).

The role of WM also varies across different sport skills. For example, decision-making in football heavily relies on WM in comparison to a putt in golf that does not (Furley & Memmert, 2010). Furthermore, WM has also been recognized as a cognitive skill that is a predictor of success in expert football players (Vestberg et al., 2012).

The digit span is a commonly used subtest of WM that is not sensitive to language nor culture, and is commonly used within local practice, was included in this study. The findings of the current study showed that, on a test of verbal working memory, individuals who play contact sports perform similarly to individuals who play non-contact sports. To corroborate these findings, other studies have also reported no significant difference in WM in athletes who practice contact and athletes who practice non-contact sports (eg. Mayers et al., 2011; Willer et al., 2018).

In a study that recruited athletes who participate in head-contact sports and non-head contact sports, together with a control group of non-athlete college students, results indicated no long-term impairment in WM capacity in individuals who practice contact sports, including football and soccer (Mayers et al., 2011). Another study conducted by Willer et al. (2018) also concluded no significant differences in performance on the digit span test between contact and non-contact sport players.

However, other studies have indeed highlighted WM difficulties in athletes (eg. Keightley et al., 2014). They highlighted poorer working memory accuracy in a group of 15 youths who had sustained a sport-related concussion within 9-90 days prior to testing in comparison to a group of 15 healthy subjects. WM abilities were examined using functional magnetic resonance imaging (fMRI) and neuropsychological tests, and results suggested that further investigation is warranted. When comparing Keightley et al.'s (2014) conclusions to the findings of the current study, it is possible that another test of WM may have been more suitable to detect WM difficulties in the sample, such as the letter-number sequencing that is also part of the WAIS-IV (Wechsler, 2008).

Furthermore, since the inclusion criteria of the current study did not require participants to have a history of sport-related concussions (SRC), this could have also influenced the findings when comparing them to studies that recruited individuals who specifically had a history of SRCs. In view of this, further research is warranted to assess WM abilities contact sport players regardless of whether they have a history of SRC or not. Furthermore, since this study only used a test measuring one domain of WM (verbal WM), it would be ideal if a test of visual WM were to also be included in future studies. Examples of tests measuring visual WM are the spatial span and the spatial addition tests that are part of the Weschler Memory Scale (WMS-IV; Wecshler, 2009) assessment battery.

Response Inhibition

Response inhibition is also referred to as inhibitory control, and both terms are used to define the ability to inhibit prepotent responses to stimuli and to select more appropriate responses. Inhibitory control is recognised as a central aspect of cognition that is closely related to participation in sport (Albaladejo-García et al., 2023), and the ability to inhibit responses is suggested to enhance performance in sport due to its positive influence on decision-making skills (Brick et al., 2016; Van Biesen et al., 2016). Inhibitory processes may also be employed across multiple situations during sport practice (Bravi et al., 2022). For example, prior to a successful shot in a game of tennis, an athlete is required to restrain a motor response, be observant of, and adapt to the opponent’s moves prior to taking action (Bravi et al., 2022).

The current study findings showed that, on a test of inhibitory control, the performance of individuals who play contact sports was similar to the performance of the non-contact sport players. A recent study by Willer et al. (2018) also corroborated these finding and indicated that both groups performed similarly when required to inhibit particular responses according to a given rule, thus accepting the null hypothesis (Willer et al., 2018). However, to the author’s knowledge, most studies appear to have compared inhibitory control abilities in athletes who have and have not sustained a concussion in sport (rather than according to the type of sport, that is contact vs non-contact). Therefore, it is difficult to compare the current findings to other studies. Nonetheless, as previously discussed in the literature review, sustaining a head injury in sport appears to be more common in contact sports, therefore remaining an area that requires further investigation. Further research may therefore investigate response-inhibition in contact and non-contact sport players, possibly using other tests of inhibitory control, such as a computerized Go/No-go task.

Cognitive Flexibility and Task Switching

Cognitive flexibility has been defined as the ability to selectively shift between mental processes to general appropriate responses (Dajani & Uddin, 2015). The study findings revealed that, on tests of cognitive flexibility, the performance of individuals who play contact sports was similar to the performance non-contact sport players.

Recent comparative studies investigating cognitive flexibility and task-switching between contact and non-contact sport players appear to be limited. One of the few studies was conducted by Koerte et al. (2017), and they sought to investigate the influence that repetitive head injuries had on cognitive flexibility in soccer players in comparison to a group of non-contact sport athletes. The findings of their study indicated that the soccer players showed subtle deficits in cognitive flexibility due to errors on a set-shifting task (Koerte et al., 2017).

In comparison to findings of this study, another study by Hume et al. (2017) concluded a difference between scores in a group of elite rugby players and a group of non-contact sport players. They reported that the recruited rugby players performed worse on tests measuring cognitive flexibility in comparison to the non-contact sport group (Hume et al., 2017). When comparing these findings to the present findings, it is important to consider that the study sample of the current study did not solely include elite rugby players.

Furthermore, it is also difficult to identify a common ground between what is considered as elite across worldwide studies, thus leading to inconsistencies in results. This will be further discussed in the section of this chapter which focuses on EF performance and level of sport (page 87).

Therefore, the current study indicates that further research to investigate cognitive flexibility in people who play sport is warranted. In order to do so, it is suggested that future studies may also include different tests of cognitive flexibility, such as the Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948). Furthermore, it is suggested that including a group of pre-determined professional athletes may also provide further opportunity to compare findings with previous studies that have compared elite contact sport players to non-contact sport players.

Planning and Organisation

The executive functions involved in the planning and organising of tasks are of paramount importance in sport (Rincón-Campos et al., 2019). The ability to plan refers to the executive functioning (EF) skills that help individuals to formulate a strategy towards a set goal. Therefore, the executive skill of planning allows an athlete to execute a strategy on the playing field in a pre-determined manner. On a test of strategy formation (Key Search test), the individuals who play contact sports performed similarly to the non-contact sport players.

To the author's knowledge, previous studies which have investigated planning and organization skills in individuals who play sports appear to be limited. In a study by Willer et al. (2018), they used the BRIEF-A self-report measure which includes a scale that assesses planning and organization skills. Willer et al. (2018) concluded that, with time, the majority of former contact sport players will experience significant difficulties related to planning. Additionally, another study by Seichepine et al. (2013) also concluded self-reported difficulties relating to planning and organization in an adult group of former football players.

Therefore, it is suggested that future studies could also include a group of former contact-sport players to assess for any significant difficulties related to planning that may have evolved after retiring from the sport. Furthermore, it is suggested that future studies can also assess athletes longitudinally to identify any long-term difficulties related to cognitive flexibility and task switching that may develop over time.

Other Remarks

Moreover, when further evaluating the raw data of all the performance-based measures, relatively wide confidence intervals were noted for some of the administered measures in this study, and these intervals could be suggestive of variability in the scores albeit not reaching statistical significance. Considering the relatively small sample size of this study, it is possible that the statistical tests which were used did not hold sufficient power to detect any further differences between the CONTACT and NON-CONTACT groups.

Self-Reported Executive Functioning Deficits in Daily Living

Self-report measures have been recognized as ecologically valid measures of EF by focusing on the self-reported difficulties which individuals face, and to rate how any of these difficulties may impact their everyday functioning (Burgess et al., 1986). Dating back to 1991, Saver and Damasio also postulated that difficulties with EF may not always tie in with actual performance on EF tests. Furthermore, performance-based tests of EF may fail to measure any difficulties with emotional regulation which are typically present in executive dysfunction (Chan et al., 2008).

The Dysexecutive Questionnaire (DEX) questionnaire (Wilson et al., 1996) was used to analyse self-reported EF difficulties amongst the recruited athletes in this study. All individuals who played contact or non-contact sports reported similar ratings on a self-report measure (DEX) of EF. However, a possible group difference on the Behaviour domain of the DEX was highlighted as the *p*-value was near approaching the *p*-value of significance. This indicated that the contact sport players self-reported more behavioural difficulties in comparison to the non-contact sport players. As outlined in Chapter 2 (page 48), the DEX includes eight statements within the Behaviour factor which measure different behavioural difficulties that are associated with EF. For example, as part of beheaviour, impulsivity is measured according to the following statement: ‘I act without thinking, doing the first thing that comes to mind’.

Whilst the DEX questionnaire is a commonly used measure that is also used within the local context, to the author’s knowledge, it appears that worldwide studies have mostly used different rating scales to measure self-reported EF. A recent study by Willer et al. (2018) used the adult version of the Behavior Rating Inventory of Executive Function (BRIEF-A) questionnaire as an assessment to detect impairments in EF in two groups of athletes (BRIEF; Gioia et al., 2000). Although the self-report measure that was used in this study (DEX) is different to the one used by Willer et al. (2018) they both assess the behavioural aspect of EF. Wilson et al. (2018) used the BRIEF-A to assess EF in retired National Football League (NFL) and National Hockey League (NHL) players in comparison to an age-matched group of non-contact sport athletes. The study findings concluded that the NFL and NHL players perceived more EF difficulties in comparison to the non-contact group, however the only significant difficulties were found on the Working Memory and Initiation executive functions (Willer et al., 2018). Thus, in comparison to the findings of the present study which suggested a possible group difference in the Behaviour factor of the DEX, Willer et al. (2018) only reported differences between groups on the Cognition domain of the BRIEF-A and not within the Behavioural Regulation domain. Additionally, when the BRIEF-A informant questionnaire was provided to the spouses of the participants in the NFL, NHL and non-contact groups, no statistically group differences were revealed across any of the domains of the BRIEF-A questionnaire (Wilson et al., 2018).

A recent focus review has also highlighted an association between the impulsivity (which is part of behaviour) and type of sport (eg. Liebel et al., 2021). It was stated that impulsivity appears to be a common personality trait amongst athletes who participate in high-contact sports, and the susceptibility of sport-related concussions (SRC) in such sports is thought to heighten this impulsivity (Liebel et al., 2021). However, despite this, definite causal relationships between type of sport, impulsivity and SRC have not yet been shown (Liebel et al., 2021). Furthermore, a study by Rincón-Campos et al. (2019) sought to investigate several aspects of EF in a group of undergraduate American football players. Apart from other EF measures that were used in their study, the Barratt Impulsiveness Scale Version 11 for adults (Patton et al., 1995) was also used to measure impulsive behaviour at two stages, namely pre-season and after four months (post-season). When comparing impulsivity before and after the season, the recruited football players showed increased impulsivity post-season (Rincón-Campos et al., 2019). This may suggest that self-reported behavioural difficulties may present over time, and that self-reported difficulties may also be experienced before any marked changes in performance on EF tests.

Moreover, Murphy and Mitchell (2022) contend that the use of self-report measures in combination with performance measures may also offer valuable information about the individual's insight and awareness of any EF difficulties. However, although the DEX questionnaire was administered in the current study to provide an understanding of any self-reported EF difficulties in the sample, the DEX was only used as a means of investigating EF and not as a measure of insight and awareness.

Therefore, past studies have suggested the importance of report-measures when assessing EF in individuals who play sport. Furthermore, it is possible that the participants in this study may have been influenced by a social desirability bias when completing the DEX questionnaire, thus leading to results that may not be representative of actual experienced difficulties. Future studies may also consider using the informant version of the DEX questionnaire to provide a more comprehensive understanding of any reported EF difficulties.

Moreover, using both the self and informant versions of the DEX may also capture a more thorough understanding of EF across day-to-day scenarios, especially when assessing for insight of any EF deficits.

Differences in Performance on Tests of Executive Functioning in People who Play Contact Sports

History of Concussion/Head Injury in Sport

The CONTACT group was further divided into two groups, with the first group having a history of concussion/head injury in sport, and the second group not having a history of concussion/head injury in sport. On a test of inhibitory control (CWIT condition four), contact-sport players who had a history of head injuries/concussions in sport performed worse than non-contact sport players. However, on the remaining of performance tests and the self-report measure assessing working memory, cognitive flexibility and task switching, planning and organization, and EF in everyday functioning, both groups showed similar performance.

Several studies have highlighted disruptions in inhibitory control (eg. Hudac et al., 2022) that may persist for months to years following a sport-related concussion (SRC) (eg. McGowan et al., 2019). In a large study investigating concussion-related deficits, 19,261 individuals were recruited to complete a demographic questionnaire along with a battery of 12 performance tests (Stafford et al., 2020). These tests measured various cognitive abilities, including attention, inhibitory control, memory, problem-solving and reasoning (Stafford et al., 2020). The recruited participants included individuals from the general population and a cohort of college American football players (Stafford et al., 2020). The objective was to use the findings of post-concussion and non-concussed individuals from the general population group to predict how varsity American football players would perform on alike cognitive tasks. The EF tests of the said study were specifically chosen based on their sensitivity, with the objective to recognise even the smallest differences in performance (Stafford et al., 2020). When comparing the performance of the non-concussed and post-concussion participants in the general population sample, no group differences were noted on 11 of the tests (Stafford et al., 2020). However, on a computerised test of inhibitory control which was based on the Stroop test (1935), post-concussion participants demonstrated difficulties on the incongruent conditions of the test (Stafford et al., 2020). Therefore, the post-concussion participants from the general population showed difficulties when presented with colour words did not match the colours which the words were printed in, such as the word ‘green’ written in red font or vice versa. In comparison to the healthy (non-concussed) controls of the general population sample, the cohort of American football players yielded similar performance, having significantly lower scores on the task which measured inhibitory control (Stafford et al., 2020). Thus, these scores indicate that frequent sport-related head impacts in American football may result in deficits related to inhibitory control.

Another study by Monroe et al. (2020) evaluated whether there is an association between brain functional connectivity and exposure to head-impact in intercollegiate water-polo players. They used cap-worn inertial sensors to measure the incidence and extent of head impacts during a season of play. Along with these sensors during the season, they used electroencephalographs and a computerized version of the Stroop test to assess the recruited athletes pre- and post-season (Monroe et al., 2020). They concluded that all participants had sustained head impacts during the season and showed lower scores on the incongruent trials of the Stroop in comparison to the congruent trials of the task (Monroe et al., 2020).

In sum, the pattern of results in the present study indicated that, when comparing performance of contact sport players who had a history of concussion/head-injury in sport (M=10.29) against those who did not (M=11.73), the concussion group showed significantly lower scores on a test of inhibitory control, with unimpaired performance on the other administered EF tests. Therefore, the findings of the present study are in-line with existing studies, indicating that repetitive head impacts in sport appear to be associated with difficulties related to inhibitory control. Such cognitive difficulties may also impact everyday functioning in several ways, such as in poor decision-making and difficulties with impulse control.

Furthermore, in order to examine for any group differences in individuals who have a history of head-injury in sport and those who do not, it is recommended that future research recruits equal amounts contact sport players who have sustained mild, moderate and severe head injuries. Together with these groups, having a control group of non-contact sport players will be able to offer further comparison between the TBI groups of contact sport players and non-contact sport players.

Level of Sport

Secondly, the CONTACT group was further divided into two groups, including a professional group and a non-professional group according to level of sport. Individuals who played a contact sport at a professional level and those that did not showed similar performance on all the EF tests that were included in this study.

In a recent study conducted by Rodrigues et al. (2019), comparisons were evaluated between cognitive performance of professional soccer players and a control group of individuals who did not practice soccer or only practiced the sport. The choice of tests covered various aspects of cognition, including tasks of response inhibition, switching and working memory (Rodrigues et al., 2019). When evaluating performance on computerized tasks that specifically assessed executive skills (eg. number-letter-test, two-back-test and Stroop test[2]), the active soccer group demonstrated better scores (Rodrigues et al., 2019). A

[2] The number letter test comprised of number-letter pairs which is presented in one of four quadrants on a screen. The subject is required to indicate (by pressing a particular key) whether a shown number is an odd or an even number when the number-letter pair is presented in the two quadrants at the top of the screen.

further analysis of these scores indicated that the soccer group showed better performance on the accuracy measures of the EF tests in comparison to the control group (Rodrigues et al., 2019). However, on the Neupsilin battery (conventional neuropsychological testing method), no differences between groups were concluded (Rodrigues et al., 2019).

Although this present study did not reveal any differences between the level of sport in the CONTACT group, it is possible that the participants had different perceptions of what is considered professional, and this could have influenced the findings. Since the category of level of sport was not pre-determined, participants were categorized as professional or no dependent based on their own impression. Indeed, most of the participants noted that they classified their participation in sport as professional or non-professional based on whether practice and competition was with or without remuneration, rather than on the frequency of participation in competitions. To overcome this, it is suggested that future studies have inclusion criteria that specify what is considered professional, such that the participants must be practicing the sport on a full-time basis, and this will allow comparisons to international studies.

Conclusion

In this chapter, the findings gathered from an examination of group differences were discussed with reference to previous studies investigating EF performance in individuals who play sports. Overall, the present findings highlighted that inhibitory control is a key EF that may be impacted in contact-sport players, therefore warrants future attention.

When number-letter pairs are presented at the bottom of the screen, the subject is required to indicate whether the letter is a vowel or a consonant. For the two-back-test, the subject is instructed to look at quickly changing numbers on a screen and is asked to press the ‘enter’ key whenever a number is the same as the number presented in the trial before the last. The Stroop test follows the same rules as previously mentioned earlier on in the discussion.

Chapter 6: Conclusion

Introduction

This study investigated whether any group differences in executive functioning (EF) performance are associated with the type of sport played (contact or non-contact). A review of the literature relevant to the study was provided, with a specific focus on head injuries, sport categorisation and EF in sport. Group comparisons that were carried out to test the hypotheses of the study were then presented. Lastly, the study's findings were discussed and further explored with reference to relevant literature.

This first part of this chapter will provide a summary of the study findings which were further explored in the discussion (Chapter five). The following sections will then present the strengths, limitations and implications of the study, followed by recommendations for future research.

Summary of Study Findings

Three main hypotheses related to EF were tested through examination of group differences. In this study, the two groups (CONTACT and NON-CONTACT) were gauged according to the type of sport identified by the participants in the demographic questionnaire. In total, 43 of the 60 participants formed part of the CONTACT group, whilst the remaining (n=17) were categorised as the NON-CONTACT group. The sample comprised of both male (n=41) and female (n=19) participants between the ages of 20 and 50 years old.

Data was collected through a demographic questionnaire, a self-report measure of EF and five performance-based assessments measuring EF. The raw data was examined through statistical tests, and the sample results presented one significant finding. Poorer performance on a test of inhibitory control (CWIT condition 4) was indicated in individuals who play contact sports and had a history of one or more head injuries/concussions in sport in comparison to contact sport players who did not. Furthermore, although not statistically significant, the 0.051 *p*-value of the Behaviour factor of the self-report measure (Dysexecutive Questionnaire; DEX) indicated a possible group difference between the CONTACT and NON-CONTACT groups.

Apart from these findings, no other significant group differences were observed on the tests of EF that were used in this study. Therefore, the study findings only presented limited support for the developed hypotheses.

Strengths of the Study

This study has highlighted several strengths which can be considered and implemented to improve future studies. Primarily, the use of both self-report and performance-based measures of EF provided a more comprehensive understanding of the EF abilities of the recruited sports players. Since performance-based assessments are conducted in a relatively standardised and controlled environment that is limited in distractions (Toplak et al., 2013), it can be difficult to gather an understanding of EF abilities in daily living. The use of the DEX questionnaire served as a supplementary measure to identify any EF difficulties which the participants face in their everyday cognitive functioning.

Moreover, some of the chosen EF tests for this study are known to demonstrate strong ecological validity. The demands of ecologically valid tests are believed to resemble the cognitive demands of everyday tasks (Franzen & Wilhelm, 1996), so therefore it is assumed that they would more easily detect day-to-day difficulties. Another key strength was that the EF tests that were chosen for this study were not culturally specific, therefore reducing any cultural biases of the study findings. Additionally, this study has used the most recent versions of the tests which are used within the local clinical practice.

More broadly, this study highlighted that individuals who play contact sports may experience EF difficulties. The significant findings of this study may also encourage further research within the local context to increase public awareness of the consequences of concussion in sport on executive functioning (EF).

Limitations of the Study

Despite the strengths of this study, several limitations were also highlighted. Firstly, the recruited sample was relatively small in number (n=60) which could have lowered the power of identifying significant group differences, therefore limiting the study findings. Considering that most of the participants played a contact sport (n=43), the comparison of EF abilities in groups was based on an unequal number of participants in the two groups, thus lowering the power of the sample.

Unlike past studies that have considered education and employment, demographic information pertaining to the levels of education and employment of the participants was not gathered in this study. Furthermore, the use of self-report measures are vulnerable to inaccurate responses by the rater (eg. Latkin et al., 2017), who in this study was the participant. However, participants were asked to complete the DEX questionnaire in an unaided manner to mitigate any social desirability bias which may influence the study findings.

A further limitation was the possible language bias. Considering that the test instructions were provided in English within a Maltese population, this may have influenced the participants' understanding of the tests. However, to minimise this possibility, the tests which were used for this study were not significantly reliant on language.

Additionally, the EF measures that were used in this study are not validated on a Maltese population, and no alternative testing measures were available due to the absence of EF tests that are standardised within the local context.

A sixth limitation of the study is the absence of examination of confounding variables which may influence performance on neuropsychological testing. For example, consumption of alcohol may cause an alteration in mental status which may in turn impact cognitive performance upon testing. Therefore, this limitation may also lead to performance results that are not representative of the examinees' EF abilities.

Implications of Findings

Although the study findings are based on a limited sample, they have shed light on various implications which are listed below.

Clinical Implications

Several protocols related to sport-related concussions are well-documented and should be given importance. To mitigate the consequences related to head injuries in sport, the following clinical recommendations are some examples that have been mentioned in previous studies.

- It is recommended that individuals who have sustained a head injury in sport are given a period of cognitive and physical rest in the initial post-injury phase. This has been recommended as it is likely to support the recovery process (McLeod et al., 2017).
- It is recommended that individuals who have sustained a concussion in sport are closely monitored until full recovery. This is because the effects of repeated concussions on executive functioning has been well-documented. Furthermore, individuals who return to play prior to full-recovery of a head-injury are at a heightened vulnerability of repeat concussion (McCrea, 2009).

- The rule of thumb is that any athlete who is suspected to have sustained a head injury should be immediately removed from the playing ground for a thorough evaluation prior to return to play (Sahler & Greenwald, 2012).
- Lastly, it is recommended that contact sport players who experience difficulties related to inhibitory control are encouraged to participate cognitive training. Dhir et al., (2021) state that cognitive training is a well-established intervention to improve inhibitory control abilities. Engagement in tasks that require inhibitory control skills may therefore strengthen the neural systems that are involved in response inhibition.

Research Implications

This study also revealed significant findings which can be further investigated in future research. The recommendations for research have been listed below.

- Longitudinal studies may be considered to assess for any neuropsychological symptoms of chronic traumatic encephalopathy (CTE) over time due to the increased risk of repetitive head trauma in contact sports.
- Using more than one test and more than one modality to assess the same executive function may reveal further group differences between contact and non-contact sport players. For example, when assessing working memory, using individual tests that measure visual WM and verbal WM individually may provide a more comprehensive idea of current functioning.

Along with the above mentioned research implications of this study, further directions for future research are listed in the following section.

Further Recommendations

Primarily, recruiting a larger sample to test the developed hypotheses would increase the chances of elucidating additional significant findings. It is likely that having a larger sample of contact and non-contact sport participants would increase the power of the statistical tests that are used to test for group differences. It is also recommended that a whole assessment battery is chosen for future studies, such as the BADS assessment (Wilson et al., 1996) which is an ecologically valid test of executive dysfunction and provides a total score for all the six subtests of the test.

Additionally, considering that the study sample was limited to 12 contact sports (see Appendix A), it is recommended that future studies include other types of contact sports. This will allow future researchers to investigate EF abilities across specific contact sports rather than solely based on groups (contact or non-contact sport). Furthermore, since the majority of available studies have been conducted on an international level, a potential local study may also include international contact sport players to compare their performance to national contact sport players.

This current study may also set the ground for a larger study to investigate other domains of cognitive functioning in contact sport players. These domains may include memory, processing speed and attention amongst others. Through examination of the different domains of cognitive functioning, potential study findings may also highlight specific cognitive deficits according to type of sport played.

Since this study did not gather any information pertaining to level of education and employment, obtaining such information in future studies is also recommended. Ideally, future research will also follow a consensus of how different types of contact sports sports are categorised based on risk of head injury and exposure of head injury.

Moreover, since individuals categorise whether a sport is considered to be a contact or non-contact sport in different ways, it may be suitable for future studies to group sports in a pre-determined manner. For example, by recruiting individuals who practice sports according to the level of contact, that is, high contact, limited contact and no contact.

Another recommendation for a potential study is to introduce a control group of individuals who do not practice a sport. This would provide further information about any EF differences in people who practice a sport in comparison to those who do not.

Lastly, as outlined in the discussion, a recent study by Monroe and colleagues (2020) concluded a difference in scores between pre- and post-season testing in a group of waterpolo players. A replication of the current study could include pre-and post-season neuropsychological testing to examine for any changes in EF performance based on the number of head impacts during the season.

Conclusion

In conclusion, this study has contributed to the branch of neuropsychology pertaining to EF impairments in individuals who play contact sports. Although the study findings are based on a relatively small sample (*n*=60), they contribute to further local research as a preliminary attempt to emphasise the importance of neuropsychological testing for contact sport players.

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Appendices

Appendix A: List of Sports included in the Study

Table 14

List of contact and non-contact sports included in the two groups in this study.

CONTACT group (*n*=43)	**NON-CONTACT group (*n*=17)**
Football (*n*=15)	Athletics (*n=1)*
Rugby (*n*=11)	Triathlon (*n=1)*
Handball (*n*=1)	Softball (*n=1)*
Waterpolo (*n*=2)	Swimming (*n=2)*
Krav Maga (*n=1)*	Tennis (*n=2)*
Boxing (*n=3)*	Climbing (*n=1)*
Jiu Jitsu (*n=4)*	Padel (*n=2)*
Basketball (*n=1)*	Sailing (*n=1)*
Karate (*n=1)*	Gymnastics (*n=1)*
Futsal (*n=1)*	Crossfit (*n=3)*
Kickboxing (*n=2)*	OCR (*n=1)*
Combat (*n=1)*	Diving (*n=1)*

Appendix B: Recruitment Forms

Information letter

Dear ___________________________

My name is Michaela Scerri and I am a student at the University of Malta, presently reading for a Master of Psychology in Neuropsychology. I am presently conducting a research study for my dissertation titled 'A Comparison Study of Executive Functioning Abilities in Individuals who Play Contact Sports', and it is being supervised by Dr Kristina Bettenzana. This letter is an invitation to participate in this study. Below you will find information about the study and about what your involvement would entail, should you decide to take part.

The aim of my study is to investigate executive functioning abilities in contact sport players. Any data collected from this research will be used solely for purposes of this study.

Should you choose to participate, you will be asked to sign a consent form prior to your participation. As to collect information, a demographic questionnaire, a self-rating questionnaire and five assessments will be administered. The demographic questionnaire aims to obtain information regarding demographics such as age, gender and type of sport. The self-rating questionnaire involves rating the degree to which a number of short statements used to describe how people feel apply to you. Five performance-based assessments that assess executive functioning using paper-pencil tasks will be used. You will be asked to attend an assessment that will last between 1 hour to 1 hour and 30 minutes. The information you provide will be noted down on paper and you will not be required to disclose any personal information.

Data collected will be kept confidential and your identity will be anonymous and unidentifiable.

Participation in this study is entirely voluntary; in other words, you are free to accept or refuse to participate, without needing to give a reason. You are also free to withdraw from the study at any time, without needing to provide any explanation and without any negative repercussions for you. Should you choose to withdraw, any data collected from your interview will be erased as long as this is technically possible (for example, before it is anonymised or published), unless erasure of data would render impossible or seriously impair achievement of the research objectives, in which case it shall be retained in an anonymised form.

If you choose to participate, please note that there are no direct benefits to you. Your participation does not entail any known or anticipated risks.

Please note also that, as a participant, you have the right under the General Data Protection Regulation (GDPR) and national legislation to access, rectify and where applicable ask for the data concerning you to be erased. All data collected will be stored in an anonymised form and separate from your signed consent form and all data will be erased upon completion of the study and following publication of results (September 2023).

A copy of this information sheet is being provided for you to keep and for future reference.

Thank you for your time and consideration. Should you have any questions or concerns, please do not hesitate to contact me by e-mail on michaela.scerri.14@um.edu.mt; you can also contact my supervisor over the phone: 23402312 or via email: kristina.vella@um.edu.mt.

Sincerely,

Ms Michaela Scerri
michaela.scerri.14@um.edu.mt

Dr Kristina Bettenzana
kristina.vella@um.edu.mt
23402312

Participant's Consent Form

A Comparison Study of Executive Functioning Abilities in Individuals who Play Contact Sports

I, the undersigned, give my consent to take part in the study conducted by Michaela Scerri. This consent form specifies the terms of my participation in this research study.

1. I have been given written and/or verbal information about the purpose of the study; I have had the opportunity to ask questions and any questions that I had were answered fully and to my satisfaction.
2. I also understand that I am free to accept to participate, or to refuse or stop participation at any time without giving any reason and without any penalty. Should I choose to participate, I may choose to decline to answer any questions asked. In the event that I choose to withdraw from the study, any data collected from me will be erased as long as this is technically possible (for example, before it is anonymised or published), unless erasure of data would render impossible or seriously impair achievement of the research objectives, in which case it shall be retained in an anonymised form.
3. I understand that I have been invited to participate in an assessment in which I will be asked to complete a demographic questionnaire and a self-rating questionnaire. Five performance-based assessments that assess executive functioning using paper-pencil tasks will also be administered. I am aware that the assessment will take approximately 1 hour to 1 hour and 30 minutes and I understand that the assessment is to be conducted at a place and time that is convenient for me.
4. I understand that my participation does not entail any known or anticipated risks.
5. I understand that there are no direct benefits to me from participating in this study. I also understand that this research may benefit others by providing information about executive functioning in contact sport players.
6. I understand that, under the General Data Protection Regulation (GDPR) and national legislation, I have the right to access, rectify, and where applicable, ask for the data concerning me to be erased.
7. I understand that my assessment scores will be stored in an anonymised form and separate from my signed consent form and all data will be erased upon completion of the study and following publication of results (September 2023)

8. I have been provided with a copy of the information letter and understand that I will also be given a copy of this consent form.

I have read and understood the above statements and agree to participate in this study.

Name of Participant: ____________________

Signature: ____________________

Date: ____________________

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Michaela Scerri

michaela.scerri.14@um.edu.mt

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Dr Kristina Bettenzana

kristina.vella@um.edu.mt

2340 2312