Mental Fatigue: Effect on Basketball Specific Skill and Performance

by Bryce Daub

Thesis submitted in fulfilment of the requirements for the degree of

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under the supervision of Dr Blake McLean and Distinguished Professor Aaron Coutts

University of Technology Sydney
Faculty of Health

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Certificate of Authorship and Originality of Thesis

I, Bryce Daub declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Sport, Exercise and Rehabilitation, Faculty of Health, at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.
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Bryce Daub

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Publications

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Preface

This thesis for the degree of Doctor of Philosophy is in the format of published or submitted manuscripts and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology Sydney; Policies and Directions of the University'.

From the research design and data collection by the candidate, three manuscripts have been accepted and published to peer reviewed journals, with a fourth paper in preparation for submission. These papers are initially brought together by an Introduction, which provides background information, defines the research problem and the aim of each study. The Literature Reviews then follow to provide an overview of previous knowledge regarding; i) student-athletes and collegiate basketball and ii) mental fatigue. The manuscripts are then presented in a logical sequence *(Chapter 4 to Chapter 8)* following the development of research ideas within this thesis. Each manuscript outlines and discusses the individual methodology and the findings of each study separately. All studies are combined into a discussion chapter, which integrates the collective findings and limitations. This thesis finishes with an overall conclusion, practical applications, an overview of the impact of thesis findings, and directions for future research.

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List of Abbreviations

AAU	Amateur Athletic Union
ACADEMIC	Observational week with High Academic Volume
ACC	anterior cingulate cortex
ANOVA	Analysis of Variance
AX-CPT	Continuous Performance Test
BET	Brain Endurance Training
Bla	Blood Lactate
BRUMS	Brunel Mood Scale
CPT	Continuous Performance Tasks
CV	Coefficient of Variation
d	Cohen's d effect size
dACC	Dorsal anterior cingulate cortex
DI	Division one
DL-PFC	Dorsolateral prefrontal cortex
EDA	electrodermal activity
EEG	Electroencephalography
EMG	electromyography
Free Throw Makes	sum of free throws from 60 attempts
GAME	Observational week with High Game Volume
GSR	Galvanic skin response
HCC	High cognitive control
HR	Heart Rate
HRV	heart rate variability
ICC	Intra-class correlations Coefficient
$MAKE_{4MIN}$	sum of the makes during 4 min shooting
MDC	Minimal Detectable Change
ME	Mental Effort
MF	Mental Fatigue
$MISS_{4MIN}$	sum of the misses during 4 min shooting
MO	Motivation
MVC	Maximum Voluntary Contraction
NASA	National Aeronautics and Space Administration
NCAA	National Collegiate Athletic Association
p	P-value
PFC	Prefrontal cortex
PL	Player Load

POMS	Profile of Mood State
PRACTICE	Observational week with no academic load and no games
PVT-B	Brief psychomotor vigilance test
REST-Q	Recovery Stress Questionnaire
RM-ANOVA	Repeated measures analysis of variance
RPE	Rating of Perceived Exertion
S-RPE	Session Rating of Perceived Exertion
SD	Standard Deviations
SE	Standard Error
SNRs	Signal-to-Noise Ratios
SST	Standardised Shooting Task
SST_{SPOTS}	Sum of the spots completed during 4 min shooting
$SST_{TOTALSHOTS}$	Sum of the total shots 4 min shooting
TE	Typical Error of Measurement
TTE	Time to Exhaustion
TYPICAL	Observational week with Standard number of games and standard academic requirements
UTS	University of Technology Sydney
VAS	Visual Analogue Scale
VO_2	Volume of Oxygen Consumed

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Abstract

While physical fatigue is frequently monitored in elite sport, mental fatigue on athletes' performance is not routinely assessed by coaching staffs. Understanding mental fatigue, especially among student-athletes in universities, could offer valuable insights. Given that student-athletes, particularly basketball players, face multifaceted stressors, there is a need to investigate the presence and impact of mental fatigue on their performance. This thesis contains four independent studies which aim to develop tools which can be incorporated into the applied setting for monitoring student-athletes performance. Once established these assessment methods were then incorporated into a series of related studies designed to advance our understanding of the implications of mental fatigue on collegiate basketball performance.

Study 1 was a novel basketball shooting task. This study aimed to establish a reliable shooting task that is sensitive to detect changes in performance and possesses adequate construct validity. The study was designed to provide a measurement tool that could be applied to college basketball to evaluate sport-specific performance. Study 2 then utilised the SST (Standardised Shooting Task) to understand the effects of mental fatigue on shooting performance in elite level basketball student-athletes. This study sought to evaluate the presence of mental fatigue after sport specific film sessions and its subsequent effect on acute basketball shooting performance. Study 3 aimed to evaluate mental fatigue throughout the course of the NCAA Division I season. Basketball shooting performance was assessed along with objective and subjective markers of mental fatigue, academic study load, film session requirements, training load and game minutes were collected during four distinct phases (GAME: high game volume; ACADEMIC: high academic load; PRACTICE: no academic load (i.e., no classes), no games, multiple practices; TYPICAL: standard number of games and academic requirements during conference play) of an NCAA season. Finally, Study 4 aimed to assess the perceptions of elite student-athletes on their academic and athletic experiences, to better understand the potential presence and manifestations of mental fatigue.

A primary goal of this thesis was to develop a practical sport specific assessment to be utilised in evaluating mental fatigue within a unique population, student-athletes. The main outcomes of this thesis are: i) the novel basketball shooting task, SST, possesses sufficient reliability and sensitivity to detect meaningful changes in performance, as well as adequate construct validity, offering an ecologically valid measurement which can be incorporated to athlete monitoring

strategies in elite basketball; ii) basketball shooting performance in elite student-athletes was significantly reduced following increased levels of mental fatigue and sport-specific Film sessions require a large amount of mental effort, possibly having a detrimental effect on subsequent basketball shooting performance; iii) basketball shooting performance was significantly reduced following increased levels of mental fatigue during periods of increased academic load. However, the period of increased sport-specific training or games had no effect on subsequent basketball shooting performance; iv) perceptions of student-athletes outline pressures to perform both academically and athletically, as well as a consistent belief that the most challenging times academically come during midterm and final exam weeks.

This thesis addressed the gap in current knowledge by developing a novel shooting task and implementing it into a real high performance college basketball setting. The SST was then utilised to evaluated acute mental fatigue in elite student-athletes. The task was then integrated into a Division I basketball season to explore the effect of academics and sport specific scenarios on shooting outcomes. Collectively, the findings of this thesis provide evidence that mental fatigue negatively impacts basketball shooting performance and mental fatigue for student-athletes is highest during periods of increased academic stress.

CHAPTER 1

INTRODUCTION

1.1. Background

During college, students experience a significant amount of change from a variety of new challenges. Students must adjust to an assortment of stressors including social demands, new standards of academic performance, financial concerns and life away from home (Humphrey et al., 2000a; Paule & Gilson, 2010). These stressors have been known to interfere with mental health, concentration and the student's ability to learn (Humphrey et al., 2000b), warranting the large body of research surrounding the effects of stress on college students. Indeed, it has been shown that when stress is perceived as negative or excessive, it can lead to harmful effects on both health and academic performance (Campbell et al., 1992; Humphrey et al., 2000a).

Student-athletes are a unique cohort of individuals who participate in organised sports while also pursuing a secondary education. These student-athletes not only have outstanding skills in their respective sports but also the academic prowess necessary for eligibility (Play Division I Sports). To compete, they must be enrolled as full-time students and uphold academic criteria. This includes maintaining a certain grade point average, consistent enrolment, and showing satisfactory progress towards earning their degree (Play Division I Sports). Because of their combined academic and athletic responsibilities, they are commonly known as 'student-athletes'.

Student-athletes face numerous pressures as they strive to balance sports and academics. Beyond regular academic pressures, student-athletes must maintain grades for eligibility, juggle tight schedules, and find efficient ways to manage study time. This often results in them experiencing greater academic stress than their non-athlete peers (Humphrey et al., 2000a; Pritchard et al., 2007a). From the athletics perspective, factors like time demands of training, coach-athlete relationships, and the pressure to win are significant contributors to stress (Gould & Whitley, 2009). The combination of academic challenges and rigorous athletic training could place a considerable mental and physical strain on these individuals, potentially affecting overall performance in their respective sport.

Success in College basketball depends on a player's ability to integrate their skill, tactical, and physical abilities (Castagna et al., 2008; Stojanović et al., 2018). Sport-specific skills like shooting, dribbling, and passing are essential to offensive performance (Karipidis et al., 2001). Shooting plays a pivotal role in both team and individual outcomes of success (Ibáñez et al., 2003; Karipidis et al., 2001). There are various shooting techniques that are common in basketball, but 'jump shots' make up a majority of shots executed during games. These shots can be taken from any spot on the court, but those made from beyond the 3-point line earn 3 points, while those inside it are worth 2 points. Previous research has highlighted the importance of jump shots, the accuracy of these shots being shown to significantly affect a team's chances of winning (Pojskić, et al., 2009; Smith et al., 2016a; Svilar & Jukić, 2018). However, despite its importance there's an absence of consistent and valid assessments for shooting in basketball. Such a tool would be valuable to monitor skill development and evaluate training methods (Conte et al., 2019; Sunderland et al., 2006).

There are relatively few studies that have developed methods for assessing basketball shooting performance (Boddington et al., 2019; Pojskić et al., 2010; Pojskic et al., 2018), and existing protocols exhibit limitations. Some tests suffer from high variability as athletes pick their shooting spots (Vernadakis et al., 2004). Other protocols have been poorly described, making them hard to replicate (Pojskić et al., 2014; Robertson et al., 2014; Thakur & Mahesh, 2016). For basketball professionals, a reliable assessment of shooting skills is invaluable. While tests with real-game relevance are desired, many are unfeasible for regular use during a season. Most current methods aren't practical due to their structure and length (Filipas et al., 2021a; Thakur & Mahesh, 2016). Thus, creating a realistic and feasible basketball shooting test could aid in identifying talent, tracking athletes, and improving sport-specific skills. Once established and demonstrated to be reliable, such a test would allow coaches to evaluate players under varied conditions.

The impact of fatigue on sport performance has long been an interest to scientists and practitioners. While fatigue can manifest in different ways, a complex system operates involving both physiological and psychological processes. Understanding the mechanisms of fatigue is critical for coaches, athletes, and sport practitioners as it aids in the development of effective and efficient training programs intended to optimize performance outcomes. Indeed, these mechanisms have been researched extensively, however, traditionally fatigue has been investigated under a neuromuscular and metabolic approach (Bangsbo et al., 2007; Smith et al., 2016). While relevant, recent discussions in sport performance have diverged mental fatigue from the common factor of physical fatigue.

Mental fatigue is a psychobiological state caused by exposure to prolonged periods of cognitively demanding tasks and has many implications on performance (Boksem et al., 2005, 2006a; Job & Dalziel, 2001; Lorist et al., 2005). Investigations in the literature on the effects of mental fatigue on task performance date back to the nineteenth century in the book "La Factica" by Alessandro Mosso (Mosso, 1891). In this study, repeat submaximal contractions were reduced by not only by prior physical exercise but also excessive mental work (prolonged lectures). More recently, the negative effect of mental fatigue on muscle endurance was reinforced in a study by Pageaux et al., showing isometric knee extensor exercise to exhaustion was impaired by mental fatigue (Pageaux et al., 2013a). Muscular endurance tasks typically involve a single muscle or group of muscles, however, whole-body endurance assessment also demonstrated that 90 minutes of cognitively demanding task elicited mental fatigue and negatively affected performance (Marcora et al., 2009a). In more recent work mental fatigue has been shown to be associated with a decline in physical performance during intermittent running, isolated bouts of aerobic efforts, anaerobic efforts and maximum voluntary contraction (Brown et al., 2019; Smith et al., 2015a).

In more recent years, attempts to offer a more comprehensive understanding of mental fatigue, showing that it arises not only from prolonged tasks but also from high cognitive effort in varying conditions. Lopes et al. highlights the dynamic nature of mental fatigue, emphasizing its dependence on both task duration and intensity, and stress the importance of connecting laboratory findings to real-world applications, such as sports performance (Lopes et al., 2023). Fortes et al. expanded this perspective, demonstrating that even short-term, high-effort tasks can cause mental fatigue, reducing the rate of force in resistance training (Fortes et al., 2024). This evolving understanding of mental fatigue highlights the importance of recognizing high cognitive effort as a key factor (Fortes et al., 2024; Lopes et al., 2023). Furthermore, expanding these perspectives enables better strategies for mitigating mental fatigue, enhancing performance, and promoting well-being across various domains.

Whilst these previous investigations may provide insight into the physical performance consequences associated with mental fatigue, these tasks are not representative of complex, skill based, team sports such as basketball. The game of basketball requires intermittent bouts of acceleration, deceleration, change of direction and jumping, which all vary in duration and intensity (Stojanović et al., 2018). Additionally atheltes are required to make critical decisions throughout the game which impact success of the individual and team (Bar-Eli & Tractinsky, 2000). Despite the negative effects of mental fatigue on multiple facets of performance, and the significant mental load and stress imposed on student-athletes from multiple domains, the possible manifestation of mental fatigue during the intercollegiate basketball season has not been investigated. Moreover, mental fatigue has also been shown to increase following other tasks which are likely part of student-athletes weekly routines, such as screen time on social media (Fortes et al., 2021a), prolonged tactical sport videos (Filipas et al., 2021a), and video games (Faro et al., 2022a). Therefore, research examining the presence of mental fatigue and potential effects on basketball performance in the collegiate setting is required.

1.2. Statement of the Problem

In recent years there has been an emphasis on understanding the physical demands of sport on high level athletes. The popularity of basketball, coupled with extensive resources for many college teams, has allowed for the implementation of strategies and technology to assess these physical loads. However, there is very limited information about the cognitive demands on high level athletes and the ability to assess the presence of mental fatigue.

Furthermore, understanding physical load demands on athletes has been known to help inform periodization strategies and mitigate risk of injury (Aoki et al., 2017; Caparrós et al., 2018; Moreira et al., 2015; D. J. Smith, 2003). This same concept could potentially be applied when assessing mental fatigue and cognitive demands of the student-athlete. Moreover, the high cognitive demands of sport could be mentally fatiguing when endured for a long period of time.

From a theoretical perspective, sustained mental fatigue is rooted in the depletion of cognitive resources, which are finite and require regular replenishment through rest or reduced mental workload (Boksem & Tops, 2008a). This depletion impairs the brain's ability to maintain optimal functioning, leading to a decline in cognitive performance, decision-making, and overall productivity (van der Linden et al., 2003a).

The cumulative effect of sustained mental fatigue occurs when repeated exposure to cognitive stressors is paired with insufficient recovery time. Over time, this lack of recovery leads to an escalating deficit in cognitive resources. Theories such as the *Ego Depletion Theory* (R. F. Baumeister et al., 1998) and *Compensatory Control Model* (Robert J. Hockey, 1997) suggest that the brain adapts to prolonged fatigue by reallocating resources, prioritizing critical tasks at the expense of less essential cognitive functions. While this compensatory mechanism can temporarily maintain performance, it contributes to a more profound and enduring state of fatigue when overstretched.

This opens new opportunities to improve performance by minimising as much as possible the mental load, and its potentially fatiguing effects, leading up to or during competitions and/or by increasing resistance to the negative effects of mental fatigue on perception of effort and performance.

Based on these limitations, this thesis aimed to establish reliable assessment protocols to identify the presence of mental fatigue and its impact on subsequent basketball shooting performance. This information could then be used to better understand current stressors faced by student-athletes and provide insight for future performance improvements. This would also allow for future work identifying cognitive demands of a National Collegiate Athletic Association (NCAA) basketball athlete across different phases of the season. Through optimised strategies aimed at managing mental fatigue, practitioners may provide a competitive advantage to the student-athletes.

1.3. Research Objectives

The thesis consists of a series of studies with the collective aims of enhancing our understanding of how mental fatigue impacts elite level student-athletes. Through the planned series of studies, the aim is to: i) develop a sensitive and reliable assessment for basketball shooting performance; ii) assess the effects of mental fatigue and sport specific film sessions on changes in basketball shooting performance; iii) assess changes in basketball shooting performance throughout the course of an NCAA basketball season; iv) gain insight into the perspectives and experiences of elite basketball student-athletes. The overarching goal of this research is to improve current methodologies in assessing mental fatigue within the practical setting and provide coaches and practitioners insight to potential performance decrements (Figure 1).

1.3.1 Study 1: The reliability and usefulness of a novel basketball Standardized Shooting Task (Chapter 4)

Aims: To establish a reliable shooting task that is sensitive to detect changes in performance.

Hypothesis**:** It is hypothesised that this test will possess sufficient reliability and sensitivity to detect meaningful changes in performance, as well as adequate construct validity. Therefore, offering an ecologically valid measurement.

Significance: This study aims to establish a reliable shooting task that is sensitive to detect changes in performance. Subsequently, this will provide sport coaches and practitioners with a valuable tool to utilise in the evaluation of sport specific performance. Furthermore, deviations in skill can be quantified and may allow for the implementation of interventions throughout the course of the training or season.

1.3.2 Study 2: Impacts of mental fatigue and sport specific film sessions on basketball shooting tasks (Chapter 5)

Aims: To understand the effects of mental fatigue on shooting performance in elite level basketball athletes. Furthermore, this study sought to evaluate the presence of mental fatigue after sport specific film sessions and its subsequent effect on acute basketball shooting performance.

Hypothesis**:** It is hypothesised that mental fatigue will be present in both the Film and Stroop conditions, but not the Control. Furthermore, when mental fatigue is present there will be a decrease in basketball shooting performance.

Significance: This study provided a novel insight to the presence of mental fatigue and its effects on basketball shooting performance. Whilst previous investigations may provide insight into the physical performance consequences associated with mental fatigue, these tasks are not representative of complex, skill based, team sports such as basketball. This will provide insight to the application of a practical skill task for use during the season.

1.3.3 Study 3: Mental fatigue and basketball shooting performance over different phases of an NCAA Season (Chapter 6)

Aim: To evaluate mental fatigue throughout the course of the NCAA Division I season. Data will be garnered from four distinct phases of an NCAA season.

Hypothesis**:** It is hypothesised that levels of mental fatigue will increase during times of high academic demand and negatively impact subsequent basketball shooting performance.

Significance: Cognitive demands may vary based on the unique phases throughout an NCAA Division I season. This could be important for collegiate athletes as mental fatigue may accumulate from various stimuli, including academic requirements, social commitments, media obligations and team duties. Evaluating changes in basketball shooting performance during those time points is critical to better understand and most appropriately prescribe and periodise training.

1.3.4 Study 4: Division I Collegiate Basketball Players Perspective of mental fatigue (Chapter 7)

Aim: To qualitatively examine the perceptions of elite student-athletes on their academic and athletic experiences, in order to better understand the potential presence and manifestations of mental fatigue.

Hypothesis**:** It is hypothesised that student-athletes endure added stress and likely increased mental fatigue due to the emphasis on academic expectations and athletic demands.

Significance: This investigation would offer valuable insight into perspectives and experiences of elite student-athletes. As such it would provide practitioners, coaches and players the opportunity to address potential concerns in order to improve performance.

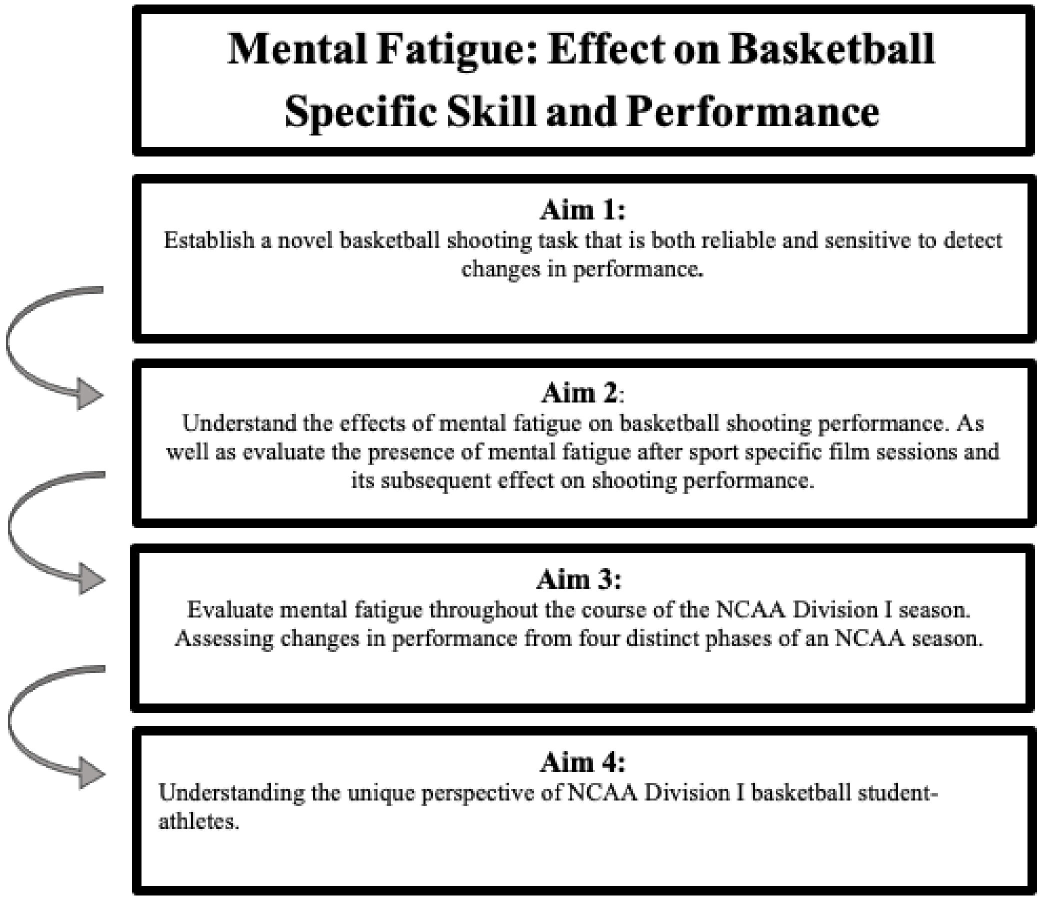

Figure 1-1: Progression of research studies.

CHAPTER 2

LITERATURE REVIEW:

THE STUDENT-ATHLETE

2.1. Student-athletes in USA College

In the USA the NCAA governs the highest level of intercollegiate athletics, Division I. The student-athletes selected to compete in NCAA Division I are an exclusive group, with only 2.5% of high school athletes receiving the opportunity to compete at that level (Irick, 2019). These student-athletes are not only exceptional in their sport-specific skills but also possess the academic aptitude required for eligibility (Play Division I Sports). To compete in NCAA events, athletes must be full-time students and meet rigorous academic criteria. They are required to maintain a minimum GPA that aligns with escalating benchmarks: 90% of the institution's minimum GPA needed for graduation (e.g., 1.8) by the end of their second year, 95% (e.g., 1.9) by the end of their third year, and 100% (e.g., 2.0) by their fourth year. Additionally, athletes must demonstrate continuous enrolment and satisfactory academic progress, completing at least 40% of their degree requirements by the end of year two, 60% by year three, and 80% by the conclusion of year four (Play Division I Sports). Athletes who do not meet these academic and enrolment standards risk losing eligibility to compete, along with potential forfeiture of athletic scholarships and university enrolment. The dual commitment to managing rigorous academic schedules alongside sporting excellence underscores the challenges these individuals face, highlighting why they are genuinely regarded as 'student-athletes'.

Student-athletes competing in NCAA Division I have been reported to spend considerable time in both academic and athletic domains, investing as much as 39 and 34 hours per week, respectively (*NCAA GOALS Study of the Student-Athlete Experience: Initial Summary of Findings*, n.d.). Previous investigations show that the time and effort required to excel in both areas can contribute to higher academic stress compared to non-athletes (Humphrey et al., 2000a; Pritchard et al., 2007a). This stress could not only impact their academic performance but may also influence their athletic performance and health. Indeed, a link between academic stress and injury rates has been demonstrated in collegiate football players (Mann et al., 2016a). The findings of this previous study showed that student-athletes carrying heavier academic loads were more susceptible to injuries, indicating that psychological stress can have tangible physical consequences for athlete health (Mann et al., 2016b). The combination of academic expectations, demanding training schedules, and the pressure to perform at a high level in both academics and sports places substantial mental and physical burdens on student-athletes.

2.1.1. Student-athlete perceptions

With regard to student experience, student-athletes have previously been shown to perceive greater amounts of stress than traditional non-athlete students (Watson, 2016). Indeed, is has been reported that 30% student-athletes perceived themselves as severely overwhelmed by their responsibilities each month and an additional 33% reported struggling to perform tasks outside of their sport (NCAA GOALS Report, 2016). In contrast, it has been shown that only 10-12% of non-athlete students experience “serious” stress (Abouserie, 1994; Pierceall & Keim, 2007). It has also been reported that the student-athletes lack sufficient time to cultivate social relationships outside of sport, which contributes to lower levels of self-reported “wellness” when compared to non-student-athletes (Watson & Kissinger, 2007). There is a myriad of factors that contribute to increased stress for the student-athlete, including time demand, conflict with coaches, fear of injury, team dynamics and loss of playing time (Pritchard et al., 2007b). However, the strongest association to increases of perceived stress was attributed to academic anxiety (Hwang & Choi, 2016). Nevertheless, despite this increase in perceived stressors, the student-athletes must balance the full academic expectations of traditional students while navigating practice, competition, travel, and team obligations. It is therefore understandable that student-athletes have higher levels of anxiety, depression, and psychological stress than non-student-athletes, who don’t experience the added rigors from sport (Demirel, 2016).

While some research has been conducted surrounding the student-athlete, significant gaps still exist in the literature relating to the interplay of academics and sport performance. As such, researchers, coaches and practitioners should further explore the challenges faced by this unique population and examine how these stressors might affect their academic and athletic performance.

2.2. Collegiate Basketball in the USA

Despite being amateurs, Division I basketball players are generally considered elite athletes. Athletes who compete at the Division I level are typically highly skilled and talented individuals who have demonstrated exceptional athletic abilities (McKay et al., 2022a). In addition to the athletes, Division I basketball features some of the most competitive and prestigious college basketball programs in the country. These programs compete against each other in regular-season games, conference tournaments, and the NCAA Division I Men's

Basketball Tournament (often referred to as "March Madness"), which determines the national champion. Each year this tournament produces millions of viewers with the 2023 championship game alone bosting 18.1 million views (apnews.com). Furthermore, the revenue for this event also has substantial implications with the 2023 tournament grossing 1.28 billion dollars (apnews.com).

The NCAA Division I collegiate basketball season extends over a period of five months and comprises around 30 regular season games. During these games athletes are required to perform frequent bursts of high-intensity movement in intricate scenarios, which has led most research on athlete stressors to focus on the sport's physically rigorous demands (Stojanović et al., 2018). Although the research focus has traditionally been physical aspects of the game, recent studies have begun to explore the cognitive aspects of basketball, specifically examining the impact of mental fatigue on basketball-specific performance (Cao et al., 2022). Some of this previous research in basketball has demonstrated that mental fatigue negatively affects both technical and cognitive performance, particularly in decision-making (Cao et al., 2022; Daub et al., 2022). Furthermore, studies have also revealed that mental fatigue tends to increase following other tasks that are likely part of student-athletes' weekly routines, such as engaging in social media (Fortes et al., 2021a), watching prolonged tactical sport videos (Filipas et al., 2021a), and playing video games (Faro et al., 2022b). Despite these adverse effects of mental fatigue on various performance aspects and the considerable mental load and stress that student-athletes experience across different domains, the potential manifestation of mental fatigue during the intercollegiate basketball season has yet to be explored. Therefore, future research should explore specific underlying mechanisms and contributors of mental fatigue in elite collegiate basketball. Additionally, researchers should examine how mental fatigue specifically affects the performance of student-athletes in basketball.

CHAPTER 3

LITERATURE REVIEW:

FATIGUE AND HUMAN PERFORMANCE

3.1. Introduction to fatigue

Fatigue is a complex phenomenon that affects individuals in many contexts, encompassing physical, mental, and emotional realms. Although many definitions exist, fatigue is commonly described as a state of diminished physical or mental capacity resulting from prolonged exertion, insufficient rest, or a combination of both (Abd-Elfattah et al., 2015; Gandevia, 2001a). Fatigue arises from a multifaceted interplay of physiological and psychological factors and leads to a decline in performance and/or altered subjective experience of individuals (Enoka & Stuart, 1992a; Gandevia, 2001b; S. Russell et al., 2020a). Early investigations into the mechanism of fatigue focused on isolating a single primary cause (Abbiss & Laursen, 2005a). However, more recent emphasises a more comprehensive perspective that considers multiple contributing factors (Knicker et al., 2011a; Mendez-Villanueva et al., 2007). This approach is conceptually more robust, as it recognises that fatigue is most likely the result of multiple physiological mechanisms working together in a coordinated dynamic fashion, rather than functioning independently in isolation. Based on their origin along the motor pathway, these physiological mechanisms are typically defined as peripheral fatigue and central fatigue (Ament & Verkerke, 2009a; Gandevia, 2001a).This section will review both the peripheral and central components of fatigue, as well as introduce the concept of mental fatigue.

3.1.1. Peripheral fatigue mechanisms

Peripheral fatigue is defined as a reduction in the force-generating capabilities of skeletal muscle and involves changes in processes at or distal to the neuromuscular junction(Ament & Verkerke, 2009b; Ross et al., 2007). With peripheral fatigue, skeletal muscles become unable to respond adequately to central activity, with peripheral factors becoming the primary limitation in force production (Ament & Verkerke, 2009b; Ross et al., 2007). Various mechanisms have been reported to contribute to peripheral fatigue, including alterations in neuromuscular transmission and sarcolemma excitability, disruptions in excitation-contraction coupling, changes in contractile activity, and decreases in metabolic energy supply and metabolite accumulations (Allen et al., 2008; Kent-Braun et al., 2012).

Neuromuscular transmission initiates the process of excitation-contraction coupling, leading to the propagation of action potentials across the sarcolemma (Allen et al., 2008; Ament & Verkerke, 2009a). Prolonged depolarization during activity may impact ion channels in the tubules, influencing the electrochemical gradient and, consequently, decreasing the release of

Ca^{2+} and overall force production (Allen et al., 2008; Kent-Braun et al., 2012). Completing muscle contractions necessitates the reabsorption of Ca^{2+} into the sarcoplasmic reticulum (SR) (Kent-Braun et al., 2012). Fatigue can alter this reuptake process, affecting the duration of relaxation(Allen et al., 2008). Metabolic imbalances, characterised by increased inorganic phosphate, adenosine diphosphate, adenosine monophosphate, Mg^{+}, and reactive oxygen species, along with decreased pH, ATP, and overall substrate availability, contribute to peripheral fatigue (Allen et al., 2008). These disruptions in homeostasis impact both contractile activity and excitation-contraction coupling (Allen et al., 2008; Myburgh, 2004).

Fatigue that manifests during intense activity is thought to result from the increase in inorganic phosphate which reduces the sensitivity of myofibrils to Ca^{2+} and increases titanic [Ca^{2+}] levels and this interferes with actomyosin interactions (Allen et al., 2008; Kent-Braun et al., 2012). As a result, muscle force production is diminished. In addition, metabolic shifts, such as rises in adenosine diphosphate concentration and reactive oxygen species, can impact the velocity of muscle shortening, contributing to muscle fatigue (Allen et al., 2008). Depletion of substrates and alterations in energy availability, including reductions in ATP, creatine phosphate, and muscle glycogen, further influence fatigue by affecting SR Ca^{2+} ATPase (SERCA) function, leading to increased leakage and elevated intracellular Ca^{2+} levels. These combined factors contribute to the intricate phenomenon of peripheral fatigue (Allen et al., 2008; Kent-Braun et al., 2012). While peripheral fatigue mechanisms focus on the limitations within the muscles themselves, such as energy depletion and metabolite accumulation, central fatigue mechanisms highlight the role of the brain and nervous system in regulating performance, particularly through reduced neural drive and altered motivation during prolonged or intense activity.

3.1.2. Central Fatigue Mechanisms

Central fatigue is characterised by a diminished drive of motor cortical output, resulting in a decline in performance or cessation of activity, primarily involving changes proximal to, but not encompassing the neuromuscular junction (Ament & Verkerke, 2009b). Commonly referred to as a decrease in central drive, the central nervous system (CNS) fails to adequately stimulate motor neurons (Enoka & Stuart, 1992b; Gandevia, 2001a). While conventional belief implicated any point in neuromuscular transmission affecting cross bridges as the origin of central fatigue, recent studies propose the brain as its primary source (Zając et al., 2015).

Notably, one of the critical elements is the accumulation of extracellular serotonin during exercise, along with other molecules such as gamma-aminobutyric acid, glutamate, or dopamine (Meeusen et al., 2006).

Central fatigue can be categorised into supraspinal fatigue, associated with reduced motor cortex output, and spinal fatigue, involving the inhibition of motor neuron excitability within the spinal reflex network (Enoka & Stuart, 1992b; Gandevia, 2001a). Certain areas of the brain, through a decrease in vascular resistance and an increase in perfusion, actively maintain homeostasis (Gandevia, 2001a). These areas include the vestibular nuclear area, cerebellar ventral vermis, floccular lobe, cardiorespiratory control (medulla and pons), and vision-related regions (dorsal occipital cortex, superior colliculi, and lateral geniculate body) (Gandevia, 2001a). Conversely, regions related to hearing (cochlear nuclei, inferior colliculi, and temporal cortex) and smell (olfactory bulbs and rhinencephalon) remain constant and unaffected by exercise (Gandevia, 2001a). Another significant brain structure involved in central fatigue is the insula, with its right part associated with sympathetic activity and the left part with parasympathetic activity (Delp et al., 2001). Furthermore, alterations at the spinal cord level regarding the afferent input of neuromuscular spindles and tendon organs, which encompass Golgi structures and nerve fibre circuits (Gandevia, 2001a).

Beyond its impact on physical output, central fatigue leads to cognitive fatigue phenomena, associated with behavioural and mood disorders (Leavitt & DeLuca, 2010). Prolonged acute central fatigue can result in sleep disturbances, depression, pain, a sense of fatigue, difficulty in maintaining cognitive vigilance, and challenges in sustaining mental attention (Leavitt & DeLuca, 2010). Building on the understanding of central fatigue mechanisms, which emphasize the brain's role in modulating physical performance, we turn to the constructs of mental fatigue, a cognitive phenomenon characterized by reduced psychological and attentional capacity that can further influence central processes and overall performance.

3.1.2.1. Constructs of Mental Fatigue

Due to the potential for fatigue to affect an individual’s ability to continue exercise, the origins and effects of fatigue within sport have been investigated extensively (Abbiss & Laursen, 2005b; Ament & Verkerke, 2009c; B. K. Barry & Enoka, 2007; Knicker et al., 2011b). Athlete fatigue in response to training loads, its impact upon performance and response to various recovery strategies have been well established, as well as work exploring the psychobiological origins of fatigue. In recent years however, mental fatigue has been increasingly investigated as a distinct component of fatigue. Specifically, relatively less attention has been given to the psychological and cognitive aspects of fatigue and how it may impact sports performance.

Mental fatigue is a psychobiological state often caused by exposure to prolonged periods of cognitively demanding tasks and has many implications on performance (Boksem et al., 2005, 2006a; Job & Dalziel, 2001; Lorist et al., 2005). Mental fatigue can manifest subjectively, behaviourally, and physiologically:

- Subjectively, mental fatigue is characterised by feelings of "tiredness" and "lack of energy", as well as decreased motivation and alertness (Boksem & Tops, 2008b; Marcora et al., 2009a).
- Behaviourally, mental fatigue is represented by decreases in cognitive task performance (i.e. accuracy and reaction time) (Marcora et al., 2009a).
- Physiologically, changes in brain activity have been associated with the manifestation of mental fatigue (Cook et al., 2007a; Wascher et al., 2014).

Investigations into the effects of mental fatigue on task performance date back to the nineteenth century, when Mosso (Mosso, 1891) reported that submaximal contractions were reduced by excessive mental work. During that same time, psychologists also began to explore mental processes and their limitations while delving into subjective experiences of mental fatigue (Wilhelm Wundt, 1904; William James, 1890). However, it is relatively recently that studies have investigated the effects of mental fatigue on sport performance (Marcora et al., 2009b; Smith et al., 2015b). Understanding the potential implications of mental fatigue on skilled sport performance provides coaches, athletes, and sport practitioners with valuable insight, which can be incorporated into athlete monitoring strategies.

3.2. Inducing Mental Fatigue Experimentally

When developing experimental models to better understand mental fatigue, and its effect on athletic performance, it is important to establish that mental fatigue was induced/present. As mental fatigue can manifest via subjective, behavioural and physiological mechanisms, a need for well-defined paradigms that consider the contribution of multiple outcome parameters is necessary (Van Cutsem et al., 2017a). Previous studies have used both pen /paper and computer-based tasks requiring high vigilance with varying duration and demands to deliberately induce mental fatigue (Filipas et al., 2021b; Russell et al., 2020b; Smith et al., 2017a). These studies have shown that it is possible to elicit acute mental fatigue if a large enough cognitive stimulus is presented through an appropriately designed/controlled task (Marcora et al., 2009a; Smith et al., 2016b). However, to date, most studies have used experimental protocols to induce mental fatigue that may not represent the extent of mental fatigue in the sport setting. Understanding which tasks are cognitively demanding in the applied setting could offer insight into implications on performance in sport. This section will explore a range of standardised tasks, that have been used to induce mental fatigue for experimental purposes.

3.2.1. Modified Stroop

The modified Stroop task is prominent within the literature and a commonly used method of inducing mental fatigue (Boat et al., 2020; Smith et al., 2019). It demands response inhibition and sustained attention to stimulate the activation of the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DL-PFC), straining decision-making, attention, and cognitive flexibility (Banich & Depue, 2015; MacDonald et al., 2000; Pageaux et al., 2014). During the Stroop task, four words (red, blue, green, and yellow) are displayed in a repeated fashion. Participants are required to respond to each word, with the correct response corresponding to the ink colour of the word (red, blue, green, and yellow), rather than the words meaning. Therefore, if the word ‘‘green’’ is printed in blue ink, the correct response is ‘‘blue’’. However, if the ink colour of the word is red, the correct response corresponded to the meaning of the word, rather than its printed colour. Therefore, if the word ‘‘green’’ is displayed in red ink, the correct answer is ‘‘green’’. In the literature the modified Stroop test is completed via computer or paper-based version for a duration of 15-90 minutes (Smith et al., 2018; Van Cutsem et al., 2017).

3.2.2. AX-CPT

Continuous Performance Tasks (CPT) require the participants to see or hear a series of stimuli and for each stimulus, they must provide or withhold a response depending on instruction. One variation of the CPT is the AX-CPT, which examines context processing and goal maintenance through the activation of the DL-PFC (Cohen et al., 1999; Lopez-Garcia et al., 2016). In this version of the CPT, randomly chosen letters are presented sequentially in a visual display, and participants are instructed to respond only to the letter X, and only when it follows an A. Performance relies on the representation and maintenance of context information, as the correct response to X depends on the previous stimulus (A or not A)(Cohen et al., 1999). If the latter A is followed by X, participants press the right button, for any other letter combinations, the left button is selected. Incorrect responses are indicated by an audible "beep", encouraging prompt and accurate responses (Cohen et al., 1999; Lopez-Garcia et al., 2016). In recent years several studies have adopted the AX-CPT for assessing mental fatigue, specifically in endurance performance (MacMahon et al., 2014; Marcora et al., 2009a; Smith et al., 2015a).

3.2.3. Eriksen Flanker test

The Eriksen Flanker Test is a set of response inhibition tasks requiring quick and precise identification of alphabetical letters (Eriksen & Eriksen, 1974). This task is primarily controlled by the prefrontal cortex (PFC) and dorsal anterior cingulate cortex (dACC), requiring participants to select the correct response to a central letter while remaining letters in a horizontal row act as "flankers" (Blasi et al., 2006). Each stimulus contains either congruent (both the target stimulus and the flankers correspond to the same directional response) or incongruent (where the central target letter and the flankers correspond to opposite directional responses) stimuli. Other variants of the Eriksen Flanker Task have used numbers, colours, or arrows as stimuli. Mental fatigue has been evaluated using the Eriksen Flanker Test in previous investigations using protocols lasting up to 120 minutes (Faber et al., 2012; Lorist et al., 2005).

3.2.4. Go/NoGo

The Go/NoGo task, in which subjects have to respond to one stimulus (Go) but not respond to another stimulus (NoGo) challenges response inhibition as subjects must use speed and accuracy while executing responses (Kato et al., 2009). When shown "Go left" or "Go right", participants press the corresponding keypad (e.g. using the right-handed keypad to confirm "Go right"), however a "NoGo left" or "NoGo right" stimulus is ignored (Menon et al., 2001). Participants are to respond as swiftly and accurately as possible, with each stimulus presented equally in a random fashion. Menon et al. recently demonstrated the GO/NoGo task to elicit high activity among the PFC and ACC, suggesting complex decision making as well as demand on attention. Furthermore, the Go/NoGo task has been shown in previous work to induced mental fatigue in healthy populations (Kato et al., 2009).

3.2.5. Auditory

Few studies have attempted to assess changes in fatigue during sustained listening. Prolonged listening, despite limited physical requirements, may be considered tiring (McGarrigle et al., 2017a). Much like the demands of other cognitive tasks (AX-CPT and Stroop), prolonged listening requires sustained attention and focus (McGarrigle et al., 2017a). McGarrigle et al., recently investigated the impact of continuous listening and its impact on arousal and mental fatigue (McGarrigle et al., 2017b). Participants pupil size and response times were monitored while performing a speech-picture verification task. During the task participants were also exposed to task varying signal-to-noise ratios (SNRs). Results from the investigation found that pupil diameter was significantly increased in the latter half of the trial, indicating a reduction in physiological arousal. Subsequently, Moore et al. quantified mental fatigue using self-report and response time accuracy during a 50-minute choice listening task (Moore et al. 2017). Subjective and behavioural measures revealed reduced motivation and changes in neural activity were similar to that of decreased arousal. These studies may have relevance as some athletes are exposed to prolonged periods of listening (e.g. meetings, lectures, tactical observations and classes/lectures).

3.2.6. Driving

Driving is an example of a complex task that requires continuous attention in order to detect possible hazards (Zhao et al., 2012a). Thus, several studies have emphasised the impact of driving protocols on subjective and objective measures of mental fatigue. One study using Electroencephalography (EEG) found that following 90 minutes of driving simulation activity resulted in a subject's reporting a significant increase in subjective feelings of tired, bored and drowsy (Zhao et al., 2012b). Furthermore, subjects displayed increases in alpha brain activity along with a reduction in beta brain activity when compared with baseline (Zhao et al., 2012a). These findings suggested mental fatigue was present as it has been previously shown that a rise in alpha brain activity is associated with declined attention levels and a decrease in beta brain activity is associated with deteriorated arousal levels (Okogbaa et al., 1994). In other research, Lal and Craig also revealed that monotonous driving simulations of two hours in length resulted in significantly greater delta and theta brain activity, suggesting a reduction in driver alertness (Lal & Craig, 2002). Furthermore, unique to this investigation, was the use of the Brunel Mood Scale (BRUMS) questionnaire. Subjective responses to the driving showed significantly greater levels of anxiety, tension and fatigue along with reduced vigour with extended driving tasks (Lal & Craig, 2002).

Several tasks have been used in the literature to induce mental fatigue. Each with a common objective of providing varying task complexity to increase brain activity and stimulate mental fatigue. These tasks provide practitioners with a validated and simple to administer construct when inducing mental fatigue for real world conditions. However, limitations of these tasks may exist in a more dynamic setting (i.e. sport). Thus, further research is necessary to understand the implications of varying exercise in applied environments.

3.3. **Quantifying Mental Fatigue**

3.3.1. *Physiological Measures of Mental Fatigue*

Mental fatigue can be assessed using different indicators including changes in performance, psychological state, and physiological function. To better comprehend the cognitive demands of a given tasks it is critical to be able to understand the methods used to measure mental fatigue. This section will discuss common physiological measures used to assess mental fatigue. These objective measures give practitioners insight into the benefits and limitations associated with each technique and will provide valuable insight for both researchers and practitioners to understand how to it may be applied in their work.

3.3.1.1. Electroencephalography (EEG)

EEG is a commonly utilised method to assess mental fatigue in the experimental setting (Teplan, 2002). EEG detects electrical currents, measuring the spontaneous electrical brain activity through delta, theta, alpha and beta waves (Teplan, 2002). Measuring directly from the cortical surface through electrodes, this non-invasive procedure can be applied repeatedly with virtually no risk or limitation. The initial observation of electrical currents in the brain by Richard Caton in 1875, lead to Hans Berger using radio equipment to amplify the brain's electrical activity on the human scalp in 1924 (Teplan, 2002). Current EEG measurement methods consist of a cap worn on the scalp with 32, 64, 128 or 256 active electrodes, amplifiers with filters, analogue to digital converter and a computer with data storage and display (Teplan, 2002). McEvoy et al. showed high levels of test-retest reliability of EEG responses with cognitive tasks, supporting its use in assessing transient changes in neurophysiological signals of cognition due to fatigue (McEvoy et al., 2000).

Some challenges exist when incorporating EEG with physical activities as these measures are highly responsive to minor disturbances such as exposure to light, noise, perspiration and movement. These perturbations can negatively influence the signal strength, thus critically effecting the quality of data collection (Britton, 2016; Reinecke et al., 2011). As such investigations using EEG measures have primarily been in tasks that are static in nature, such as driving (Lal & Craig, 2002; Ting et al., 2008; Zhao et al., 2012a) and computer-based vigilance tasks (Berka et al., 2004; Gevins et al., 1998). However, some researchers have used EEG to measure brain activity in a controlled setting via treadmill endurance performance (Brownsberger et al., 2013) and knee extension exercises (J. Baumeister et al., 2012). Also, Pires et al. explored how mental fatigue affects cortical activation and psychological responses during a cycling trial, finding that mental fatigue significantly impaired performance and was associated with alterations in brain activity patterns (Pires et al., 2018). Furthermore, Baumeister et al., investigated more dynamic settings, putting in golf (J. Baumeister et al., 2008; Reinecke et al., 2011), and Nintendo Wii (physically active computer games) (J. Baumeister et al., 2010). Additionally, Habay et al. also explored the electrophysiological signature of mental fatigue in table tennis performance, also utilizing EEG to explore how mental fatigue can influence brain activity and performance (Habay et al., 2021). Similarly, of note in the aforementioned investigations, it is essential to emphasize the importance of properly processing EEG signals to ensure accurate and reliable data. Unwanted noise and movement artifacts are common challenges when recording EEG during physical tasks. Given the limitations in assessing EEG reliably in complex tasks that require high physical demands, EEG may not be suitable for assessing mental fatigue in sport-specific tasks.

3.3.1.2. Heart Rate Variability

Several investigations have used heart rate variability (HRV) as a method for assessing cognitive load during task performance. HRV serves as an indicator of the autonomous regulation of the heart, specifically referring to the fluctuations in the time intervals between consecutive heartbeats (Thayer et al., 2012). It has connections to numerous regions of the brain and encompasses a range of psychological phenomena, some of which are similarly linked to fatigue (Thayer et al., 2012). The autonomic nervous system, serving as a neurophysiological foundation for adjusting behaviour in response to environmental changes, plays a crucial role in handling cognitively challenging and prolonged tasks (Giuliano et al., 2018; Lin et al., 2020). Consequently, it's reasonable that prior studies have investigated the relationship between mental fatigue and HRV. Specifically, HRV were shown to increase in pilots during flight simulations in the take-off and landing portions of the journey (Hankins & Wilson, 1998). Additionally, research in simulated work environments involving computer tasks, has revealed an increase in HRV in response to increased mental stress (Garde et al., 2002; Hjortskov et al., 2004; Taelman et al., 2011). Nevertheless, careful consideration and caution must be noted when using heart rate variability as a remote gauge of mental capacity.

3.3.1.3. Pupillary response

Ocular parameters have been used in previous investigations to capture changes in pupillary diameter, pupillary reaction to light and saccadic velocity when exposed to cognitive tasks (Morad et al., 2009). Changes in pupil diameter have been recognised as indicators of psychophysiological arousal or neural activity, with dilation often associated with the occurrence of task-related events (Gilzenrat et al., 2010). The pupil's sensitivity to momentary cognitive load and effort during mental tasks has specifically linked pupil size to task engagement and disengagement. Furthermore, studies have connected pupil diameter to levels of task engagement, noting that moderate engagement is associated with intermediate pupil sizes and large dilations in response to greater stimuli (Gilzenrat et al., 2010; Jepma & Nieuwenhuis, 2011). For example, video analysis tracking changes in pupillary has been recorded for individuals that have been exposed to prolonged tasks that induce mental fatigue such as truck driving (Morad et al., 2009), reading text (Yong et al., 2004) and aircraft piloting (LeDuc et al., 2005). However, pupillary diameter can be influenced by additional factors such as light, arousal, and sleep, causing limitations in the applied setting. Therefore, when evaluating mental fatigue, it is recommended that ocular measurements be used along with other physiological parameters.

Physiological measures can be particularly useful offering objective insights into mental fatigue. However, these techniques often demand specialised equipment, expertise, and may involve invasive procedures, rendering them costly. Furthermore, these assessments offer understanding to the underlying biological processes affected by mental fatigue. When combined with subjective assessments, these measures can provide a comprehensive picture of how mental fatigue impacts individuals, leading to more effective strategies for management and mitigation.

3.3.2. Perceptual Measures of Fatigue

Given the personal nature of mental fatigue, it is commonly assessed using self-reporting techniques, including questionnaires and scales. These instruments enable individuals to evaluate and report their own feelings and perceptions of fatigue, exhaustion, and energy levels, offering perspective into their unique experiences with fatigue.

3.3.2.1. Visual Analogue Scale

The visual analogue scale (VAS) is a subjective measurement tool commonly used in research and clinical settings to assess the intensity or magnitude of a person's subjective experience or perception. It typically involves a straight line or numerical scale with endpoints representing extreme feelings or conditions, allowing individuals to mark their position along the continuum to quantify their subjective response. With the VAS, participants are first given a statement or a question and then instructed to use a 0-100 mm scale to represent their answer. The VAS has shown to be a valid and reliable method of measuring fatigue (Lee et al., 1991) and has been used to measure mental fatigue in previous research centred around sport (Smith et al., 2018; Van Cutsem et al., 2017). In some cases, the VAS outperformed similar scales such as the Likert scale and Borg scale for sensitivity and reproducibility (Grant et al., 1999; Reips & Funke, 2008). Often fatigue is measured using one item with individuals being asked to rate their level of fatigue using a Likert-type scale. Caution should be advised when using one-item measurements of fatigue as this can be an unstable estimate of subjectivity. In addition, concern for correct terms and consistent adjectives must be emphasised when using a VAS (Lee et al., 1991). The VAS is simple and cost effective to administer, however, the term "mental fatigue" is challenging to define, and participants may misinterpret it with similar constructs. Making clear definitions within the VAS is imperative to study designs.

3.3.2.2. Profile of Mood State

The Profile of Mood State (POMS), developed in 1971, is a valid and reliable psychometric questionnaire used to assess distinct mood states. The POMS consists of 65 adjectives (e.g. sad, confused, exhausted, restless, active) rated on a five-point Likert scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely) that can be administered through written or computer-based forms. A second form of the POMS assessment was introduced in 1983 by Shacham et al, this version reduced the number of questions from the original 65 down to 37 and is considered to be an excellent alternative when a brief measure of psychological stress is desired (Shacham et al., 1983).

3.3.2.3. Brunel Mood Scale

The Brunel Mood Scale (BRUMS) questionnaire contains 24 items divided into the same six respective sub-categories, as well as the same five-point Likert scale and scoring system. The slightly shorter BRUMS (Pageaux et al., 2013b, 2014; Rozand et al., 2014; Smith et al., 2015a) assessment along with the POMS (MacMahon et al., 2014; Martin et al., 2015; Suzuki et al., 2004) have been used to measure mental fatigue, however some ambiguity exists when distinguishing between physical and mental fatigue.

It is important to note that previous studies have indeed raised concerns about the effectiveness of the POMS and the BRUMS in accurately detecting mental fatigue. These scales have primarily been used to assess general mood states, and while they may offer insights into aspects of psychological distress, they have not consistently demonstrated strong sensitivity to mental fatigue specifically (Lopes et al., 2023). A more promising approach may be to highlight the "Subjective Fatigue" subscale in the BRUMS, which could potentially provide a better measure for detecting mental fatigue, as it focuses more directly on feelings of exhaustion and lack of energy that are central to the concept of mental fatigue (Pageaux et al., 2013a).

Perceptual measures of mental fatigue provide valuable insights into individuals' subjective experiences and perceptions, which may not always align with objective measures of performance or physiological markers. These measures are critical for understanding the impact of mental fatigue on function, productivity, and well-being, and can guide interventions and strategies for managing, mitigating or reducing cognitive strain in various contexts.

3.3.2.4. Nasa Task Load Index

The National Aeronautics and Space Administration (NASA) Task Load Index (NASA-TLX) is a widely used subjective workload assessment tool developed by the Human Performance Group at NASA's Ames Research Center. It was introduced in 1988 by Sandra Hart and Lowell Staveland as a method to measure perceived workload in human-machine interaction tasks and other complex operational environments (Hart & Staveland, 1988). The tool evaluates workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration, offering a comprehensive assessment of cognitive and physical task demands. Participants compare the importance of each dimension in paired combinations to determine their relative weights. Next, participants rate their experience for each dimension on a scale (typically 0 to 100) based on their task performance. The ratings are multiplied by the weights and combined to calculate an overall workload score. The NASA-TLX has primarily been applied in fields such as aviation (Said et al., 2020), healthcare (Hoonakker et al., 2011), and automotive systems (von Janczewski et al., 2022).

3.4. Reducing Mental Fatigue

With increasing evidence surrounding the prevalence of mental fatigue, it becomes imperative to identify solutions to mitigate its impact when required. Although limited evidence exists on methods to minimise or reduce it deleterious effects, managing mental fatigue may be critical for performers who experience periods when mental fatigue will be high (i.e., during period of high work or stress) or periods where mental fatigue may need to be minimised (i.e., prior to important performances). Accordingly, it is necessary to develop interventions to reduce or prevent feelings of mental fatigue, many of these interventions focus on manipulating motivation, consuming stimulants and most recently mental training (Azevedo et al., 2016a; Brown & Bray, 2017a).

3.4.1. Motivation

Strategies that increase motivation prior to and during cognitively demanding tasks can help defend against the deleterious effects of mental fatigue on physical performance. Brown and Bray recently demonstrated that financial incentives can increase subject motivation and improve ability to maintain task performance following a mentally fatiguing task (Brown & Bray, 2017b). This study examines the effect of monetary incentives on physical performance and muscle activation. Participants completed two isometric handgrip trials, using a cognitive control via Stroop task (HHC) or documentary (low cognitive control) with (incentive/no incentive) design. Results showed that mental fatigue was significantly higher in the HCC conditions. Decrements to performance were significant in the HCC/no incentive condition, but task performance was unaffected in the HCC/incentive condition. These findings coupled with the electromyography data revealed that incentives counteract the negative effects of high cognitive load, altering central drive to motor units and improving physical endurance (Brown & Bray, 2017a).

Additionally, Ferreira et al. provide evidence that a "head-to-head" strategy using a shadow opponent during cycling time trials can mitigate the effects of mental fatigue (Ferreira et al., 2023). Their findings revealed an increase in pupil diameter—a physiological indicator of motivation—under experimental conditions with this strategy. This demonstrates how innovative approaches can help maintain performance in mentally fatigued athletes, further linking laboratory insights to practical applications in sports.

3.4.2. Stimulants

Caffeine is the world's most widely consumed stimulant (Barone & Roberts, 1996). It is rapidly absorbed by the gastrointestinal track and diffuses throughout the entire body, quickly penetrating the brain (Blanchard & Sawers, 1983). Caffeine inhibits adenosine receptors (Fredholm, 1995) and reduces the inhibition of dopamine, both of which coincided with the onset of mental fatigue (Martin et al., 2018a). The positive effects of caffeine supplementation include a reduction of reaction times (Jacobson & Edgley, 1987) along with increased arousal (Barry et al., 2005) and therefore may reduce the subjective feelings of mental fatigue. Thus, caffeine may sustain or even increase physical and cognitive performance.

Recent research has examined the ergogenic benefits of using oral caffeine to protect against the effects of mental fatigue in cycling. Azevedo et al. recruited eight physically active cyclists to perform a cycling to exhaustion test at 80% of maximal power output in order to examine the effects of caffeine ingestion on physiological and perceptual responses in mentally fatigued individuals (Azevedo et al., 2016b). Subjects completed four cycling constant-workload tests in four experimental conditions (control, mental fatigue, mental fatigue + caffeine, and mental fatigue + placebo). Caffeine was administered (5 mg•kg^{-1}) to both the mental fatigue and caffeine group 90-min before the cycling test. Mental fatigue was induced by a continuous performance task A-X version (AX-CPT) for 90 minutes. Before and after the AX-CPT, POMS and blood samples for lactate measurement were collected. Oxygen consumption (VO_2), rating of perceived exertion (RPE), and electromyography (EMG) activity were measured during the cycling test. Results from the investigation showed that caffeine ingestion allotted for longer time to exhaustion, increasing endurance performance approximately 14% when compared to the other groups. Also, caffeine significantly increased perceived mood state (i.e., vigor) compared to the control and mental fatigue trails (Azevedo et al., 2016b).

In addition to oral caffeine ingestion, similar findings were presented from a recent study measuring the impact of a caffeine mouth rinse (Van Cutsem et al., 2018). Participants first completed two Flanker tasks, separated by a 90-min Stroop task. At eight evenly spaced time points prior to, every 12.5% completion, at the end of the Stroop task participants were administered a caffeine-maltodextrin mouth rinse or a placebo. Findings showed that frequent caffeine mouth rinse during prolonged and demanding cognitive tasks, reduced self-reported mental fatigue and improved performance in the Stroop task (Van Cutsem et al., 2018).

3.4.3. Carbohydrate Mouth Rinse

In addition to caffeine, another promising intervention for mitigating the effects of mental fatigue on physical performance is the use of carbohydrate mouth rinse. Previous studies have demonstrated that carbohydrate mouth rinse can enhance performance in mentally fatigued subjects, offering a potential strategy to improve endurance and cognitive output during prolonged tasks. The mechanism behind carbohydrate mouth rinses effectiveness is thought to involve the activation of brain regions responsible for motor control and energy metabolism, which may help counteract the decline in performance typically seen with mental fatigue.

Brietzke et al. investigated the impact of carbohydrate mouth rinse on mentally fatigued cyclists and found that it improved physical performance despite showing no significant effects on psychological responses (Brietzke et al., 2024). This suggests that while carbohydrate mouth rinse may not directly alleviate feelings of fatigue or improve mood states, it may enhance the physical capabilities of individuals experiencing cognitive fatigue. The study highlights that carbohydrate mouth rinse can act as a stimulant, providing a brief boost in performance, likely by modulating central nervous system activity rather than addressing the psychological aspects of fatigue.

Further research by Brietzke et al. explored the effects of carbohydrate mouth rinse during maximal incremental tests in mentally fatigued individuals (Brietzke et al., 2020). Their findings indicated that carbohydrate mouth rinse mitigated the negative effects of mental fatigue on performance but did not significantly alter cortical brain activity. This suggests that while carbohydrate mouth rinse can influence motor performance, its impact may not extend to changes in brain activity related to mental fatigue, further reinforcing the notion that the benefits of carbohydrate mouth rinse are more physical than psychological.

These studies support the use of carbohydrate mouth rinsing as an effective, non-invasive strategy to improve performance under conditions of mental fatigue. While it does not directly alleviate the subjective feelings of fatigue or alter cortical responses, Carbohydrate mouth rinse appears to have a positive effect on physical output, especially in endurance-based tasks. This makes it a valuable tool for athletes and individuals needing to maintain performance despite experiencing mental fatigue.

3.4.4. Brain Endurance Training

Recent studies have investigated the effects of using deliberate cognitive training, or brain endurance training (BET), as a training method to protect against mental fatigue. Indeed, Marcora et al., incorporated prolonged cognitive task in conjunction with physical training in cyclists (Marcora et al., 2009b). In this investigation researchers used BET to induce mental fatigue through 60 minutes of computer-based AX-CPT task whilst cycling for the same duration at 65% VO_2max. Results from the 35 participants showed significant improvements in time to exhaustion (TTE) for the BET group (pre-test 28±9 min; mid-test 39±11 min; post-test 55 ± 17 min) compared to the control group (pre-test 18±5 min; mid-test 23±7 min; post-test 28±12 min) as well as a reduced session RPE in the BET group. Additionally, BET has been shown to improve dynamic rhythmic hand grip endurance in young adults (Dallaway et al., 2023). More specifically, BET in sport has shown to improve intermittent fitness tests, repeat sprint ability, and agility in soccer (Staiano et al., 2022), as well as faster and more accurate shots in paddle tennis (Díaz-García et al., 2023). Although novel insights into BET and team sports are emerging, future research should continue to explore possible implications given the varying complexity of sport and the feasibility of training with elite performers (Díaz-García et al., 2023). Although novel insights into BET and team sports are emerging, future research should continue to explore possible implications given the varying complexity of sport and the feasibility of training with elite performers.

Overall, while these interventions hold promise in mitigating mental fatigue's impact on physical performance, further research is necessary to explore their efficacy across diverse populations and sports contexts. Additionally, ongoing investigation into novel approaches and their implications for elite performers is crucial for advancing our understanding and application of strategies to combat mental fatigue effectively.

3.5. Mental Fatigue and Physical Performance

Mental fatigue can result in a myriad of psychological, physiological, and behavioural adjustments. Psychological outcomes typically centre around increased reports of tiredness, lack of energy and decreased motivation (Boksem et al., 2006a; Boksem & Tops, 2008b; van der Linden et al., 2003b). Physiological manifestations of mental fatigue are often recorded through alterations in brain activity (Cook et al., 2007a; Hopstaken et al., 2015). Finally, behaviourally, mental fatigue is recognised by declines in cognitive task performance through reduced accuracy or poorer reaction times (Möckel et al., 2015; Wascher et al., 2014). Although all can occur, all three do not have to be present for mental fatigue to be present. For example, cognitive performance does not necessary decline when mentally fatigued as a result of a compensatory effort, such as increased motivation (Hopstaken et al., 2015; Möckel et al., 2015). Nevertheless, these manifestations of mental fatigue have be studied in relation to physical performance in three distinct categories: whole body endurance, muscular endurance, and anaerobic bouts (e.g. power, maximum strength).

3.5.1. Whole Body Endurance

In previous investigations psychological outcomes during whole body endurance were often measured through subjective readings of effort, motivation, and work output (Brownsberger et al., 2013; Pageaux et al., 2014; Smith et al., 2015a). During whole body endurance, exercise perceived exertion was most frequently measured through Borg's 15-point RPE scale (Borg, 1998). Results showed that a higher level of perceived exertion was present when mentally fatigued (Martin et al., 2018; Pageaux et al., 2014; Smith et al., 2015a). Interestingly, when assessing motivation in association with whole body endurance, overwhelmingly the results revealed no differences in motivation between conditions despite the use of variety of scales. For example, Marcora et al.(Marcora et al., 2009a) used a scale developed and validated by Basner et al. (Basner et al., 2011), in contrast, Martin et al. used a different scale (Situational Motivation Scale) to assess motivation. Furthermore, other studies have utilised a 10-cm VAS scale (Smith et al., 2015a), while still others have used a 7-point Likert scale (MacMahon et al., 2014), yet no differences in motivation occurred.

Effects of mental fatigue on performance outcomes of whole-body endurance are inconclusive. Several studies have selected a distance-clamped self-paced running protocol and demonstrated increased completion time when participants were mentally fatigued (Pageaux et al., 2014; Smith et al., 2015a; MacMahon et al., 2014). Separately, Smith et al. considered the effect of mental fatigue on a Yo-Yo intermittent recovery test, level 1and observed a decrease in the covered distance in this test when mentally fatigued (Smith, Coutts, et al., 2016). In cycling, the experimental protocols differed, and consequently so did the outcome measures of performance. Marcora et al. (Marcora et al., 2009a) used a fixed resistance time-to-exhaustion cycling protocol and observed a mean decrease of 15% in time to exhaustion due to mental fatigue. Brownsberger et al. (Brownsberger et al., 2013) studied the effect of mental fatigue on power output with a time-clamped (10-min) and RPE clamped protocol. Participants completed two 10-min cycling bouts at self-selected intensities representative of fairly light effort (RPE 11) and hard effort (RPE 15). In both the RPE 11 and the RPE 15 trial, participants chose lower self-selected power outputs in the mental fatigue condition. In shorter bouts of cycling Pageaux et al. (Pageaux et al., 2015) measured RPM in a 6 min resistance clamped bout, while Martin et al. (Martin et al., 2015) used a 3-min all-out time-clamped protocol, both showing no difference due to mental fatigue. In other investigations, researchers have also found that mental fatigue reduced repetitions completed (Gantois et al., 2021) and total training volume during muscular endurance activity(Queiros et al., 2021). In summary, while mental fatigue appears to increase perceived exertion and potentially affects completion times and power outputs in endurance activities, it does not seem to alter motivation levels. The effects on performance outcomes remain inconclusive, varying significantly with the type of activity and the experimental protocol employed.

Physiological measurements during whole body endurance studies have also varied. Marcora et al. (Marcora et al., 2009a) reported a higher heart rate (HR) and blood lactate (Bla) in the control condition, while Brownsberger et al. (Brownsberger et al., 2013) also reported a higher HR in the control condition during the bout. Other physiological measures of oxygen uptake, stroke volume, cardiac output, and blood pressure showed no influence from mental fatigue (Marcora et al., 2009a). Brain activity was also not differently altered during a whole-body endurance performance after a mentally fatiguing task (Brownsberger et al., 2013). It is plausible that increases in mental fatigue and thus RPE, may subsequently affect physiological outputs such as HR and BLa, masking changes that would otherwise occur. For instance, Pageaux et al. demonstrated that mental fatigue increases RPE during physical tasks without necessarily altering central cardiovascular responses, suggesting that perceptual mechanisms can mediate physical performance reductions (Pageaux et al., 2013a). Similarly, Martin et al. found that mental fatigue reduces endurance performance by impairing motivation and increasing perceived effort, potentially leading to submaximal exertion despite no significant alterations in physiological capacity (Martin et al., 2018b). The increased RPE resulting from mental fatigue may lead participants to reduce their effort output, effectively lowering exercise intensity and physiological stress markers like HR and BLa. This phenomenon limits the ability to observe typical increases in these markers under physically demanding conditions. For example, Van Cutsem et al. suggested that mental fatigue alters effort regulation by changing the perception of effort rather than the actual physiological capability (Van Cutsem et al., 2017b).

Furthermore, conflicting results surrounding EMG showed the rectus femoris has no effect during whole body endurance, while mental fatigue was associated with increased EMG of the vastus laterals (Pageaux et al., 2015). Lastly, Smith et al. (Smith et al., 2015a) reported a lower VO_2 (6%) during the exercise in the mentally fatigued condition.

Collectively, these studies demonstrated that physiological measurements during whole-body endurance under conditions of mental fatigue reveal a complex picture. While some findings suggest variations in heart rate and blood lactate levels between control and mentally fatigued conditions, others show no significant differences in parameters such as oxygen uptake, stroke volume, cardiac output, blood pressure, and brain activity. Conflicting results also arise regarding electromyography readings, with differing effects on muscle activity noted across studies.

3.5.2. Muscular Endurance

Few studies evaluated the effects of mental fatigue on psychological outcomes during muscular endurance tasks. However, when investigated findings indicated that during muscular endurance, subjects reported higher RPE values when mentally fatigued (Pageaux et al., 2013b). Interestingly, there were no differences in RPE at the point of exhaustion and no differences in motivation toward the task were observed (Pageaux et al., 2013b).

Although research is limited, behavioral changes in muscular endurance tasks suggest that mental fatigue negatively impacts performance. More specially, results during isometric handgrip tasks (Bray et al., 2008), submaximal isometric contraction of the knee extensors (Pageaux et al., 2013b) and wall sit tasks (Boat et al., 2020) all indicated reduced time to exhaustion in the mental fatigued condition. However, observations of physiological outcomes showed no difference between control or mentally fatigued conditions. For example, Pageaux et al., continuously monitored heart rate during isometric knee extension and noted that subjects displayed no difference between groups throughout the task or at the point of exhaustion (Pageaux et al., 2013b). Furthermore, studies evaluating EMG showed no difference during both handgrip (Bray et al., 2008) and knee extensor tasks (Pageaux et al., 2013b).

3.5.3. Anaerobic Bouts (power, maximum strength)

Unfortunately, most of the studies that examined the effects of mental fatigue on prior to anaerobic exercise did not always report on the psychological responses. Of the few that reported RPE responses, mental fatigue showed no difference when compared to the control (Duncan et al., 2015; Martin et al., 2015). Similarly, one study assessed the impact of mental fatigue on the participants, motivation for the upcoming task and reported no differences compared to a control group (Martin et al., 2015).

Many studies examined the behavioural effect of mental fatigue on anaerobic based exercise (Budini et al., 2014; Duncan et al., 2015; Martin et al., 2015; Pageaux et al., 2013b, 2015). The majority of these studies assessed maximum voluntary contraction (MVC) of the knee extensor muscles, concluding that a mentally fatiguing task has no effect on subsequent performance (Duncan et al., 2015; Martin et al., 2015; Pageaux et al., 2013b). However, Budini et al. reported a decrease in leg extension MVC after a 100-min mentally fatiguing task (Budini et al., 2014). Similarly, a study examining the effects of mental fatigue on countermovement jump performance revealed no difference between conditions for all observed outcomes (jump height, mean power, peak force, concentric peak velocity, or eccentric displacement)(Martin et al., 2015). Moreover, Duncan et al. reported that mental fatigue had no effect on mean cycling power during four consecutive 30-s Wingate anaerobic tests (Duncan et al., 2015). Collectively, a majority of these studies suggest minimal impact of mental fatigue on psychological and behavioural responses during anaerobic exercise. However, there is variability in findings, indicating the need for further research to elucidate the relationship between mental fatigue and anaerobic performance.

Similar to the psychological responses, studies that examined the effects on mental fatigue on the physiological responses to anaerobic exercise revealed varied results. For example, mental fatigue was shown to have no effects on HR or blood lactate responses to endurance exercise (Duncan et al., 2015). Similarly, others reported no effect from mental fatigue on any parameters of neuromuscular function. For example, several studies examined single electrical stimulation to evaluate peak twitch, time to peak twitch, and half-relaxation time, as well as double electrical stimulation to evaluate the peak torque of the doublet (Pageaux et al., 2013b, 2015). Finally, Budini et al. used springs to induce a 5-Hz frequency oscillation (associated with the central component of the stretch reflex) during a 20-s MVC and found no difference in the mental fatigued condition (Budini et al., 2014).

Whilst these previous investigations may provide insight into the physical performance consequences associated with mental fatigue, these tasks are not representative of complex, skill based, team sports such as basketball. Additionally, athletes are required to make critical decisions throughout the game which impact success of the individual and team (Bar-Eli & Tractinsky, 2000). At present it is not known if these intricate cognitive processes in conjunction with physical output are affected by the presence of mental fatigue. Therefore, research examining the effects of mental fatigue on the execution of complex sport-specific skills is required.

3.6. Mental Fatigue and Motor Control

Similar to studies on physical performance described above, others have also investigated the impacts of mental fatigue on motor performance. In a laboratory environment, motor skills are well investigated. A such, it is known that a relationship exists between the movement speed and the movement accuracy (i.e., speed-accuracy trade-off) of motor control, with movement duration increasing in relation to the movement difficulty(Fitts, 1954). While previous investigations have demonstrated that muscle fatigue has led to an increase in movement duration (Missenard et al., 2009), recent work has shown a similar response in the presence of mental fatigue (Duncan et al., 2015; Pageaux et al., 2015). As mental fatigue alters the speed-accuracy trade-off, it is also likely that more complex sport skills could be impaired.

3.7. Mental Fatigue and Skill Performance in Sport

Skilled performance in sport is defined as the ability to perform at a high standard effectively and efficiently (Koopmann et al., 2020) and it determines the outcomes in sport (Allard & Burnett, 1985). In recent years, the focus of mental fatigue research has shifted to investigate these complex skills in the applied setting. Moreover, investigations on the impact of mental fatigue in the sport setting often centre around the technical or tactical components. The sections below will highlight previous investigations into each of these components and call attention to shortcomings for future investigations.

3.7.1. Technical Performance

Several studies have examined the effects of mental fatigue in sport-specific skilled performance. For example, Smith et al. (Smith et al., 2016; Smith et al., 2016b) and Badin et al. (Badin et al., 2016) described the deleterious effects of mental fatigue through a decrease in soccer-technical performance. Furthermore, the negative impacts of mental fatigue were associated with ball speed and accuracy in table tennis (Le Mansec et al., 2018) and technical skills performance in cricket (Veness et al., 2017). The negative impact of mental fatigue on both upper and lower limb motor skills suggests potential impacts on other sports, which employee a variety of sport specific skill moments. For example, in basketball, mental fatigue has been shown to increase the number of turnovers during small-sided-games (Moreira et al., 2018) and decreases three-point shooting (Bahrami et al., 2020) and free-throw scores (Filipas et al., 2021a). While studies have identified negative impacts of mental fatigue in specific sports like soccer, table tennis, cricket, and basketball, it is unclear how generalisable these findings. Different populations within each sport involve unique skill sets, physical demands, and environmental factors, which may interact with mental fatigue differently. Furthermore, longitudinal studies tracking athletes over time could provide insights into the cumulative impact of repeated exposure to mental fatigue on skill development, performance consistency.

3.7.2. Tactical Performance

In addition to technical performance, skilled sport performance also relies on a tactical component. This tactical element is underpinned by players on perceptual-cognitive abilities, such as response times, visual behaviour and quick and accurate decision making and processing (Farahani et al., 2020; McGuckian et al., 2018). Some studies conducted in soccer demonstrated that mental fatigue causes changes in visual search strategy. The first study used eye-tracking and found that compared to a control condition, that mentally fatigued athletes tended to focus more on the ball and defender rather than on free spaces and unmarked attackers (Smith et al., 2016b). The second study found that mental fatigue resulted in a reduction in the visual field, which can be detrimental to decision-making as it reduces the input of critical information (Kunrath et al., 2020). These findings have potential impact on performance as recent research has suggested that soccer athletes with greater peripheral perception also possess greater tactical efficiency (de Andrade et al., 2021).

Other studies in sport have shown impairment with decision-making with mental fatigue. In soccer, athletes demonstrated reduced accuracy when determining the best option and slower response times when mentally fatigued (Gantois et al., 2020). The effects of mental fatigue have also been documented in basketball, where athletes displayed compromised decision making through lowered accuracy and extended response times (Moreira et al., 2018). Both aforementioned investigations utilised simulated cognitively demanding Stroop tasks in order to induce mental fatigue, however, these results were supported in other mentally fatiguing activities. To demonstrated higher ecological validity researchers have looked at video games, social media usage and sport specific film session as a causation of mental fatigue. Specifically, videogames have been known to cause mental fatigue in basketball (Faro et al., 2022b) and boxing (L. S. Fortes et al., 2023). Furthermore, social media usage has induced mental fatigue in volleyball (L. S. Fortes, Fonseca, et al., 2021a), swimming (L. S. Fortes, Lima-Júnior, et al., 2021) and boxing (L. S. Fortes et al., 2023). Lastly, Filipas et al, has recorded increased levels of mental fatigue following sport specific film sessions in basketball (Filipas et al., 2021a).

3.7.3. Mental Fatigue and Sport Conclusion

The demands placed on student-athletes in both academics and athletics can be overwhelming, leading to heightened stress levels (Abouserie, 1994; Pierceall & Keim, 2007; Watson, 2016). As previously stated, mental fatigue can manifest in various ways, affecting an athlete's concentration, focus, reaction time, and decision-making skills, all of which are essential for peak athletic performance. Despite its potential significance, the evaluation of mental fatigue in athletes still lacks consistency. There is a need for further investigation, particularly in the context of collegiate sports, where athletes face unique challenges.

CHAPTER 4

STUDY 1:

THE RELIABILITY AND USEFULNESS OF A NOVEL BASKETBALL STANDARDIZED SHOOTING TASK

Related manuscript: Daub, B., McLean, B., Heishman, A., Coutts, A. The reliability and usefulness of a novel basketball Standardized Shooting Task. *International Journal of Sports Science and Coaching (2022)*.

4.1. Prelude

Assessing changes in basketball shooting skill is crucial for coaches and practitioners. While tests that include various basketball skills are appealing, at present, there are very few that can be feasibly applied within a high-performance setting without significant disruption to athletes and/or coaches. Therefore, creating a test that is valid, reliable and appropriate to the training environment is required. Such a test could be used to improve sport-specific skills, assist in monitoring player progressions and identify talent. Study 1 was conducted in the applied setting, within a Division I basketball team. The test, which was developed in consultation with the coaching staff, assessed shooting accuracy and could be applied during normal training and practices with very little disruption. Once the test protocol and measurement qualities were established, coaches were able to assess and compare players progression with greater confidence.

4.2. Introduction

Although basketball is a team game consisting of technical and tactical components, individual performance requires the integration of skill, talent and physical capabilities (Castagna et al., 2008; Stojanović et al., 2018). Sport specific skills such as shooting, dribbling and passing are a key aspect of offensive success in basketball players (Karipidis, A., Fotinakis, P., Taxildaris, K., & Fatouros, 2001; Lorenzo et al., 2010). Indeed, shooting has been shown important for both team and individual success (Ibáñez et al., 2003; Karipidis, A., Fotinakis, P., Taxildaris, K., & Fatouros, 2001). There is a myriad of shooting skills such as the layup, dunk, free throws, and jump shot, all requiring a different degree of difficulty, which can be used when attempting to score. However, the majority of shots executed during elite level basketball games are 'jump shots' (i.e., a basketball shot attempted by jumping into the air and releasing the ball at the peak of the jump). Jump shots can occur from any location on the court, but jump shots behind take behind the 3-point line (6.75m distance) are awarded 3 points, rather than jump shots taken within the 3 point line are worth 2 points. It also appears jump shots are important for team successes, as previous research has shown that superior in-game shooting accuracy (from both two- and three-point shots) increases win probability (Pojskić, et al., 2009; Smith et al., 2016b; Svilar & Jukić, 2018). Despite the importance of jump shot performance in contributing to team success, there is a lack of standardised, valid shooting assessments that have been developed and used in basketball. A simple, repeatable skill assessment could allow for the monitoring of progress in skill performance development which may help to assess the effectiveness of implemented training interventions (Conte et al., 2019; Sunderland et al., 2006).

Relatively few studies have investigated shooting performance in basketball (Boddington et al., 2019; Pojskić et al., 2010; Pojskic et al., 2018) and methodological shortcomings limit the existing jump shooting protocols. For example, the American Alliance for Health, Physical Education, Recreation and Dance basketball test, was developed to evaluate basketball passing, spot shooting, dribbling and defence, but the tests has high variability between subjects, as the athletes choose their shooting locations after satisfying basic conditions (i.e., minimum one shot from each location) in the beginning stages of the assessment (Vernadakis et al., 2004). Additionally, protocols emphasising the physiological demands experienced during basketball have also shown high variably (Boddington et al., 2019; Pojskić et al., 2014). Furthermore, ambiguous information detailing shot order, shot location and duration from other assessments weakens reproducibility (Pojskić et al., 2014; Robertson et al., 2014; Thakur & Mahesh, 2016). For example, in the Spot Up Shooting Test players attempt 5 jump shots from different locations, however the exact location is not defined, and it is unclear if the shots at each location are in succession (Thakur & Mahesh, 2016). Similarly, Pojskić et al., used a protocol with fewer shot attempts, that allowed players to attempt two shots from five locations, however it is unclear if these were completed as two consecutive shots or separate shots in the repeated protocol (Pojskić et al., 2014).

The ability to assess changes in shooting skill performance is an attractive proposition for practitioners working in basketball. While assessments that have higher ecological validity and specificity are appealing (e.g. involve multiple sport-specific skills), there are few ecologically valid assessments that are feasible for regular implementation throughout a basketball season. Most existing protocols lack feasibility in applied settings due to test construct and duration, and assessments to test basketball shooting accuracy are limited (Filipas et al., 2021a; Thakur & Mahesh, 2016). Therefore, the development of ecologically valid test of basketball shooting performance, that can be feasibly implemented, may assist in talent identification, athlete monitoring strategies, and skill development. Once a test is developed and reliable, assessing its sensitivity would enable coaches and practitioners alike to directly compare performances among players subject to different conditions (Currell & Jeukendrup, 2008). In addition, when examining the efficacy of new interventions, tests with high ecological validity and strong relationships with performance outcomes (e.g., shooting accuracy) may provide the most valuable information. Therefore, the aim of this study was to construct a new test to assess basketball shooting accuracy and subsequently investigate the measurement characteristics, including interday reliability, construct validity and the acute impacts of a basketball practice.

4.3. Methods

4.3.1. Experimental Approach to the Problem

To assess basketball specific performance, a Standardized Shooting Task (SST) was developed in conjunction with experienced basketball coaches. The study began with a familiarisation session, where athletes were provided with standardised instructions for the SST and test preparation on future testing days. Test preparation instructions directed participants to maintain regular sleeping patterns, and diet, and avoid caffeine, nicotine, alcohol, and physically demanding tasks immediately preceding subsequent testing sessions. A repeated measures study design was used to establish the intersession reliability of the SST (Part 1), as well as to assess the sensitivity of the SST to a sport specific basketball practice (Part 2) in a group of elite collegiate basketball players. Finally, the construct validity of the SST (Part 3) was examined by comparing the Shooters Performance ranking, determined by the experienced basketball coaches, to their performance during the SST performance (Figure 1).

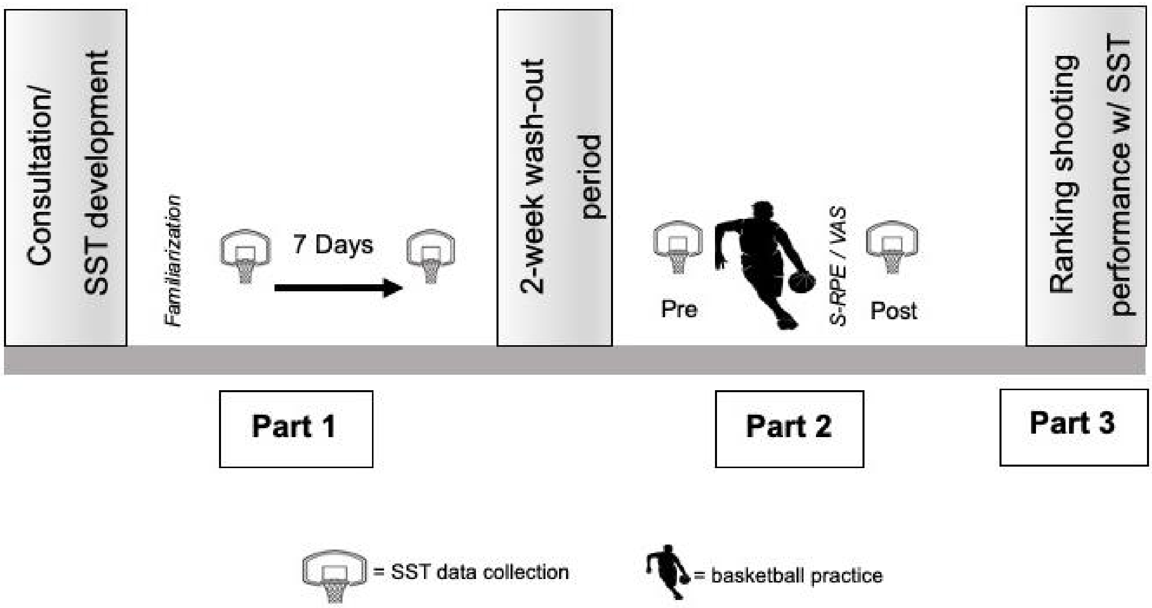

Figure 4-1: Schematic timeline of study design.
SST, Standardized Shooting Task; Pre, pre-practice SST; Post, post-practice SST; S-RPE, session rating of perceived exertion; VAS, visual analogue scale.

4.3.2. Subjects

Twenty-eight (16 male, 12 female) elite basketball players (Male- age: 20.4 ± 1.2 y, height: 197.4 ± 7.5 cm, body mass: 93.8 ± 8.9 kg; Female- age: 20.2 ± 1.6 y, height: 179.3 ± 9.4 cm, body mass: 80.9 ± 9.7 kg) volunteered to participate in Part 1 & 2 of this study. During Part 3, thirteen male elite basketball players volunteered to participate (Age: 20.2 ± 1.2 y, height: 199.3 ± 7.1 cm, body mass: 93.1 ± 8.6 kg). All testing sessions took place during the preseason training phase. During this phase participants engaged in 6 sessions per week of basketball specific practice on the court, as well as 3 strength training sessions per week. All participants were active squad members of the University of Oklahoma's Men's and Women's basketball team, competing in NCAA Division I and were provided with verbal and written instructions outlining the procedures prior to providing written informed consent. All participants were healthy, free from musculoskeletal injuries and any other medical condition that may limit their full participation in team practice. Any participant unable or not cleared by the medical staff to participate in a full team practice at the time of testing was excluded from this study. This research was approved by the Human Research Ethics Committee of the University of Technology Sydney (UTS).

4.3.3. Procedures

Development of the SST: In order to develop an ecologically valid shooting test, 5 expert basketball coaches advised on its design. All coaches were actively coaching in NCAA Division I basketball and have a minimum of 5 years experience at that level, 4/5 coaches had also previously played basketball at the NCAA Division I level. The aim of the consultations was to create a standardised and quantifiable protocol, which is representative to the training and shooting skill tasks commonly used in elite basketball. This process also involved reviewing previous shooting protocols, as well as commonly used drills implemented during training session to ensure the development assessment could become seamlessly integrated into practice, which would ultimately maximise the test's practical relevance.

SST Protocol: The SST was comprised of 60 consecutive free throws and a 4-minute spot-to-spot shooting protocol. Prior to testing sessions all athletes were given a 5-minute 'free shooting' period, whereby players took self-selected practice shots with the assistance of one rebounder.

Free Throws: To start the SST each athlete attempted 60 consecutive free throws. One rebounder/passer was present to return balls to the subject and another researcher was responsible for collecting outcome variables (make/miss). Athletes were instructed to make the maximum number of free throws possible from 60 attempts and that the shot attempt must come within 5 seconds of receiving the pass. During the 60 free throw attempts no encouragement or technical suggestions were provided by the researchers.

Spot-to-Spot Shooting: Next, subjects immediately moved to the spot-to-spot protocol, which required athletes to shoot from 7 different locations on the court, depending upon their classification as either '3-point shooter' or a 'non 3-point shooter' (see Figure 2). Player classification was determined by the expert coaching staff and depended upon the athlete's role within the team. Stratifying players into two sperate shooting locations (i.e., 4.57 m / "15-feet" from the rim, or outside the 3-point line) enhances the ecological validity of the assessment, ensuring athletes take game-like shot attempts similar to shots they would experience during competition.

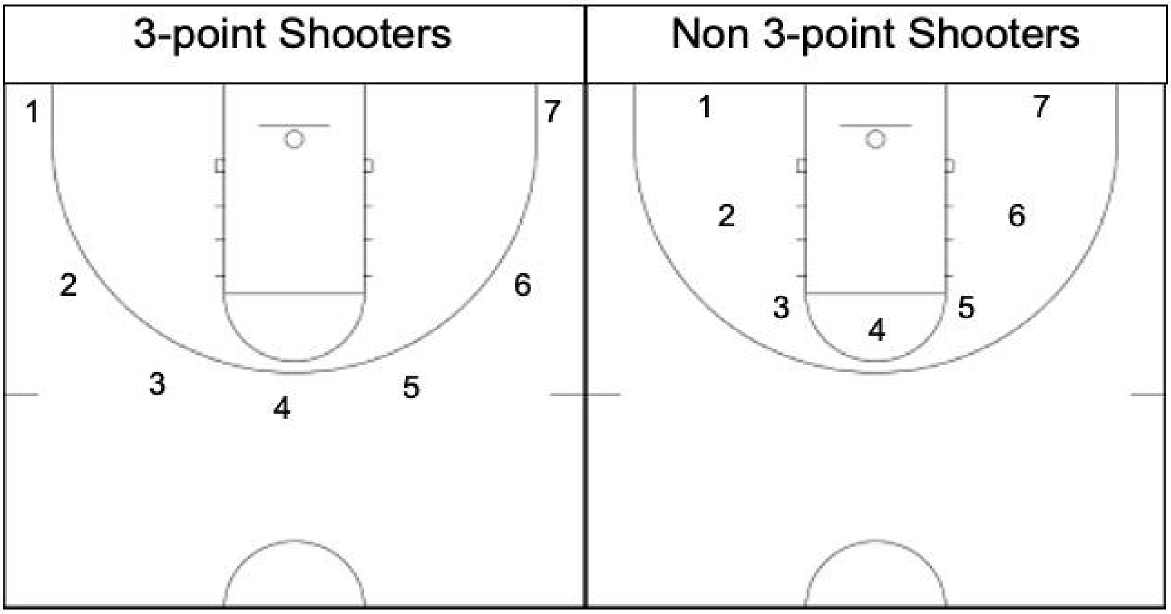

Figure 4-2: Layout of the shooting locations during SST.
Location 1-7 for 3-point shooter and locations 1-7 for non 3-point shooters.

Prior to the start, athletes were instructed to achieve as many total spots as possible during the 4 min shooting. To begin spot-to-spot protocol, all athletes start from location 1 (i.e., the baseline on the left side of the court) and were required to successfully make two consecutive shots, before moving to the next spot (i.e., location 2; see figure 2). Each spot was clearly marked with an "x" at each location. Once the athlete reached the opposite baseline and makes two consecutive shots at spot 7 (i.e., baseline on the right side of the court), they repeated the shooting sequence in reverse (i.e., spots completed in the following order: 1, 2, 3, 4, 5, 6, 7, 7, 6, 5, 4, 3, 2, 1, 1, 2, 3, 4, etc.). Each SST was performed with two balls, with one rebounder and one passer for all trials, the same rebounder and passer were used for all trials. The objective for the rebounder and passer was to return the ball as quickly as possible based on the readiness of the shooter. 'The Rebounder' was instructed to chase down rebounds as fast and efficiently as possible, while 'The Passer' was instructed to deliver a chest pass in rhythm to the shooter as soon as the shooter reached the next shooting location. Passes were made from the location in which the shooter moves to next (i.e., when shooting from spot 1, the pass comes from spot 2), until the shooter completes location 4 (i.e., in the centre of the court), to which the pass was then delivered from the preceding shot location (i.e., shooting from spot 5, pass from spot 4). Once the shooter completed spot 7 with the pass coming from spot 6, the passes were then executed in reverse order. All shots were attempted without dribbling and any attempt with the shooter deviating from the spot or stepping on the line was deemed invalid and awarded a missed attempt.

Outcome measures of the SST were: 1) sum of made free throws from 60 attempts (Free Throw Makes); 2) sum of the makes during 4 min shooting ($MAKE_{4MIN}$); 3) sum of the misses during 4 min shooting ($MISS_{4MIN}$); 4) sum of the total shots 4 min shooting ($SST_{TOTALSHOTS}$); 5) sum of the spots completed during 4 min shooting (SST_{SPOTS}). As done in previous work, researchers recorded free throws in four different categories (1-20,21-40,41-60 and total) for analysing (Filipas et al., 2021a). Additionally, researchers separated outcome measures from the spot-to-spot shooting into 2-minute segments for analysis ($MAKE_{4MIN1/2}$, $MISS_{4MIN1/2}$, $SST_{TOTALSHOTS1/2}$, $SST_{SPOTS1/2}$ $MAKE_{4MIN2/2}$, $MISS_{4MIN2/2}$, $SST_{TOTALSHOTS2/2}$, $SST_{SPOTS2/2}$).

4.3.4. Part 1: Reliability

Participants performed the SST during two sessions, separated by 7 days (Buchheit et al., 2010; Conte et al., 2019; Düking et al., 2016). Trials were recorded using a pen and paper log. All testing sessions were conducted at the same time of the day (09:00-11:00), (Heishman et al., 2017) with testing sessions lasting approximately 10 minutes. Practice and training loads were matched in the 48 hours prior to the test and re-test sessions and all sessions took place during the preseason training phase.

4.3.5. Part 2: Practice Intervention

Following a wash-out period of at least 2-weeks from Part 1, the SST was performed pre-practice (13:00) and post-practice (15:00) during the basketball preseason. The practice was sport specific and consisted of both individual and team-based drills. The majority of the time was spent performing activities in the half court and full court setting with an emphasis on offensive and defensive skill development. In addition, at least 25% of the time was spent in segments of live scrimmage play. The pre-test assessments were completed within 20 minutes of prior to the start of practice, while the post-test assessment was completed within 20 minutes following the conclusion of the team practice. In an effort to reduce total testing time, shooting was completed on multiple goals, with subjects using the same goal for each session. External training load was quantified using the Catapult T6 inertial measurement units (Catapult Sport, Melbourne, Victoria, Australia), and examined through 3-dimensional accelerometer load (i.e. PlayerLoad ; PL), and duration (Fox et al., 2018; Halson, 2014; Heishman et al., 2020; Svilar & Jukić, 2018). Internal training load was assessed using the session rating of perceived exertion (S-RPE) method with the modified Borg's category ratio–10 scale (Foster et al., 2001). Subjective ratings of mental fatigue, mental effort, and motivation which were scored using 100-mm visual analogue scale (VAS) (Smith et al., 2016b). The VAS was anchored at one end with ''none at all'' and at the other end with ''maximal.'' Each VAS score was determined by measuring the distance on the paper from the left end to the pen mark in which the participants felt represented their current state.

Part 3: Construct Validity

Construct validity of the SST was assessed by comparing shooter rank, determined by five expert coaches, to the number of made shots during the SST and shooting percentages during live simulated game play, in practices, over the course of the preseason. "Shooter Rank" was determined by asking the expert coaches to "rank each athlete from best shooter to worst shooter." Inter-rater reliability was established by comparing the rank order for each of the expert coaches. Shooting percentage during live play was calculated for made shots per attempt during simulated games. For this portion a separate cohort of athletes was used all of which completed the SST protocol from the 3-point location.

4.4. Statistical Analysis

Means and standard deviations (SD) were calculated for all SST scores across each of the trials. In Part 1, relative reliability was assessed using intra-class correlations coefficient (ICC). In addition, absolute reliability was assessed using Coefficient of Variation (CV) and expressed as a percent. Thresholds of ICC ≥ 0.70 and CV <10% have often been suggested (Baumgartner & Chung, 2001), however, previous literature suggests test reliability ultimately should be determined by the individual researcher based on intended use as the most reliable variables may not be the most practical (Cormack et al., 2008). Typical error of measurement (TE) was calculated by dividing the SD by the square root of 2 (Hopkins et al., 2009). Minimal detectable change (MDC), which indicates the smallest change that is not due to error, was calculated as followed: MDC = Standard error (SE) x $\sqrt{2}$ x 1.96 (Weir, 2005). In Part 2, a Repeated Measures Analyses of Variance with Bonferroni post hoc analysis was used to examine differences in variables for pre/post basketball intervention. Additionally, effect sizes (Cohen's *d*) were calculated for each pairwise comparison based on the following classifications: 0–0.19, trivial; 0.20–0.49, small; 0.50–0.79, medium; and >0.80, large (J. Cohen, 1992). In Part 3, the Spearman Ranked Correlation was used to compare Shooter Rank (determined by expert coaches) with outcome performance and interpreted as follows: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and 0.9–1.0, almost perfect (Pyne et al., 2008; A. T. Scanlan et al., 2012). Additionally, inter-rater reliability was established through ICC(2,*k*) and interpreted with the classifications as: 0-0.5, poor; 0.5-0.75, moderate; 0.75-0.9, good; > 0.90, excellent (Koo & Li, 2016). Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) software (v 25.0; IBM Corp., Armonk, NY, USA) and statistical significance was set at $p \leq 0.05$.

4.5. Results

4.5.1. Part 1: Reliability

Reliability analysis showed high relative reliability, with ICC values ≥ 0.70 in all variables (Table 1). The highest absolute reliability (i.e.CV) was in $SST_{TOTALSHOTS}$ (1.9%), FT Makes (5.5%) and $MAKE_{4MIN}$ (7.9%). The capacity to detect change through MDC showed lowest values for $SST_{TOTALSHOTS}$ (0.77), followed by FT Makes (0.92), SST_{SPOTS} (0.95), $MAKE_{4MIN}$ (1.71) and $MISS_{4MIN}$ (1.81).

Table 4-1: Inter-day reliability of Standardized Shooting Test (SST) performance indicators (n=28).

	Day 1 Mean (±SD)	Day 2 Mean (±SD)	TE	CV (%)	ICC	MDC
FT Makes	48.5 ± 6.7	47.9 ± 8.0	3.4	5.5	0.79	0.92
$MAKE_{4MIN}$	44.0 ± 10.1	45.3 ± 10.1	3.8	7.9	0.86	1.71
$MISS_{4MIN}$	30.0 ± 9.1	29.4 ± 8.6	4.3	11.9	0.77	1.81
$SST_{TOTALSHOTS}$	74.0 ± 4.1	74.8 ± 4.5	1.7	1.9	0.85	0.77
SST_{SPOTS}	16.8 ± 5.8	17.1 ± 5.9	2.3	12	0.85	0.95

Data presented as Mean ± Standard Deviation. FT Makes, successful free throws from 60 attempts; $MAKE_{4MIN}$, sum of shots made during 4 min shooting; $MISS_{4MIN}$ (sum of the misses during 4 min shooting), $SST_{TOTALSHOTS}$ (sum of the total shots 4 min shooting), SST_{SPOTS} (sum of the spots completed during 4 min shooting); TE-typical error; CV- Coefficient of Variation; ICC- intraclass correlation coefficient; MDC- Minimal detectable change.

Part 2: Practice Intervention

When comparing outcome measures pre- and post-practice there was a small effect for $MAKE_{4MIN}$ ($d = 0.32$), $SST_{TOTALSHOTS}$ ($d = 0.35$) and SST_{SPOTS} ($d = 0.32$), while FT ($d = 0.06$) and $MISS_{4MIN}$ ($d = 0.15$) showed a trivial effect (Table 2). Significant differences were seen in $MAKE_{4MIN}$ Pre to Post, however no main effect was observed for any other variables across time points (Table 3).

Table 4-2: Training load and subjective measures from practice session intervention (n=28).

	RPE (AU)	S-RPE (AU)	Fatigue (AU)	Effort (AU)	Motivation (AU)	PL (AU)	PL/min	Duration (min)
Mean (±SD)	5.5 ± 1.6	594 ± 259	47± 26	58 ± 28	75 ± 27	636 ± 189	6.2 ± 1.7	112 ± 43

RPE, rating of perceived exertion; S-RPE, session rating of perceived exertion load; Fatigue, visual analogue scale for metal fatigue; Effort, visual analogue scale for metal effort; Motivation, visual analogue scale for motivation; PL, total player load form practice session; Arbitrary Units (AU); PL/min, PlayerLoad per min; Duration, duration of practice session.

Table 4-3: Pre/Post Practice Standardized Shooting Task performance (n=28).

	Pre	**Post**	**Cohen's *d***	**p-value**
FT Makes	48.9 ± 6.1	49.3 ± 5.7	0.06	0.65
$MAKE_{4MIN}$	51.6 ± 8.8	48.7 ± 9.3	0.32	0.03
$MISS_{4MIN}$	27.6 ± 6.5	28.7 ± 8.2	0.15	0.45
$SST_{TOTALSHOTS}$	79.2 ± 4.3	77.4 ± 5.9	0.35	0.09
SST_{SPOTS}	20.5 ± 5.7	18.7 ± 5.7	0.32	0.11

Data presented as Mean ± Standard Deviation. FT Makes (sum of 60 attempts), $MAKE_{4MIN}$ (sum of the makes during 4 min shooting), $MISS_{4MIN}$ (sum of the misses during 4 min shooting), $SST_{TOTALSHOTS}$ (sum of the total shots 4 min shooting), SST_{SPOTS} (sum of the spots completed during 4 min shooting); Pre, pre-practice performance measures; Post, post-practice performance measures; Cohen's d, effect size; p-value, statistical significance set at $p<0.05$

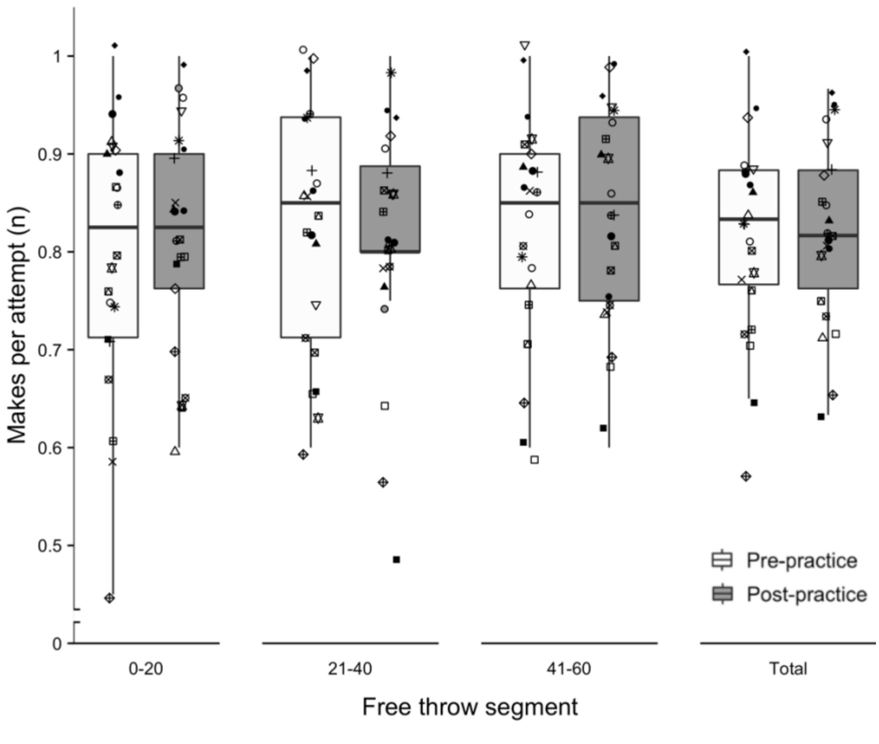

Figure 4-3: Free Throw makes Pre- and Post-Practice.

0-20, first 20 attempts; 21-40, second 20 attempts; 41-60, last 20 attempts; total, combine 60 attempts. Boxplot lower and upper hinges correspond to the first and third quartiles and whiskers extend to the value closest to the hinge between; largest/smallest value, or no further than 1.5 * the interquartile range.

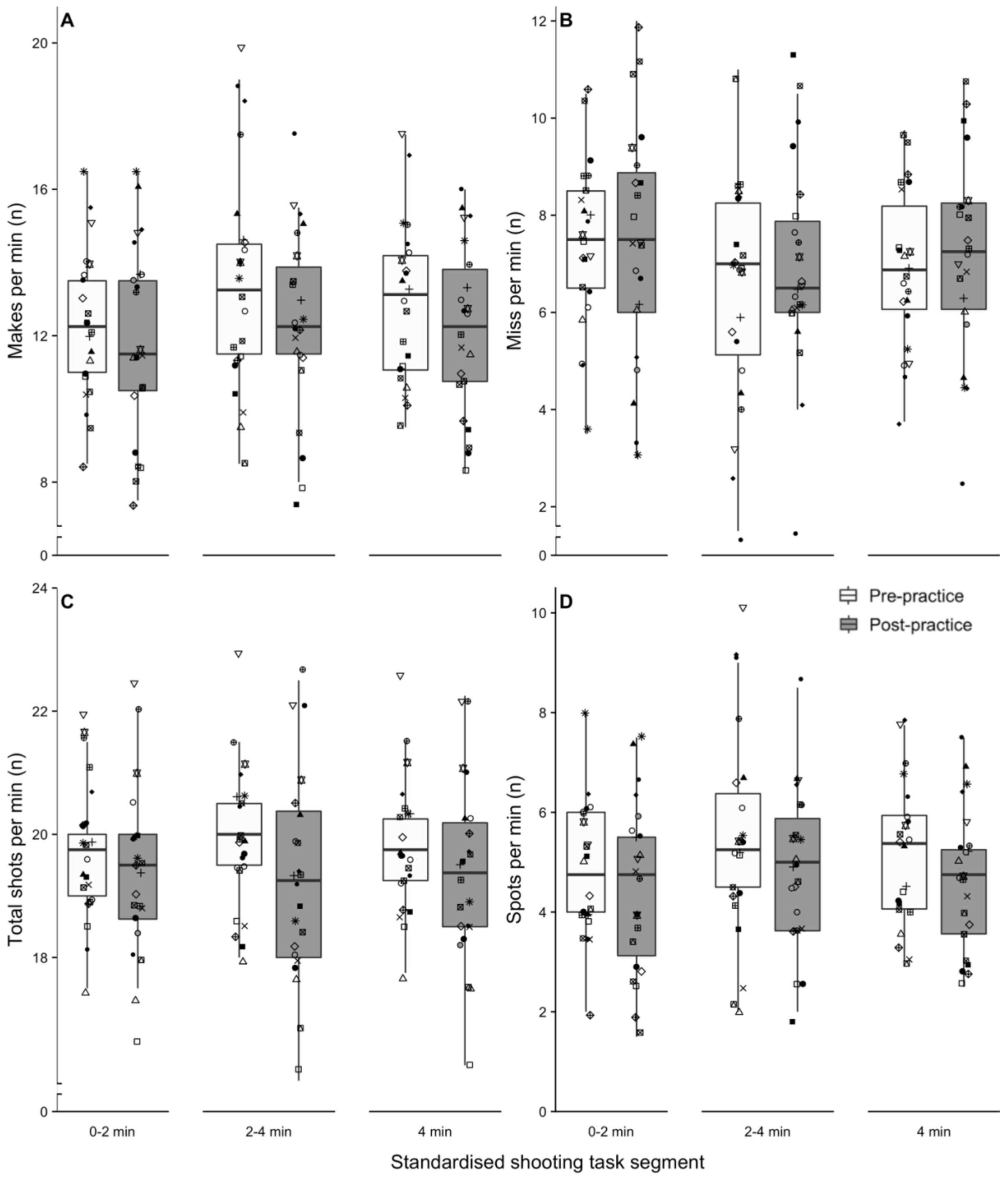

Figure 4-4: Pre- and post-practice Standardized Shooting Task outcome measures.

Pre-practice and post-practice scores for SST broken down into 0-2min, first two minutes of the assessment; 2-4min, last two minutes of the assessment; 4-min, combined 4 minutes of the assessment. Boxplot lower and upper hinges correspond to the first and third quartiles and whiskers extend to the value closest to the hinge between; largest/smallest value, or no further than 1.5 * the interquartile range.

Part 3: Construct Validity

Inter-rater reliability between the expert coaches in establishing shooter ranking showed a moderate correlation (ICC = .53). Results of the Spearman's ranked correlation indicated a very large and significant correlation between Shooter Rank and number of made shots during the SST (r = .814, p = 0.001). A similar correlation was observed between Shooter Rank and shooting percentage during live play in simulated games (r = .815, p=.001) over the course of the preseason (shots attempted = 81.4±20.3). Shooting percentage in live play compared to made shots during the SST also showed a moderate and significant correlation (r = .647, p=0.017).

4.6. Discussion

The purpose of this investigation was to develop a basketball specific shooting performance test and establish the tests interday reliability. Additionally, this test also sought to examine the sensitivity of the assessment to basketball related fatigue, as well as explore the construct validity of the newly developed test. The SST outcome variables displayed interday reliability ranging from CV ~2-12%, with the most reliable measures being $SST_{TOTALSHOTS}$ (CV = 1.9%) and $MAKE_{4MIN}$ (CV = 5.5%). Additionally, $MAKE_{4MIN}$ showed the greatest performance decrements following a standard basketball practice, showing that this measure may be useful for assessing changes in basketball shooting skill performance. This type of skill-based test could be used to track changes in athlete performance and may offer an alternative to typical athlete 'monitoring tools', which predominantly assess changes in physical capacities and subjective perceptions in both research and applied settings. In contrast, the SST is a sport specific test that shows strong ecological validity, as evidenced by the observed relationship between SST performance, coaches rankings and shooting percentages, and may therefore offer a more meaningful measure to athlete responsiveness in a variety of contexts (e.g., research and practice).

The development of the SST was undertaken in consultation with expert basketball coaches, which creates a high level of face validity and ensures practical feasibility of the test. Indeed, the SST is similar to shooting drills common in elite basketball practice, which highlights the practicability of the test. Accordingly, the SST is more likely to be adopted by elite coaches, as it only requires small changes (e.g., data recording) from typical training activities. Furthermore, previous protocols examining basketball skill shooting performance vary greatly including differences in location, shot type, duration, timing, and setting (Boddington et al., 2019; Pojskić et al., 2010). Combined with favourable measurement characteristics (e.g., reliability, sensitivity, and construct validity presented below), this high ecological validity improves upon previous 'monitoring tools' in basketball, as the SST has greater sport specificity (i.e., integrates important basketball skills) and can be easily applied by practitioners and researchers.

Prior to being integrated into practice, it is important to understand any tests measurement characteristics and the ability to detect meaningful change when implemented in an applied setting. The analysis of relative reliability for the different SST outcome variables exhibited ICC's between 0.77 and 0.86, while absolute reliability values ranged from 1.9-12.0%. The total number of shots taken was the most reliable variable in the SST protocol (CV = 1.9%), but there was no significant change in this variable following our acute intervention (i.e., basketball practice). Therefore, using this metric for tracking changes in shooting performance may provide limited value. Furthermore, in agreement with the findings of Filipas et al, FT's showed no differences between categories and displayed no change following a sport specific practice, suggesting limited application as a monitoring tool for elite basketball players (Filipas et al., 2021b). Conversely, the number of shots made (i.e., MAKE$_{4MIN}$) during the SST displayed slightly more variability (CV = 5.5) but did change significantly from pre- to post-practice ($p = 0.03$, $d = -0.32$).

Previous literature has used thresholds to establish reliability, with an ICC $\geq$0.70 and a CV <10% (Baumgartner & Chung, 2001; Cormack et al., 2008); however, using arbitrary thresholds may lead to dismissal of potentially sensitive and useful variables due to the reliability cut-off. Therefore, we chose not to use these thresholds as exclusion criteria. Alternatively, we have presented all reliability data and interpreted the meaningfulness of a given variable in the context of sensitivity to the intervention we examined. It is also important to acknowledge that sensitivity is context specific, and it is possible that other variables may display greater sensitivity in response to a different intervention/stimulus. While previous investigations have expanded our understanding of basketball shooting performance, coaches and practitioners should interpret with caution as the analysis of measurement characteristic will likely be cohort-specific, and consideration should be had when making decisions about testing implementation.

Few studies have investigated the usefulness of a basketball shooting test to measure meaningful changes in performance, and of the tests that have been explored all show greater variability than the SST (Boddington et al., 2019; Pojskić et al., 2010). For example, Pojskic et al., preformed both a 2-point (S2P60) and 3-point (S3P60) shooting protocol with CV's of 28.3% and 42.8%, while Boddington et al. demonstrated CV's of 16.2% with a test consisting of both 2-point and 3-point shots (Boddington et al., 2019; Pojskić et al., 2014) . All SST variables have stronger absolute reliability, with the higher CV being 12.0% for SST_{SPOTS}. One limitation with previous basketball assessments could be the limited number of shots attempted, for example both S2P60, S3P60 used protocols lasting 60 seconds, with subjects spending much of that time transitioning between shooting locations. Similarly, the BJSAT protocol is limited to 8 total shot attempts for each trial. The increased number of shots taken during the 4-minute SST (74.4 ± 1.5) may contribute to the superior reliability. Additionally, the SST displayed greater absolute reliability compared with skill assessments developed in other sports including golf (CV=27.5%)(Robertson et al., 2012) and soccer (CV=4.6-23.5%)(M. Russell et al., 2010). Similar to the aforementioned basketball tests, protocols in the tests developed in other sports may contribute to higher variability (e.g. 9 different golf shot types (Robertson et al., 2012)) and the integration of passing, shooting and dribbling in soccer (Smith et al., 2017b). It is reasonable for skill-based assessments to demonstrate high variability, as sport-specific technical performance (e.g., basketball shooting) is often complex and multifaceted, and therefore exhibits inconsistencies during and between competitions (Zhang et al., 2017). However, reliability and sensitivity are important test characteristics when seeking to detect meaningful changes in an athlete's status/performance, and the high variability evident in previous skills tests could be a limiting factor in the utility of those assessments to detect meaningful change.

To assess the sensitivity of the SST, we examined performance pre- and post-practice. The practice was similar volume and intensity to previous reported practices in collegiate basketball (Heishman et al., 2020) and semi-professional basketball (Fox et al., 2018). Furthermore, subjective exertion also overlapped with earlier investigations in basketball training (Fox et al., 2018; Manzi et al., 2010). These data present novel findings as the basketball intervention displayed significant decreases in shooting performance from pre to post practice with comparable load and intensity to that of previous work.

Ecological validity is highly significant when implementing assessments into the practical setting. The construction of the newly developed test in conjunction with basketball coaches increases feasibility due to the short duration and resemblance of other basketball drills. The data shows that over the course of the 4-minute assessment athletes slightly improved in the later stages of the test for $MAKE_{4MIN}$ prior to the basketball intervention. However, these effects where not present in post-basketball performance of the SST as scores plateaued or decreased. Thus, the 4-minute assessment allows for easy implementation but also shows improved sensitivity when compared to 2-min epochs of the SST.

Construct validity has been frequently examined in many other fitness tests specific to sport such as basketball (A. T. Scanlan et al., 2012), squash (Wilkinson et al., 2009), rugby league (Serpell et al., 2010), soccer (Gabbett, 2010), and water polo (Mujika et al., 2006) in order to verify whether a test measures the intended construct. Such validity is crucial in the development of a skill specific test. Still, construct validity can be assessed by comparing skill outcomes of athletes with superior shooting accuracy expected to be possessed by each individual athlete within the team. (Sampaio et al., 2004; A. T. Scanlan et al., 2012). The current results demonstrated a significant positive correlation between coaches' rankings of shooting skill and number of makes during the SST (r = .814). Additionally, a significant positive correlation was observed between number of makes during the SST and shooting percentage during live play in simulated games (r = .647). The present data suggests that SST possesses construct validity, meaning that the results can discriminate between the proficiency of the shooter.

Assessing ecologically valid changes in skill performance is difficult. The SST presents a sufficiently reliable test, that can detect change following an intervention (e.g., basketball practice). The test also shows good construct validity, with relationships between expert ranking, shooting percentage and SST performance. Therefore, this test may be a useful tool in assessing athletes over time, in response to acute interventions, or cumulative stressors (e.g., changes across the season), which should be explored more in future research. Due to the technical nature of the test, the results are likely more meaningful than commonly used 'monitoring' tools which focus on physical capacity/status.

The findings of the present study showed that the SST is a sport specific, skill-based test, that appears sensitive to environmental stimuli. The integration of cognitively demanding skills (i.e., shooting), may also help practitioners understand athlete's psychobiological responses, which are likely not captured by physical test. However, we did not test responses to cognitive stress directly, thus warranting the need for future investigations this area.

Although the findings support the use of the SST in practice, our study was subject to some limitations that warrant discussion. First, each athlete did not attempt the same shot selection (each completed either the 2-point and 3-point shot), however this was necessary to maintain time sensitivity and the practical application of incorporating the test into basketball practice. Second, the test does not replicate all shooting situations in basketball and therefore may not be reflective of various stimuli during game play. Third, in game shooting data was not accessible for all athletes due to limited shot attempts. Fourth, the findings reflect changes in the SST following an acute basketball practice and may not account for long term changes in performance. Consequently, it is encouraged that future research examine variations in shooting performance over the course of a season.

4.7. Practical applications

The SST has been shown to be a reliable test to assess basketball shooting performance in an applied setting and has demonstrated sensitivity to detect change following acute basketball activity. Compared to previous assessments, the SST presents many sport-specific characteristics associated with basketball shooting while offering an ecologically valid option for coaches and practitioners. Changes in shooting performance may emerge depending on athlete exposure to physical or mental stimulus. As a result, the SST could be utilised in monitoring shooting performance critical to team success at progressive stages of a season.

CHAPTER 5

STUDY 2:

IMPACTS OF MENTAL FATIGUE AND SPORT SPECIFIC FILM SESSIONS ON BASKETBALL SHOOTING TASKS

Related manuscript: Daub, B., McLean, B., Heishman, A., Peak, K., Coutts, A. Impacts of mental fatigue and sport specific film sessions on basketball shooting tasks. *European Journal of Sports Science (2022)*

5.1. Prelude

Results from Study 1 showed that the SST was ecologically valid, reliable, able to detect real changes in shooting performance. Therefore, in Study 2 we utilised the SST to assess changes in basketball shooting performance under different conditions. Within collegiate basketball no investigations had centred around mental fatigue and its potential detriments to sport performance. Thus, a Stroop task intervention, which has been identified in previous literature to experimentally induce mental fatigue, was employed to determine if mental fatigue acutely influenced in basketball shooting performance. Additionally, to increase the ecological validity of the research, we also developed a task specific to basketball film coaching sessions –which are common practice in high performance programs – to determine if such sessions could also impact mental fatigue and shooting performance. Accordingly, Study 2 investigated the presence of mental fatigue following a Stroop task and sport specific film sessions, and the potential impact on basketball shooting performance.

5.2. Introduction

Mental fatigue is a psychobiological state induced by sustained periods of demanding cognitive activity and characterised by feelings of tiredness and lack of energy (Boksem & Tops, 2008; Marcora et al., 2009a; Smith et al., 2016). The deleterious effects of mental fatigue on cognitive function,(Boksem et al., 2006a; Lorist et al., 2005) motor performance, (Duncan et al., 2015; Lal & Craig, 2001) and exercise performance (Smith et al., 2015a; Van Cutsem et al., 2017) have been well documented, (Habay, Van Cutsem, et al., 2021; Van Cutsem et al., 2017a) which has led to increased research examining the impact of mental fatigue on team sport performance. Earlier studies have revealed the association of mental fatigue with reductions in technical performance in both soccer and volleyball (Fortes et al., 2021a; Smith et al., 2016; Sun et al., 2021). Specifically, soccer players demonstrated reduced shooting speed and accuracy (M. R. Smith, Coutts, et al., 2016), while volleyball athletes exhibited impaired attacking skills and passing abilities with mental fatigue (Fortes et al., 2021a). Although yet to be determined, it is likely that mental fatigue may also impair performance in other sports which require similar cognitive processing, such as basketball shooting, therefore warranting investigation (Afonso et al., 2012; Laurent et al., 2006).

Basketball requires the integration of sport-specific skill and frequent bouts of high-intensity movements in complex technical-tactical scenarios (Scanlan et al., 2011; Stojanović et al., 2018). Among the various specific skills (i.e., shooting, dribbling, and passing), shooting performance has been identified as a key indicator of success for both the team and individual athlete (Ibáñez et al., 2003; Karipidis et al., 2001). The most common type of shot taken in elite level basketball games are 'jump shots' (i.e., a basketball shot attempted by jumping into the air and releasing the ball at the peak of the jump)(Erčulj & Štrumbelj, 2015). Indeed, it has been shown that superior in-game shooting accuracy (from both two- and three-point shots) increases win probability (Erčulj & Štrumbelj, 2015; Pojskić et al., 2014; Pyne et al., 2008). Accordingly, understanding the factors that affect basketball shooting performance, would assist in developing interventions to increase likelihood of success and require further investigation.

To date, few studies have examined the effects of mental fatigue on basketball shooting performance in elite players and methodological shortcomings limit the generalisability of these previous findings (Bahrami et al., 2020; Filipas et al., 2021a). However, the limited evidence available shows that mental fatigue in basketball players may increase turnovers (Moreira et al., 2018) and compromise free-throw shooting performance.(Filipas et al., 2021a). More specifically, Moreira et al., (Moreira et al., 2018) observed increased turnovers during small-sided youth basketball games after participants underwent a mentally fatiguing Stroop protocol. Similarly, Filipas et al., (Filipas et al., 2021a) reported a decrease in free throw shooting percentage, in amateur basketball players, following exposure to both a mentally fatigued and a sleep restricted condition. The observed unfavourable changes in performance may be attributed to underlying impairments such as the ability to react quickly and accurately, (Boksem et al., 2006a) as well as the capacity to identify and respond to cues (Boksem et al., 2006a; Lorist et al., 2000) when mentally fatigued. Nonetheless, these observations were documented in amateur lower level populations which may respond differently to mental fatigue compared to higher level athletes with a greater training history or even superior level of fitness (Martin et al., 2016). Furthermore, a recent systematic review exploring research related mental fatigue and basketball performance illuminated the paucity of evidence in the literature, with only 7 studies identified relating mental fatigue to basketball performance, and of those studies only 1 study incorporated the most frequently attempted shot in basketball, the jump shot (Cao et al., 2022). Ultimately, the lack of studies focusing on elite basketball athletes and the limitations surrounding the ecological validity of performance tests used previous studies (i.e., lack of detail in shot order, location, timing and number of shot attempts) warrants further investigation (Bahrami et al., 2020).

A recent systematic review demonstrated the negative impact of mental fatigue on sport specific skill (Sun et al., 2021). However, most of the experimental studies included in this review used structured interventions to induce mental fatigue (i.e.-Stroop task), (Rozand et al., 2014; Smith et al., 2016) which are rarely encountered by athletes in their normal training and competition setting. Additionally, sustained performance on mentally demanding tasks has been shown to be impacted by motivation, leading to a declined willingness to perform (Herlambang et al., 2019). While athletes are thought to be highly motivated individuals, there are circumstances or situations encountered by collegiate basketball players that may manifest mental fatigue and evoke similar adverse effects on sport-specific skill performance. For example, screen time/social media has been shown to produce a state of mental fatigue in amateur volleyball athletes, (Fortes et al., 2021a) while similar observations were made with amateur basketball players following a prolonged bout of watching tactical videos (Filipas et al., 2021a). Lengthy film sessions for tactical and technical teaching purposes are common part of basketball, thus warranting the exploration of ecologically valid tasks that potentially induce mental fatigue.

Therefore, the purpose of this investigation was to compare the impact of mental fatigue induced through a Stroop task and basketball-specific film session on basketball shooting performance. Based on the limited prior research on mental fatigue and sport performance, it was hypothesised that prolonged periods of cognitively demanding tasks would be detrimental to acute basketball shooting performance.

5.3. Methods

5.3.1. Subjects

Fifteen male elite (McKay et al., 2022b) collegiate basketball players currently competing in NCAA Division 1 (Age 20.2 ± 1.2 y, height 199.3 ± 7.1 cm, body mass 93.1 ± 8.6 kg) volunteered to participate in this study. Participants were active squad members of the University of Oklahoma's Men's basketball team and were provided with verbal and written instructions outlining the procedures, risks and benefits of the study prior to providing written informed consent. This research was approved by the Human Research Ethics Committee of the University of Technology Sydney (UTS).

5.3.2. Design

To examine the impact of mental fatigue on basketball specific shooting performance, the basketball Standardized Shooting Task (SST) (Daub et al., 2022) was utilised to assess changes following a mental fatiguing Stroop protocol (Stroop), a basketball specific film session (Film) and a control session (Control). The study began with a familiarisation session, where athletes were provided with standardised instructions for the SST, condition groups, visual analogue scales (VAS) and test preparation of future testing days. After familiarisation, participants completed the three experimental sessions. Procedures of each session were the same, with the only difference being the intervention prior to SST completion: Stroop intervention, sport-specific film and control documentary.

5.3.3. Methodology

Participants visited the testing facility on four separate occasions, with the first visit functioning as a familiarisation session. The remaining three visits included the control and two experimental sessions (Film and Stroop) and were performed in a randomized, counterbalanced order by online software (Microsoft Excel, Redmond, Washington, USA). Testing sessions were completed at the same time of day and separated by a minimum of 48 hours (Heishman et al., 2017). The researchers assessing the outcomes measures were not blinded to the treatment but refrained from providing any information to the participants. In line with the SST shoot protocol classification methods (Daub et al., 2022), before familiarisation and testing, players were categorised as '3-point' shooters and 'non 3-point' shooters by the basketball coaching staff.

During the familiarisation session, participants were provided standardised instructions for the use of the pen and paper visual analogue scales (VAS) to assess mental fatigue, mental effort and motivation. Participants were also provided with instructions for the mentally fatiguing task (Stroop Task) and practiced until comfortable. Each of the participants then participated in a practice trial of the SST protocol. Finally, the participants were provided written instructions to follow prior to the upcoming tests. Test preparation instructions directed participants to maintain regular sleeping patterns, food and fluid and prescription medications, and avoid caffeine, nicotine, alcohol, and physically demanding tasks immediately prior to subsequent testing sessions.

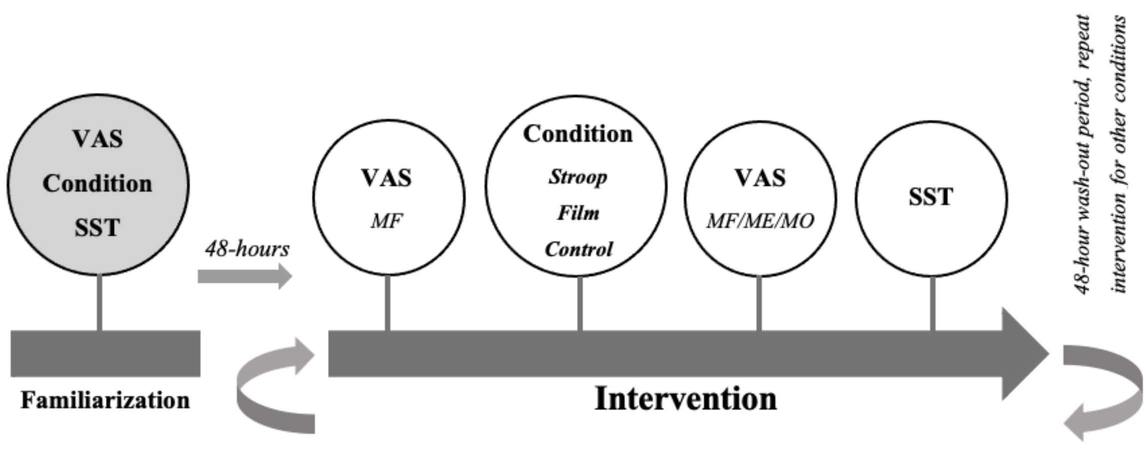

Figure 5-1: Schematic timeline of study design.

SST, Standardized Shooting Task; VAS, Visual Analog Scale; MF, Mental Fatigue; ME, Mental Effort; MO, Motivation

5.3.4. Treatment

To induce mental fatigue prior to the SST, participants performed a computerized version of the Stroop colour-word task for 30 min (Soma Technologies, Lucerne, Switzerland). This task has previously been shown to increase mental fatigue and mental effort without effecting motivation.(Badin et al., 2016; Smith et al., 2016; Smith et al., 2016b). In this task, participants were presented with six words (red, blue, pink, white, green, yellow) in random order on the screen. Participants were then required to ignore the meaning of the word and only respond to the colour. To increase difficulty, when the colour of the word was red, the correct response was to respond to the word rather than the printed colour (Rozand et al., 2014; M. R. Smith, Coutts, et al., 2016). To increase motivation a member of the research team challenged the participants to complete more words than the highest score among other participants.

In addition to the Stroop treatment, participants also engaged in basketball-specific film review. This condition included 30 minutes of basketball specific plays in which the same terminology for the tactical execution of plays both offensively and defensively was instructed to the participants. The film session was conducted by the same basketball staff member to provide continuity for each participant. While previous work has suggested performing a longer duration of a Stroop task (Habay et al., 2021; Van Cutsem et al., 2019), the authors chose to parallel the film session with the duration typically experienced by the student-athletes to maximise ecological validity of the results, while also remaining courteous with participants time commitment to the study.

The control treatment required the participants to watch a 30 minute emotionally neutral documentary (The History of the Car), similar to those used in previous investigations (Van Cutsem et al., 2017). Participants completed all treatment and control sessions in the same room while under supervision from the same member of the research team.

5.3.5. Subjective Ratings

Participants subjective rating of mental fatigue, mental effort, and motivation were assessed using the same 100-mm VAS as in previous literature (Badin et al., 2016; Smith et al., 2016). The scales consisted of one horizontal line measuring 100-mm with no markings. Each scale was anchored with the words “none at all” at the left end and “maximal” at the right end. Ratings from each participant were recorded in millimetres, with values ranging from 0-100, by measuring the distance from the left end of the scale to the self-selected vertical mark. Participants rated "current feelings" of mental fatigue both pre-treatment and post-treatment to compare differences in perceived mental fatigue induced by the stimuli. Mental effort and motivation were rated post-treatment only, with mental effort referring to the 'level of effort required from the previous task" and motivation referring to the "completion of the upcoming basketball task".

5.3.6. SST Protocol

The novel SST possesses sufficient reliability and sensitivity to detect meaningful changes in performance, as well as adequate construct validity (Daub et al., 2022). This sport-specific test requires players to first attempt 60 free throws, followed by a 4-minute shooting task comprised of "jump shots" from 7 locations on the court, either behind the 3-point line or at a 15 ft mark, as determined by expert coaches. All athletes start from location "1" and were required to successfully make two consecutive shots, before moving to the next spot. Once the athlete reached the opposite baseline and makes two consecutive shots (location 7), they repeated the shooting sequence in reverse order. The full layout of the SST and detailed procedures can be found in the reliability study (Daub et al., 2022). The objective when completing the SST is to make as many shots as possible during a four-minute shooting segment. All made or missed attempts are counted as 1 in the sum of each respective outcome measure, while spots completed refers to the number of locations obtained from making two consecutive attempts throughout the 4-minutes. Typical outcome measures of the SST include: 1) sum of the makes during 4-minute shooting ($MAKE_{4MIN}$); 2) sum of the misses during 4-minute shooting ($MISS_{4MIN}$); 3) sum of the total shots 4-minute shooting ($SST_{TOTALSHOTS}$); 4) sum of the spots completed during 4-minute shooting (SST_{SPOTS}).

5.3.7. Statistical Analysis

All data are presented as means and standard deviations (SD) unless otherwise stated. Data normality and sphericity was verified using the Kolmogorov-Smirnov test and Mauchly's test, respectively. When the assumption of data sphericity was violated, the Greenhouse-Geiser correction was used. A one-way (Film vs. Stroop vs. Control] repeated measures analysis of variance (RM-ANOVA) was used to evaluate differences in each subjective assessment, including mental fatigue, mental effort and motivation. When a significant difference was detected, a post hoc analysis with Bonferroni correction of used to isolate pairwise differences.

Effect sizes (*d*) were calculated to assess the magnitude of difference between each pairwise comparison and were interpreted based on the following classifications: trivial = 0–0.19, small = 0.20–0.49, medium = 0.50–0.79 and large = >0.80 (J. Cohen, 1992). Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) software (v 25.0; IBM Corp., Armonk, NY, USA). Statistical significance was set at $p \leq 0.05$.

5.4. Results

No significant differences were seen in mental fatigue prior to intervention ($p = 0.827$); Stroop vs Film ($p = 1.000$, $d = 0.23$) and Control ($p = 1.000$, $d = 0.09$) or Film vs Control ($p = 1.000$, $d = 0.16$), (Control: 21.5 ± 9.9; Stroop: 22.5 ± 11.9; Film: 19.6 ± 13.6). However, significant differences in subjective mental fatigue post intervention, were observed across conditions ($p < 0.001$). Post-hoc pairwise comparisons revealed significant increases in subjective mental fatigue following the Stroop condition compared to both Film ($p = 0.015$, $d = 0.63$) and Control ($p < 0.001$, $d = 1.43$). However, no significant differences in subjective mental fatigue were detected between the Film and Control conditions ($p = 0.094$, $d = 0.71$), (Control: 24.5 ± 16.1; Stroop: 54.2 ± 24.5; Film: 38.9 ± 23.8). Ratings of mental effort were significantly greater following the Stroop compared to both Film ($p = 0.046$, $d = 0.38$) and the Control ($p < 0.001$, $d = 1.83$). Additionally, Film exhibited significantly greater mental effort than the Control ($p = 0.001$, $d = 1.52$), (Control: 14.0 ± 18.5; Stroop: 61.0 ± 31.3; Film: 49.8 ± 27.7). No significant differences across conditions were observed in Motivation ($p = 0.249$) for the upcoming basketball shooting task; Stroop compared to Film ($p = 1.000$, $d = 0.65$) and the Control ($p = 1.000$, $d = 0.86$) as well as Film to Control conditions ($p = 0.516$, $d = 1.46$), (Control: 82.2 ± 23.2; Stroop: 86.7 ± 17.4; Film: 89.1 ± 12.2).

The results of the basketball performance task are shown in Table 1. There were no significant differences for Free Throw Makes across any of the conditions ($p = 0.523$). However, a significant main effect was observed for both $MAKE_{4MIN}$ ($p = 0.006$) and $MISS_{4MIN}$ ($p = 0.021$). Further analysis of $MAKE_{4MIN}$ revealed significantly lower scores in shooting performance during the Stroop compared to the Control ($p = 0.003$, $d = 0.53$). Additionally, a significant difference in $MISS_{4MIN}$ ($p = 0.034$, $d = 0.51$) between the Stroop and Control was observed (Figure 1). There were no significant differences in $MAKE_{4MIN}$ or $MISS_{4MIN}$ during the Film compared to the Control ($p = 0.098$, $d = 0.40$; $p = 0.111$, $d = 0.49$), as well as no significant difference for the Stroop compared to the Film ($p > .999$, $d < 0.01$). Additionally, no significant differences were observed for the performance outcomes across conditions for $SST_{TOTALSHOTS}$ ($p = 0.220$) or SST_{SPOTS} ($p = 0.635$). Lastly, no significant differences were observed between subject groupings across time regardless of condition ($p=.202$) and no significant difference occurred between condition order ($p=.110$).

Table 5-1: Differences in Shooting Performance across conditions (Mean ± SD).

Variable	Control	Stroop	Film
Free Throw Makes	48.9 ± 7.3	47.8 ± 7.4	49.1 ± 6.9
$MAKE_{4MIN}$	49.5 ± 10.2	44.0 ± 10.6$^{\#}$	45.1 ± 11.7
$MISS_{4MIN}$	27.3 ± 7.0	30.9 ± 7.1*	30.9 ± 7.6
$SST_{TOTALSHOTS}$	76.5 ± 6.1	75.3 ± 5.4	76.1 ± 5.9
SST_{SPOTS}	18.3 ± 7.1	17.2 ± 6.5	17.2 ± 6.4

Free Throw Makes (sum of 60 attempts); $MAKE_{4MIN}$ (sum of the makes during 4 min shooting); $MISS_{4MIN}$ (sum of the misses during 4 min shooting); $SST_{TOTALSHOTS}$ (sum of the total shots 4 min shooting); SST_{SPOTS} (sum of the spots completed during 4 min shooting); $^{\#}$=significant different from Control, $p < 0.01$; *=significantly different from Control, $p < 0.05$.

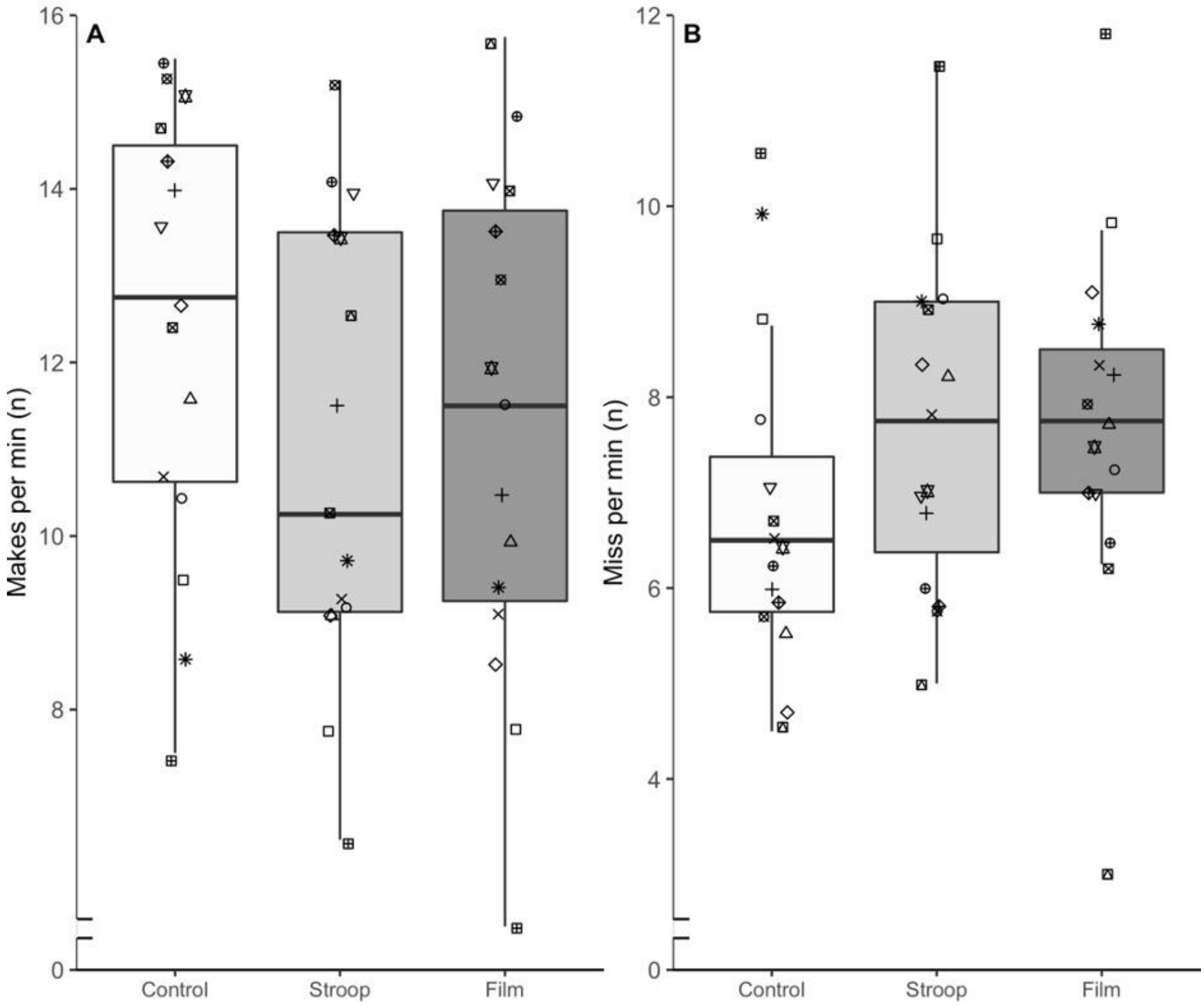

Figure 5-2: Differences in the number of A) made and B) missed shots during the SST between Control, Stroop and Film conditions.

Boxplot lower and upper hinges correspond to the first and third quartiles and whiskers extend to the value closest to the hinge between; largest/smallest value, or no further than 1.5 * the interquartile range.

5.6. Discussion

The primary purpose of this study was to examine the effects of mental fatigue, induced by the Stroop task and Film sessions, on basketball shooting performance using the novel SST. The primary finding was that the Stroop task resulted in a significant increase in subjective mental fatigue, with a subsequent reduction in shots made and increase in missed shots. There was also a non-significant moderate decrease in shots made, as well as a moderate increase in shots missed following the Film, which exceeded the minimal detectable change previously established with the SST protocol (Daub et al., 2022). Participants reported an increase in metal effort during these Film sessions, and there was a large, non-significant effect of Film on ratings of mental fatigue. These results show that elite collegiate basketball players exhibit impaired shooting performance following mentally fatiguing tasks and offers preliminary evidence that a fatiguing Film session exerts a negative effect on shooting performance.

Previous investigations that have used a prolonged Stroop task to induce mental fatigue showed a greater demand of impaired typical film sessions experienced in a typical training setting, which could subsequently reduce the likelihood of inducing severe mental fatigue. It is possible that an extended duration of the film session, which is often the case in collegiate basketball, may produce a magnitude of mental fatigue more like that of the Stroop. The decision was made to standardise the duration of film to coincide with previous Stroop protocols of 30 minutes (Smith et al., 2016; Smith et al., 2016b). Although further studies are needed to better understand this relationship, practitioners and coaches should carefully plan film sessions, specifically exercising caution when engaging in long, demanding film in close temporal proximity to sessions when high shooting performance is desired (e.g., skill development training, competition). To progress understanding in this concept, future research should explore the dose-response of relationship between film sessions and mental fatigue, as well as investigate the potential for exploring film periodization strategies that might mitigate mental fatigue, when needed, while maintaining adequate film review and instruction.

We also showed that the cognitive stimulus resulting from the Stroop task and the Film session did not significantly impact motivation to perform in the forthcoming skills assessment. Conflicting observations have been reported regarding the association of motivation and mental fatigue (Boksem & Tops, 2008; Marcora et al., 2009a; Smith et al., 2016). For example, some previous works have shown a suppression of motivation following mentally fatiguing tasks, suggesting motivation as a central component and indicator of mental fatigue (Boksem & Tops, 2008b; van der Linden et al., 2003b). However, other investigations focusing on the impact of mental fatigue on physical exertion have shown similar motivation levels between intervention and control conditions, which suggests that alterations in motivation may have been more closely related to the forthcoming task (Marcora et al., 2009a; Smith et al., 2016). In the present study, the similarity in motivation to complete the upcoming task across conditions may relate to the high intrinsic drive and competitive nature of the collegiate student-athlete participants, who typically exhibit a strong "willingness to succeed", especially in a sport specific shooting task (Brehm & Self, 1989). Ultimately, the similar levels of motivation we observed across conditions supports the postulation that changes in performance are credited to other factors related to mental fatigue rather than motivational disparities alone.

Although the importance of shooting performance to success in basketball is well established (Ibáñez et al., 2003; Karipidis, A., Fotinakis, P., Taxildaris, K., & Fatouros, 2001), it is difficult to assess due to a lack of suitably valid tests that are feasible to apply within a performance environment. The current investigation was conducted with elite collegiate basketballers utilizing the SST, which has good construct validity, sufficient reliability and is sensitive enough to detect meaningful changes in shooting performance (Daub et al., 2022). Moreover, the development of the task in consultation with expert coaches ensures high levels of ecological validity, allowing for easy implantation into the applied setting, but also an amplified translation to applied performance.

While we have shown that mentally fatiguing tasks negatively impact jump shooting performance, the same interventions had little influence on free-throw shooting performance. These findings contrast Filipas et al.,(Filipas et al., 2021a) who reported decreases in free-throw makes in amateur basketball players following 30-minutes of watching tactical videos (Filipas et al., 2021a). The differences in findings between studies may be related to the athletes' experience level, as previous research has shown that elite basketball players display greater free-throw accuracy, which may lead to increased resiliency from outside perturbations, such as mental fatigue, resulting in less impact on performance (Mandić et al., 2019; Martin et al., 2016). Similarly, previous studies in soccer have proposed that professional soccer players may be more resilient to the negative effects of mental fatigue since they display higher cognitive/executive function than less experienced athletes (Smith et al., 2018; Vestberg et al., 2012). Additionally, previous work by Martin et al, showed that professional cyclists displayed superior inhibitory control and increased resiliency to the negative effects of mental fatigue compared to their recreationally training counterparts (Martin et al., 2016). Furthermore, it is important to consider that jump shooting may require more cognitively demanding efforts than free-throws, which was reflected through performance decrements when athletes are mentally fatigued.

The current results reveal the negative impacts of mental fatigue on basketball shooting performance. Despite the noteworthy findings, the current study does contain limitations. The first limitation is the current study focused on evaluating acute cognitive stimulus on subsequent basketball shooting performance. This could be important for collegiate athletes as mental fatigue may accumulate from various stimuli, including academic requirements, social commitments, media obligations and team duties. Therefore, more research is needed in this area to assess changes in mental fatigue longitudinally, in order to understand implications over the course of the basketball season. Second, the current investigation did not include any physiological measures of the brain. In previous investigations neuroendocrine readings were recorded to help provide context into potential mechanisms of mental fatigue, however, in an attempt to limit invasiveness and be cognizant of participants time commitment, no such measures were recorded.

5.7. Practical Applications

The outcomes of this study suggest that elite collegiate basketball players should be encouraged to abstain from extremely cognitively demanding tasks prior to practice and games when shooting performance is required. Additionally, the present investigation combined with other works, suggests that practitioners and coaches should use caution when prescribing sport specific film sessions to basketball players directly preceding shooting tasks, in order to avoid the potential negative effects on performance. Furthermore, sport professionals should explore the effects of a variety of influencers on their own team, as mental fatigue could manifest from an array of circumstances within the collegiate setting.

5.8. Conclusions

Basketball shooting performance was significantly reduced following acutely increased levels of mental fatigue. In addition, this study provides novel preliminary evidence that a sport-specific Film session of 30-minutes in duration (or longer) requires a large amount of mental effort and may also have a detrimental effect on subsequent basketball shooting performance. These have significant implications for applied basketball performance, which requires players to accurately perform shooting tasks during competition, as increases in mental fatigue suppress performance. As such, practitioners should use caution when incorporating high-effort Film sessions prior to competition as they may induce mental fatigue, thus impairing acute basketball shooting performance.

CHAPTER 6

STUDY 3:

THE RELATIONSHIP BETWEEN MENTAL FATIGUE AND SHOOTING PERFORMANCE OVER THE COURSE OF AN NCAA DIVISION I BASKETBALL SEASON

Related manuscript: Daub, B., McLean, B., Heishman, A., Peak, K., Coutts, A. The Relationship Between Mental Fatigue and Shooting Performance Over the Course of an NCAA Division I Basketball Season. *Journal of Strength and Conditioning Research (2023)*.

6.1. Prelude

The results from Study 2 demonstrated a reduction in shooting performance following increased levels of mental fatigue during the Stroop task, as well as increased levels of mental fatigue following the sport specific film session. These findings provided new insight to coaches and practitioners within the setting in which it was collected, allowing them to use these interventions to identify real changes in shooting performance and to understand to potential impacts of film-based coaching sessions. Additionally, it has stimulated interest in discovering other potential sources of mental fatigue (and it impact on shooting performance) that might occur in the collegiate training and competition environment. Therefore, Study 3 was aimed to investigate mental fatigue at strategic time points throughout a Division I college basketball season, in an effort to better understand not only the presence of mental fatigue but also its potential to impact shooting performance.

6.2. Introduction

In the United States, Division I (DI) is the highest level of intercollegiate athletics sanctioned by the National Collegiate Athletic Association (NCAA). The student-athletes selected to compete in DI are an exclusive group, with only 2.5% of high school athletes receiving the opportunity to compete at that level (Irick, 2019). These highly sought after competitive student-athletes possess exceptional sport specific skills, but also the academic aptitude needed for eligibility (Play Division I Sports). In order to participate in NCAA competitions, athletes must be full-time students and are required to meet academic standards, which include a minimum grade point average, ongoing enrolment requirements, while also exhibiting adequate progress towards degree completion (*Play Division I Sports*, n.d.). According to NCAA rules, if an athlete fails to meet these standards, they will not be eligible to participate in the sport and are subject to losing athletic scholarships (Yukhymenko-Lescroart, 2021). Due to the dual demands placed on these individuals, they are often referred to as 'student-athletes'.

Student-athletes encounter an array of stressors as they attempt to succeed in their respective sports and academics (Dill & Henley, 1998; Pritchard et al., 2007a). Division I student-athletes have been reported to spend considerable time in both academic and athletic domains, investing as much as 38.5 and 34 hours per week, respectively (NCAA GOALS Study of the Student-Athlete Experience: Initial Summary of Findings). Due to these extensive time demands, previous research has shown that student-athletes report higher levels of academic stress compared to their non-student-athlete counterparts (Humphrey et al., 2000a; Pritchard et al., 2007a). Academic stress has also been linked to athletic outcomes, whereby increased academic load was associated with increased injury rates in collegiate football (Mann et al., 2016a). The academic demands, combined with an extensive training schedule and performance expectations, likely places high mental and physical load on student-athletes, which may impact their performance in both domains.

The NCAA collegiate basketball season spans five months and includes approximately 30 regular season games. A large portion of the season consists of conference games. Conference play is a part of the season where teams compete within their specific conference. These conferences are subdivisions of a larger league, usually based on geographic regions. During the regular season, teams play a set number of games against conference opponents, and the outcomes of these games determine standings and rankings. Team performance in conference play affects their eligibility for conference championships and their seeding in postseason tournaments.

As basketball requires frequent bouts of high-intensity movement in complex scenarios (Stojanović et al., 2018), most research examining athlete stressors has centred around the rigorous physical demands of the sport. However, recent investigations have begun to examine the cognitive components of the sport, including the effects of mental fatigue on basketball-specific performance (Cao et al., 2022). Mental fatigue is a psychobiological state induced by prolonged periods of cognitively demanding activity and characterised by feelings of tiredness and lack of energy (Boksem & Tops, 2008; Marcora et al., 2009a; Smith et al., 2016). It has also been well documented that mental fatigue can have deleterious effects on cognitive function, (Boksem et al., 2006a; Lorist et al., 2005) motor performance, (Duncan et al., 2015; Lal & Craig, 2001) and physical performance (Smith et al., 2015a; Van Cutsem et al., 2017). Indeed, previous work in basketball has shown that mental fatigue impairs both technical and cognitive performance (i.e. decision making)(Cao et al., 2022; Daub et al., 2022). Despite the negative effects of mental fatigue on multiple facets of performance, and the significant mental load and stress imposed on student-athletes from multiple domains, the possible manifestation of mental fatigue during the intercollegiate basketball season has not been investigated. Moreover, mental fatigue has also been shown to increase following other tasks which are likely part of student-athletes weekly routines, such as screen time on social media (L. S. Fortes, Fonseca, et al., 2021a), prolonged tactical sport videos (Filipas et al., 2021a), and video games (Faro et al., 2022b).

Therefore, the aim of this investigation was to examine the presence of mental fatigue and its relationship to sport-specific performance (i.e., shooting) throughout an NCAA Division I basketball season. It was hypothesised that high levels of academic load would cause increased mental fatigue, associated with concurrent decrements in basketball shooting performance.

6.3. Methods

6.3.1. Experimental Approach to the Problem

To better understand the effects of undulating game and academic load, 4 weeks throughout the year were selected to examine, based on the number of basketball games played and projected academic demands, as presented in Table 1. The number of games was pre-determined by the NCAA schedule, and projected academic load was categorised as low (i.e., semester break), standard (i.e., a normal academic week (semester week 7/16)), or high (i.e., exam periods). Games played and academic load varied between the 4 experimental weeks and were categorised as follows:

- GAME: high game volume.
- ACADEMIC: high academic load.
- PRACTICE: no academic load (i.e., no classes), no games, multiple practices.
- TYPICAL: standard number of games and academic requirements during conference play

To examine the impact of mental fatigue on basketball specific shooting performance in collegiate basketball, the basketball Standardized Shooting Task (SST)(Daub et al., 2022) was utilised to assess shooting performance during four weeks throughout the season.

Table 6-1: Structure of experimental weeks, determined by the basketball games and projected academic load.

Descriptor (out of 19-week season)	Number of games/practices	Projected academic load	Rationale for experimental week selection
High Games (GAME; week 3)	3/3	Standard	Highest number of games in one week
High academic load (ACADEMIC; week 7)	0/6	High	University exam week, therefore projected to be a high academic load
No academic load, no games, multiple practices (PRACTICE; week 9)	0/6	None	No basketball games and between university semesters, therefore no academic load
Standard academic load and standard games (TYPICAL; week 16)	2/4	Standard	Standard academic and game load. Increased importance of games due to conference play.

6.3.2. Subjects

Fifteen elite (McKay et al., 2022b) male basketball players currently competing in NCAA Division I (Age 20.2 ± 1.2 y, height 199.3 ± 7.1 cm, body mass 93.1 ± 8.6 kg) volunteered to participate in this study. Participants were active squad members of the University of Oklahoma's Men's basketball team and were provided with verbal and written instructions outlining the procedures, risks, and benefits of the study prior to providing written informed consent. This research was approved by the Human Research Ethics Committee of the University of Technology Sydney (UTS).

6.3.3. Procedures

The study began with a familiarisation session, where athletes were provided with standardised instructions for the SST, pen and paper visual analogue scales (VAS), brief psychomotor vigilance test (PVT-B) and recovery stress questionnaire (REST-Q). After familiarisation, athletes participated in four separate experimental weeks, during which testing sessions took place at the start (Monday) and end (Sunday) of each week, and procedures were the same for every testing session (see Figure 1). Testing at the start and end of each week took place prior to practice. In addition to these standardised tests, the athletes academic study time, exposure to coaching film sessions and training load was recorded during each experimental week. Specifically, each athlete was asked to self-report the time (minutes) spent on academic studies outside the classroom. Furthermore, researchers recorded the duration (minutes) of film sessions, as well as session rating of perceived exertion (sRPE) during basketball for each day throughout all 4 experimental weeks.

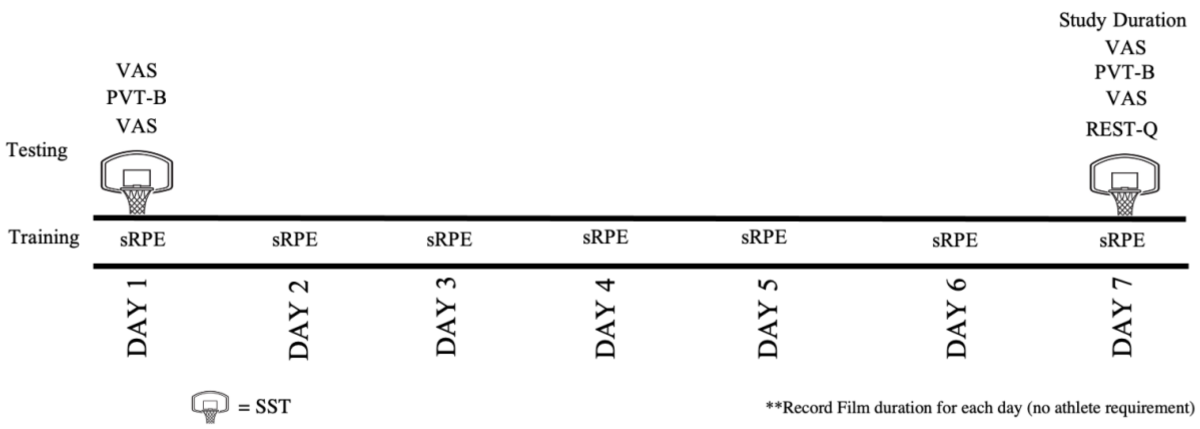

Figure 6-1: Schematic timeline during each experimental week.
SST, Standardized Shooting Task; PVT-B, brief psychomotor vigilance test; sRPE, session rating of perceived exertion; VAS, visual analogue scale; REST-Q, recovery stress questionnaire; Study Duration, minutes of individual study.

Testing sessions were completed at the same time of day and separated by a minimum of one week (Heishman et al., 2017). The researchers assessing the outcome measures were not blinded to the conditions for that week but refrained from providing any information to the participants.

Finally, the participants were provided written instructions to follow prior to each upcoming testing session. The testing preparation instructions directed participants to maintain regular sleeping patterns, food consumption, fluid intake, and prescription medications use, while avoiding caffeine, nicotine, alcohol, and physically demanding tasks immediately prior to each testing sessions.

Standardized Shooting Task (SST) Protocol

The SST has been previously validated within a similar cohort, (Daub et al., 2022) and has been shown to possess sufficient reliability and sensitivity to detect meaningful changes in shooting performance following both physically and cognitively demanding stimuli. This sport-specific test requires players to first attempt 60 free throws, followed by a 4-minute shooting task comprised "jump shots" from 7 locations on the court, either behind the 3-point line or at a 15 ft mark. In line with previous methods (Daub et al., 2022), to determine an individual's shooting location, players were categorised as either a "3-point shooter" or a "non 3-point shooter" by expert coaching staff, depending upon the player's role within the team.

During the jump shot protocol, all athletes start from location "1" and were required to successfully make two consecutive shots, before moving to the next spot. Once the athlete reached the opposite baseline and makes two consecutive shots (location 7), they repeated the shooting sequence in reverse order. The full layout of the SST and detailed procedures can be found in the reliability study(Daub et al., 2022). The verbal instructions given to the players when completing the SST was to "make as many shots as possible during a four-minute shooting segment". All made or missed attempts are counted as 1 in the sum of each respective outcome measure, while spots completed refers to the number of locations obtained from making two consecutive attempts throughout the 4-minutes. We report the following outcome measures from the SST include: 1) sum of the makes during 4-minute shooting ($MAKE_{4MIN}$); 2) sum of the misses during 4-minute shooting ($MISS_{4MIN}$); 3) sum of the total shots 4-minute shooting ($SST_{TOTALSHOTS}$); 4) sum of the spots completed during 4-minute shooting (SST_{SPOTS}).

Brief psychomotor vigilance test (PVT-B)

The 3-minute PVT-B (Soma Technologies, Lucerne, Switzerland) was performed using a handheld device (iPad, Apple, Cupertino, California, USA). The visual response time (RT) stimulus and performance feedback were presented on the device's LED display. The inter-stimulus intervals varied randomly from 1 to 4 s (including a 1s RT feedback interval). For this version of the PVT-B, subjects were instructed to press the response button (i.e., tap the screen) as soon as each stimulus (blue illuminated circle) appeared on the LED display, in order to keep RT as low as possible, but not to press the button too soon (which yielded a false start warning on the display). Based on previous systematic analysis of different PVT-B outcome measures in the literature(Basner et al., 2011), we chose to include the following variables in our analyses: (1) mean RT, (2) the performance score (accuracy), calculated as 100% minus the number of lapses and false starts relative to the number of valid stimuli and false starts.

Visual Analog Scales (VAS)

Participants subjective rating of mental fatigue, mental effort, and motivation were assessed using the same 100-mm VAS as in previous literature (Badin et al., 2016; Smith et al., 2016). The scales consisted of one horizontal line measuring 100-mm with no markings. Each scale was anchored with the words "none at all" at the left end and "maximal" at the right end. Ratings from each participant were recorded in millimetres, with values ranging from 0-100, by measuring the distance from the left end of the scale to the self-selected vertical mark. Participants rated "current feelings" of mental fatigue both pre-treatment and post-treatment to compare differences in perceived mental fatigue induced by the stimuli. Mental effort and motivation were rated post-treatment only, with mental effort referring to the ‘level of effort required from the previous task” and motivation referring to the “completion of the upcoming basketball task”.

Recovery stress questionnaire (REST-Q)

The recovery-stress state of each athlete was assessed at the end of each experimental week using the REST-Q (Kallus & Kellmann, 2001). The REST-Q begins with the stem of “In the past 3 days/nights,” and athletes indicated item responses on a 7-point Likert scale ranging from never (0) to always (6). The REST-Q consists of general stress scales (General Stress, Emotional Stress, Social Stress, Conflicts/Pressure, Fatigue, Lack of Energy, Physical Complaints), general recovery scales (Success, Social Recovery, Physical Recovery, General Well-being, Sleep Quality), sport-specific stress scales (Disturbed Breaks, Emotional Exhaustion, Injury), and sport-specific recovery scales (Being in Shape, Personal Accomplishment, Self-Efficacy, Self-Regulation).

6.3.4. Statistical Analysis

All data are presented as means and standard deviations (SD) unless otherwise stated. Data normality and sphericity was verified using the Kolmogorov-Smirnov test and Mauchly’s test, respectively. When the assumption of data sphericity was violated, the Greenhouse-Geiser correction was used. A one-way repeated measures analysis of variance was used to evaluate differences in each subjective assessment (including mental fatigue, mental effort, and motivation), session rating of perceived exertion, and psychomotor vigilance test. A multivariate analysis of variance was used to evaluate reported values for the REST-Q. Additionally, a two-way repeated measures analysis of variance was used to evaluate differences in shooting performance. When a significant difference was detected, a post hoc analysis with Bonferroni correction of used to isolate pairwise differences. Effect sizes (d) were calculated to assess the magnitude of difference between each pairwise comparison and were interpreted based on the following classifications: trivial = 0–0.19, small = 0.20–0.49, medium = 0.50–0.79 and large = >0.80(J. Cohen, 1992). A linear regression model was used to analyse trends for objective mental fatigue variables over the course of the season. Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) software (v 25.0; IBM Corp., Armonk, NY, USA). Statistical significance was set at $p \leq 0.05$.

6.4. Results

Significant differences in VAS scores for the perceptions were observed across experimental weeks ($p = 0.039$). Post-hoc pairwise comparisons revealed significant increases in perceived mental fatigue from Pre to Post PVT-B measurements at the end of the ACADEMIC week ($p = 0.002$, $d = 1.51$.) and from Pre to Post of the ACADEMIC week ($p < 0.001$, $d = 2.21$) (Figure 2). No significant differences were detected in perceived mental fatigue for any of the other experimental weeks. Perceptions of mental effort were significantly greater from Pre to Post of the ACADEMIC week ($p < 0.001$, $d = 1.67$). No significant differences across experimental weeks were observed in Motivation for the upcoming basketball shooting task ($p = 0.247$)

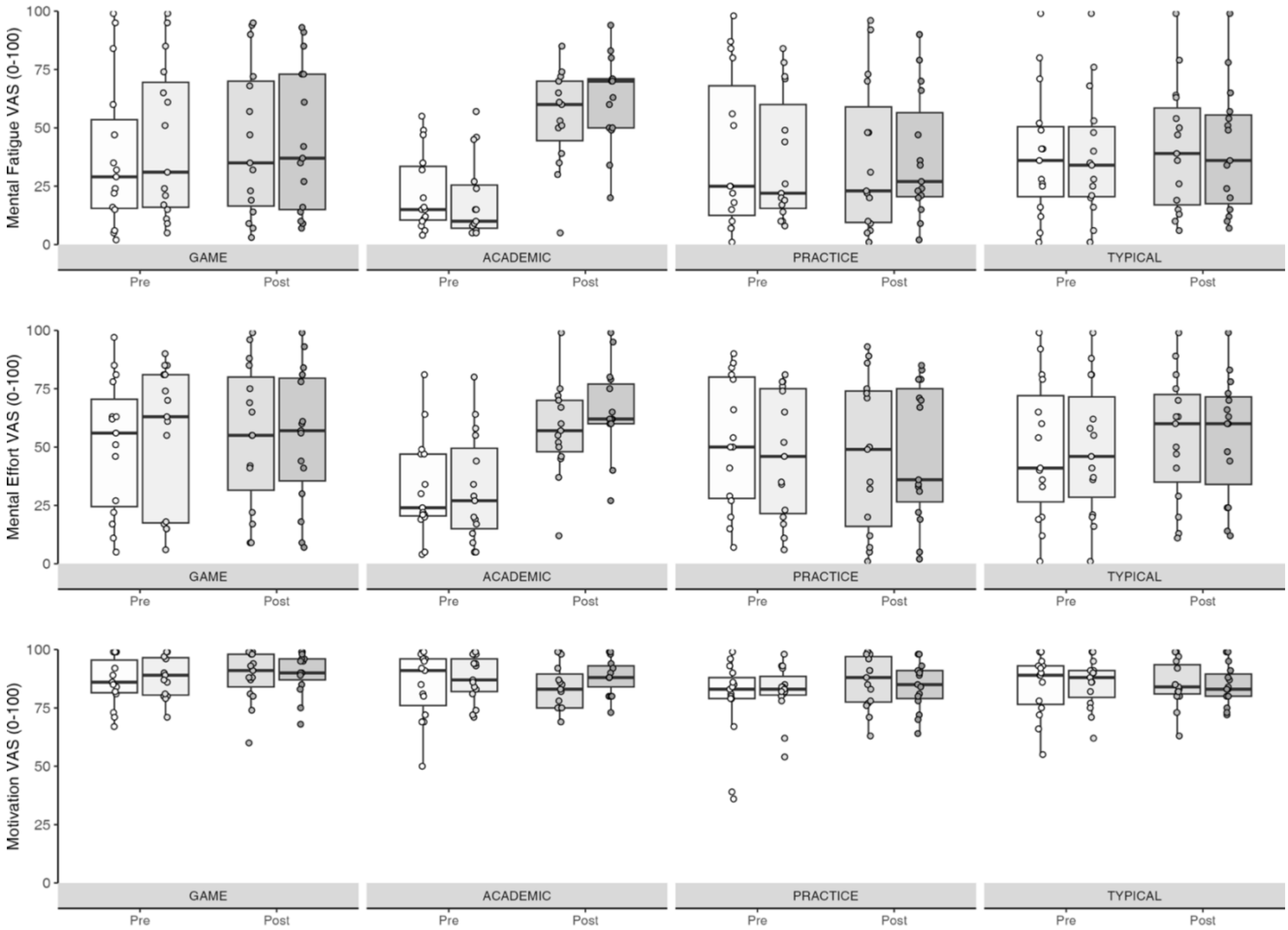

Figure 6-2: Pre- and Post- week Visual Analog Scale (VAS) for Mental Fatigue, Mental Effort and Motivation.

Boxplot lower and upper hinges correspond to the first and third quartiles and whiskers extend to the value closest to the hinge between; largest/smallest value, or no further than 1.5 * the interquartile range.

There was significant main effect across experimental weeks for both reaction time and accuracy in the PVT-B task ($p = 0.007$). There were no significant differences in Reaction time from Pre to Post for any of the experimental weeks, but reaction time was significantly higher in the TYPICAL week compared to the GAME week ($p = 0.012$, $d = 0.85$) (Figure 3). Accuracy during the PVT-B showed no significant differences between experimental weeks. However, Pre to Post values for accuracy decreased during the PRACTICE week only ($p = 0.024$, $d = 0.81$). The linear regression model for reaction time produced vales of $R = 0.27$, $p = 0.003$, while the linear regression model for accuracy demonstrated values of $R = -0.041$, $p = 0.66$ (Figure 3).

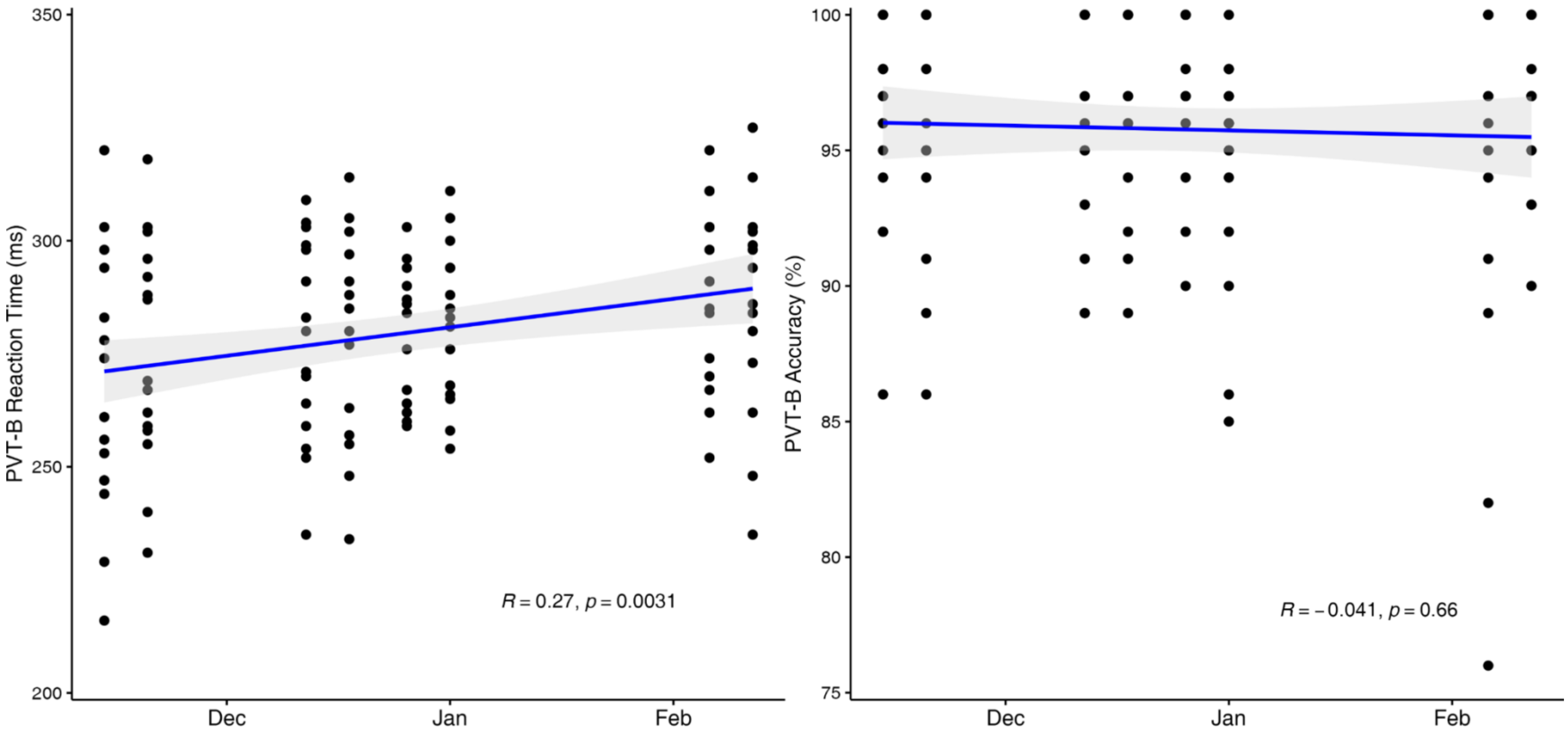

Figure 6-3: SOMA Reaction Time (ms) and Accuracy (%) during the season.

REST-Q results showed significant differences between experimental weeks (p = 0.004). The ACADEMIC week displayed higher levels of Social Stress (p = 0.001, *d* =.84), Fatigue (p = 0.021, *d* = 1.12), Disturbed Breaks (p = 0.024, *d* = .57), and Emotional Exhaustion (p = 0.035, *d* = .75) compared to GAME week. Also, the TYPICAL week showed a significant increase in Social Stress (p = 0.020, *d* = .72) compared to GAME week. No significant differences were observed for any other subcategory between experimental weeks (Table 2).

Table 6-2: Recovery stress questionnaire (REST-Q) scores measured at the end of each experimental week (Mean ± SD).

		GAME	ACADEMIC	PRACTICE	TYPICAL
Stress	General Stress	2.3 ± 2.2	3.2 ± 2.5	3.1 ± 2.4	3.5 ± 2.9
	Social Stress	2.8 ± 2.3*#	5.1 ± 3.2*	4.9 ± 3.5	4.6 ± 2.7#
	Fatigue	4.3 ± 2.9*	8.1 ± 3.8*	6.9 ± 3.9	5.9 ± 3.6
	Disturbed Breaks	2.6 ± 2.6*	4.3 ± 3.3*	2.8 ± 3.1	3.1 ± 2.7
	Emotional Exhaustion	1.7 ± 2.3*	3.5 ± 2.5*	3.0 ± 1.9	3.5 ± 2.3
	Injury	7.5 ± 4.7	9.7 ± 4.0	7.7 ± 3.8	7.9 ± 3.4
Recovery	Recovery	11.3 ± 2.6	9.6 ± 3.6	10.5 ± 2.9	11.6 ± 3.6
	Wellbeing	13.1 ± 3.1	12.8 ± 3.5	12.7 ± 3.2	13.0 ± 3.2
	Sleep Quality	9.7 ± 3.7	9.8 ± 3.4	11.7 ± 3.2	11.7 ± 3.4
	In-Shape	11.1 ± 2.5	11.2 ± 2.9	10.5 ± 3.3	12.6 ± 3.4
	Personal Accomplishment	10.8 ± 3.5	10.1 ± 3.1	8.9 ± 4.0	9.5 ± 2.8
	Self-Efficacy	11.3 ± 3.8	11.7 ± 3.4	11.1 ± 3.1	12.1 ± 3.4

GAME (high game volume), ACADEMIC (high academic load), PRACTICE (no academic load and no games), TYPICAL (standard number of games and academic requirements); *= significant differences from week GAME to ACADEMIC, p ≤ 0.05; #=significant differences from week GAME to TYPICAL, p ≤ 0.05.

Also, there was a significant difference between all experimental weeks for sRPE (GAME/ACADEMIC: p < 0.001, *d* = 2.87; GAME/PRACTICE: p < 0.001, *d* = 8.36; GAME/TYPICAL: p < 0.001, *d* = 1.51; ACADEMIC/PRACTICE: p < 0.001, *d* = 8.17; ACADEMIC/TYPICAL: p = 0.014, *d* =1.28; PRACTICE/TYPICAL p < 0.001, *d* = 7.63) (Table 3). For minutes spent on academic studies outside the classroom, significant differences were observed between GAME/ACADEMIC (p = 0.009, *d* = .87) and ACADEMIC/TYPICAL (p = 0.009, *d* =.86). Additionally, minutes of film each experimental weeks were as follows; GAME: 275min, ACADEMIC: 165min, PRACTICE: 295min, TYPICAL: 330 (Table 6-3).

Table 6-3: Session rating of perceived exertion (sRPE), Academic Load duration and Team Film duration during each of experimental weeks (Mean ± SD).

	GAME	**ACADEMIC**	**PRACTICE**	**TYPICAL**
sRPE Combined (AU)	$2456 \pm 469^{b,c,d}$	$3341 \pm 219^{a,c,d}$	$5820 \pm 369^{a,b,d}$	$3031 \pm 386^{a,b,c}$
sRPE Training (AU)	2014 ± 328	3341 ± 219	5820 ± 369	2737 ± 234
Duration	$341^{\#}$	$491^{\#}$	$819^{\#}$	$434^{\#}$
Intensity	*5.9 ± 2.4*	*6.8 ± 1.3*	*7.1 ± 2.0*	*6.3 ± 1.5*
sRPE Games (AU)	442 ± 282	0	0	294 ± 172
Duration	*110 ± 36*	*0*	*0*	*75 ± 26*
Intensity	*4.0 ± 1.1*	*0*	*0*	*3.9 ± 1.6*
Academic Load (min/week)	$194 \pm 215^{*}$	$499 \pm 449^{*}$	0	$198 \pm 209^{*}$
Team Film (min/week)	$275^{\#}$	$165^{\#}$	$295^{\#}$	$330^{\#}$

GAME (high game volume), ACADEMIC (high academic load), PRACTICE (no academic load and no games), TYPICAL (standard number of games and academic requirements); sRPE Combined: Session rating of perceived exertion for all activity, games + training (arbitrary units); sRPE Training: Session rating of perceived exertion for practice only (arbitrary units); sRPE Games: Session rating of perceived exertion for games only (arbitrary units); Academic Load: minutes of study on average per day outside of classroom; Film: total minutes of sport specific film for the week; *=significant difference between weeks, (ACADEMIC/ GAME ; ACADEMIC/ TYPICAL) p ≤ 0.05; ; ^{a}= significantly different to GAME, p ≤ 0.001; ^{b}= significantly different to ACADEMIC, p ≤ 0.001; ^{c}= significantly different to PRACTICE, p ≤ 0.001; ^{d}= significantly different to TYPICAL, p ≤ 0.001; $^{\#}$=duration the same for all participants for that week.

The results of the SST are shown in Table 4. Analysis of $MAKE_{4MIN}$ revealed a significant reduction in shooting performance scores from the beginning of the ACADEMIC week to the end of the week (p = 0.009, *d* = 0.35) and higher scores at the beginning of the TYPICAL week when compared to the end of the week (p = 0.008, *d* = 0.25) (Figure 4). A significant decrease in SST_{SPOTS} was observed from Pre to Post in the ACADEMIC week (p = 0.002, *d* = 0.43) and an increase SST_{SPOTS} was evident in the TYPICAL week ($p = 0.007$, $d = 0.25$). Additionally, a significant increase in $MISS_{4MIN}$ ($p = 0.004$, $d = 0.55$) was observed from Pre to Post during ACADEMIC week. During the GAME or PRACTICE weeks, there were no significant differences from Pre to Post in $MAKE_{4MIN}$ (GAME $p = 0.52$, $d = 0.09$; PRACTICE $p = 0.62$, $d = 0.03$) or $MISS_{4MIN}$ (GAME $p = 0.78$, $d = 0.06$; PRACTICE $p = 0.92$, $d = 0.01$). No significant difference was observed in $MAKE_{4MIN}$ when comparing Pre values across each of the experimental weeks ($p = 0.33$. Lastly, no significant differences were observed during any of the experimental weeks for $SST_{TOTALSHOTS}$ ($p = 0.123$).

Table 6-4: Differences in Shooting Performance across experimental weeks (Mean ± SD).

Variable	GAME		ACADEMIC		PRACTICE		TYPICAL	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
$MAKE_{4MIN}$	47.3 ± 10.5	46.4 ± 9.9	48.3 ± 11.0	44.3 ± 11.6*	48.6 ± 12.1	48.2 ± 11.2	45.3 ± 10.1	48.2 ± 12.1*
$MISS_{4MIN}$	29.1 ± 7.5	28.7 ± 6.7	26.3 ± 7.4	30.7 ± 8.5*	26.6 ± 8.9	26.5 ± 7.7	27.9 ± 6.3	26.7 ± 7.3
$SST_{TOTALSHOTS}$	76.4 ± 6.6	75.1 ± 6.5	74.5 ± 6.2	74.9 ± 6.3	75.2 ± 6.2	74.7 ± 6.5	72.9 ± 7.1	74.87 ± 7.9
SST_{SPOTS}	17.1 ± 6.3	18.0 ± 5.6	19.6 ± 6.5	16.8 ± 6.8*	19.7 ± 6.9	19.1 ± 6.6	17.6 ± 5.9	19.2 ± 6.5*

GAME (high game volume), ACADEMIC (high academic load), PRACTICE (no academic load and no games), TYPICAL (standard number of games and academic requirements), $MAKE_{4MIN}$ (sum of the makes during 4 min shooting); $MISS_{4MIN}$ (sum of the misses during 4 min shooting); $SST_{TOTALSHOTS}$ (sum of the total shots 4 min shooting); SST_{SPOTS} (sum of the spots completed during 4 min shooting); *=significant difference from Pre week, $p \leq 0.05$.

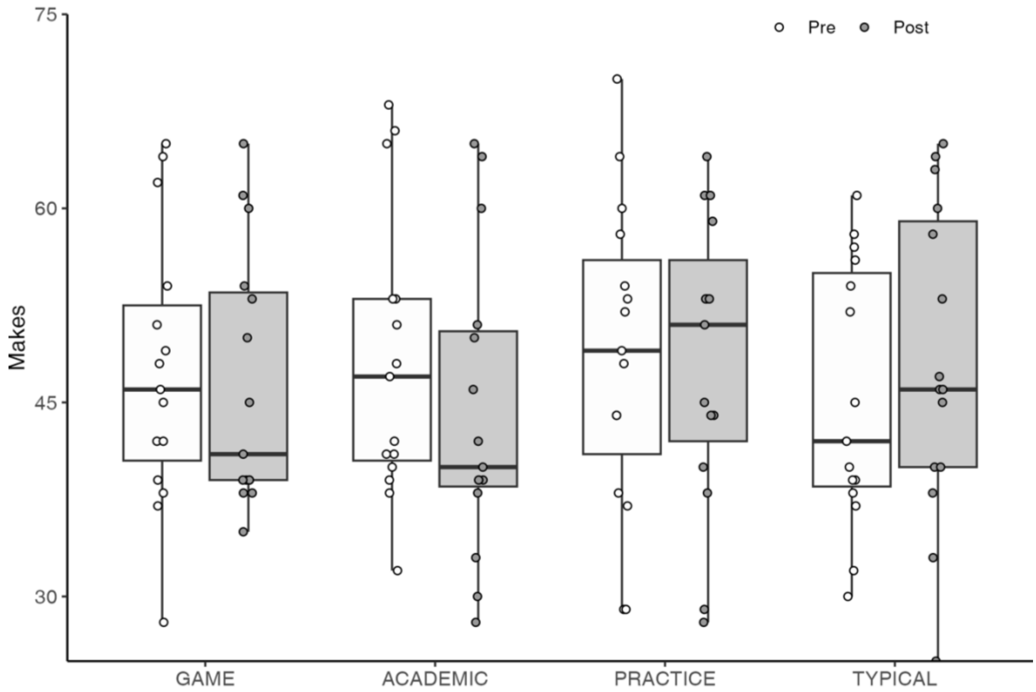

Figure 6-4: Pre- and post- week Standardized Shooting Task outcome for number of made shots (SST MAKE4MIN).

Boxplot lower and upper hinges correspond to the first and third quartiles and whiskers extend to the value closest to the hinge between; largest/smallest value, or no further than 1.5 * the interquartile range.

6.5. Discussion

The primary finding of this study was that elite college basketball players exhibit impaired shooting performance and increased mental fatigue at the end of a week with high academic demands. Conversely, decrements in shooting performance were not observed following weeks with increased games (GAME, TYPICAL) or increased training load (PRACTICE). Additionally, although subjective ratings of mental fatigue and effort were increased at the end of the ACADEMIC week, these elevated ratings of fatigue and effort were not present at any other time measured throughout the season. Furthermore, results of the objective measure of cognitive performance, displayed slower reaction times over the course of the season. These results show that elite collegiate basketball players exhibit impaired shooting performance and increased levels of mental fatigue at specific timepoints and offers preliminary evidence that cognitive performance declines throughout the season.

One unique aspect of this study was both subjective (VAS) and objective (PVT-B) measures of mental fatigue were examined. While subjective ratings of mental fatigue and effort increased from in the beginning to the end of the ACADEMIC week, this is the only experimental week where this type of change was observed. By design, the ACADEMIC week displayed the highest level of academic demands when compared to all other experimental weeks. The source of higher academic load during this week was likely outside the classroom, as official class time did not change, but student-athletes were preparing for final academic examinations. While previous investigations have shown increased stress for student-athletes from academics when compared to non-student-athletes (Dill & Henley, 1998), to our knowledge this is the first investigation to demonstrate an increase in mental fatigue following periods of high academic load in collegiate basketball student-athletes. In addition to these changes from the start to the end of the academic week, participants also reported acute changes in mental fatigue at the end of the ACADEMIC week following the cognitively challenging PVT-B. Throughout the study, VAS scores mostly remained stable when measured Pre to Post PVT-B. However, at the end of the ACADEMIC week, ratings of both mental fatigue and metal effort increased following the 3-minute PVT-B, suggesting that the increases in academic stress throughout the week lead to reduced resiliency for that short task.

Notably, the PVT-B task results did not show any changes in cognitive performance following any of the experimental weeks. However, there was a temporal trend showing an increase in reaction time over the course of the season (see Figure 4). Despite these novel findings, some studies have demonstrated that PVT-B performance returns to baseline levels following one night of recovery(Yamazaki et al., 2021). However, to our knowledge no studies have investigated cognitive response times in basketball athletes over the course of a season. Therefore, it is speculated that the longer response times observed toward the end of the season may be due to accumulated fatigue throughout the year, warranting further investigation.

Accuracy during the PVT-B showed no differences between weeks, but there were pre-post weeks decreases in accuracy during the PRACTICE week. Notably, sRPE training loads were also highest during the PRACTICE week as increased training was completed in the absences of requirements of academic commitments or games. The decrease in PVT-B accuracy could be attributed to increased physical demands, as previous studies in team sports have found that prolonged exercise causes a decline in the decision-making and attention (Skala & Zemková, 2022). However, this intensification in physical load had no impact on levels of mental fatigue or basketball shooting performance.

Altered motivation is a central component of mental fatigue (van der Linden et al., 2003b). Others have reported that motivation can be suppressed following a mentally fatiguing task, suggesting that decreased levels of motivation may be an indicator of mental fatigue (Boksem & Tops, 2008b; van der Linden et al., 2003b). Furthermore, increases in motivation have been shown to reverse declines in cognitive performance (Hopstaken et al., 2015). Previous investigations have used varying protocols to manipulate motivation including monetary incentives (Boksem et al., 2006a) and reduced duration of task requirements (Hopstaken et al., 2015). In the present study, we observed very high levels of motivation (see Figure 3) similar to our previous work in comparable basketball populations prior to shooting tasks (Daub et al., 2022b), and no difference in the student-athletes motivation across the season. This likely reflects of the collegiate student-athlete high intrinsic drive and competitive nature, especially in a sport specific shooting task (Brehm & Self, 1989).

Player Stress levels were increased during the ACADEMIC week, with elevated Social Stress, Fatigue, Disturbed Breaks, and Emotional Exhaustion. Indeed, similar increases in stress during examination periods in student-athletes are well documented (Dill & Henley, 1998; Hamlin et al., 2019) and in some cases has also been shown to increase prevalence of injury (Mann et al., 2016a). During the ACADEMIC week, this increase in Stress coupled with no change in recovery, indicating a poorer recovery-stress balance, while a simultaneous increase in subjective ratings of mental fatigue was evident. Interestingly, during the TYPICAL week athletes also reported an increase in Social Stress which took place during the most critical portion of the regular season, conference play. Although, no change in mental fatigue was observed, the elevated social stress may be due to increased pressure to perform at a critical point in the season.

When interpreting the novel findings reported in this work, several limitations should also be considered. Firstly, the basketball and academic workloads for each week were not controlled experimentally and are therefore not perfectly matched. While our approach of selecting ‘experimental weeks’ throughout the season enhances ecological validity, the differences in physical demands could impact the outcome of the shooting performance. Furthermore, because experimental weeks were selected based upon the predicted academic requirements and frequency of games, an order effect across the season could be present. Although this limitation could not be avoided, the authors attempted to limit the impact by taking Pre-Post measures each week. Finally, despite the increases in subjects' mental fatigue and effort along with changes in objective cognitive performance, the specific underpinning mechanism of these responses in the current investigation are unknown. This could be important for collegiate athletes as mental fatigue may accumulate from various stimuli, including academic requirements, social commitments, media obligations and team duties. Therefore, future research should explore specific underlying mechanisms and contributors of mental fatigue in elite college basketball players throughout the season. Moreover, future research should consider the impact of the cumulative effects of mental fatigue on performance.

6.6. Practical Applications

The current results show increased mental fatigue during periods of high academic load, which was accompanied by negative impacts on basketball shooting performance in student-athletes. Our findings suggest that high academic loads during the season leads to an increase in subjective ratings of mental fatigue and effort, which appear to be detrimental to shooting performance in the SST. Additionally, this study provides evidence that an increase in sport-specific training or games may have little to no effect on subsequent standardised basketball shooting test performance. These have significant implications for applied basketball performance in the collegiate setting, which requires student-athletes to perform both in the classroom and on the court. As such, practitioners, basketball coaches and student-athletes should use caution when academic demands are high prior to competition as these periods may be associated with increases in mental fatigue and impaired basketball shooting performance. Specifically, special consideration should be given around exam periods, when increased time commitments are required for academics. Additionally, monitoring mental fatigue or examining skill performance may help understand the impacts of training and studying on the student basketball athletes. Furthermore, coaches may periodise sport specific skill development during highly demanding academic periods and limit student-athlete exposure to potential mental fatiguing tasks, such as sport specific film sessions (Daub, McLean, Heishman, Peak, et al., 2022).

Furthermore, current mental fatigue research emphasizes short-term recovery interventions, such as listening to relaxing music (Englert & Bertrams, 2016), mindfulness practices

(Shaabani et al., 2020), self-talk (Galanis et al., 2022), and exposure to natural visual stimuli (Sun et al., 2022). For example, Galanis et al. investigated self-talk as a technique to enhance athletes' attention during tasks, suggesting its potential for use during competitions (Galanis et al., 2022). However, the more complex and persistent stressors present in real-game scenarios pose challenges to the generalization of such strategies. While these methods have been shown to reduce mental fatigue and enhance performance, their long-term impacts are not well understood. Given the extended season in sport, future studies should investigate the sustained effectiveness of these strategies. Additionally, researchers should address the challenges athletes may encounter when adapting to prolonged recovery interventions and their implications for maintaining consistent performance across a season.

Beyond traditional cognitive approaches, there is potential to explore alternative and complementary therapies for mental fatigue recovery. Aromatherapy, which involves the therapeutic use of essential oils derived from plants, has shown promise in delivering psychological and physiological benefits, including stress reduction, mood improvement, and cognitive enhancement (Gonçalves et al., 2024). Specific essential oils, such as lavender, rosemary, and peppermint, have been identified for their ability to reduce mental fatigue and improve alertness and concentration (Koulivand et al., 2013; Sattayakhom et al., 2023; Varney & Buckle, 2013). Incorporating aromatherapy may offer an accessible, non-invasive approach to reducing mental fatigue. Future research should evaluate the combined effectiveness of cognitive interventions and aromatherapy to establish a holistic strategy for mitigating metal fatigue, particularly in high-stress environments such as sports.

CHAPTER 7
STUDY 4:
ACADEMIC AND ATHLETIC PRESSURES: DIVISION I BASKETBALL PLAYERS PERSPECTIVES OF MENTAL FATIGUE

Related manuscript: Daub, B., McLean, B., Heishman, A., Peak, K., Stadnyk, A., Coutts, A. Division I Collegiate Basketball Players Perspective of mental fatigue. *Prepared for Submission (2023).*

7.1. Prelude

The results of Study 3 demonstrated that high academic demands were associated with increases in mental fatigue and decrements to basketball shooting performance. Interestingly however, increases in sport-specific training load or game play load did not seem to effect shooting performance or the presence of mental fatigue. These findings have allowed coaching staff members from the group being investigated to make decisions and altering game and training schedules around final exams. This study also demonstrates that practical utility of using the SST throughout the year as a monitoring task for mental fatigue. Additionally, due to the potential importance of these findings, the research team decided to shift the focus on the research in Study 4 so that they could better identify sources of mental fatigue in high level collegiate basketball players. This investigation was designed allow for better understanding of the student-athletes perspective on academics and athletics and how the two relate in this unique population.

7.2. Introduction

Prolonged engagement in cognitively demanding tasks can result in a psychobiological state known as mental fatigue, which encompasses behavioural, perceptual, and physiological manifestations (Cook et al., 2007b; Marcora et al., 2009b). Behavioural indicators of mental fatigue can manifest as a decline in accuracy or reaction time responses in a cognitive task, or a delay in analytical processing (van der Linden et al., 2003b). Perceptual changes, often characterised by feelings of tiredness and lack of energy (Van Cutsem et al., 2017a), represent another dimension of mental fatigue. Physiological indicators range from biochemical markers, such as salivary cortisol (Klaassen et al., 2013), to measures of brain activity such as electroencephalography (EEG)(Craig et al., 2012). Manifestations of mental fatigue also typically vary depending on the task (M. R. Smith et al., 2019), making it difficult to generalise findings across fields.

The concept of stress plays a central role in the development of mental fatigue, with stressors contributing to both its onset and intensity. According to the transactional model of stress, stress results from an individual's perception of an imbalance between environmental demands and personal resources(Lazarus, 1984). When individuals face stressors, whether physical, emotional, or cognitive, these demands can tax cognitive resources, leading to mental fatigue. Mental fatigue, therefore, can be considered a response to the cumulative effects of stress, particularly when stressors persist over time and challenge an individual's ability to adapt. This response may manifest in various forms, including reduced cognitive function, emotional depletion, and diminished physical performance (Hockey, 2013).

Training and participation in sport can create a myriad of physiological, psychological, and social stressors. As such, an understanding of the relationship between the different types of stressors and fatigue in regard to performance optimisation is required. In elite sport, many coaches implement some form of fatigue monitoring for athletes (Halson, 2014), predominantly focusing on physical or perceptual aspects. Recent studies have shown that mental fatigue can adversely affect athletes' physical and sport performance (Daub et al., 2023; Filipas et al., 2021b; L. S. Fortes, Fonseca, et al., 2021b). Despite these findings, this phenomenon remains under-explored, necessitating further investigation and evaluation. Investigating the presence of mental fatigue and its manifestations (i.e., behaviourally, physiologically, or perceptually) could provide valuable insight for athletes and practitioners alike. Specifically, the information garnered would allow sport professionals to explore the effects of a variety of mental stressors that may influence the athlete and team. This information could help drive decisions on periodization and training over the course of a competitive season.

Since high performing athletes encounter numerous stressors within their sport, it is important for practitioners to also acknowledge stress stemming from demands beyond their sporting activities. This is particularly relevant in the USA for athletes enrolled in universities or colleges, commonly known as "student-athletes." These individuals must manage full-time academic workloads alongside their sporting commitments, navigating the dual demands of academia and athletics.

Indeed, to be able to participate in the National Collegiate Athletic Association (NCAA) competitions, student-athletes must be enrolled as full-time students and meet specific academic requirements. These requirements include maintaining a minimum grade point average (e.g., must achieve 90 percent of the institution's minimum overall grade-point average necessary to graduate (for example, 1.8) by the start of year two, 95 percent of the minimum GPA (1.9) by year three and 100 percent (2.0) by year four)) and continuous enrolment, while also making adequate progress towards earning their degree (40% of required coursework for a degree must be complete by the end of the second year, 60% by the end of the third year and 80% by the end of their fourth year)(*Play Division I Sports*, n.d.). If an athlete fails to meet these requirements, they risk becoming ineligible to compete in their sport, and may also face potential loss of their athletic scholarship.

The complex demands confronting student-athletes, spanning both academic and athletic pursuits, have begun to be explored in recent research (Dill & Henley, 1998; Pritchard et al., 2007a). NCAA Division I student-athletes have been found to dedicate substantial amounts of time to both academics and athletics, investing up to 38.5 hours per week to their studies and 34 hours per week to their sports (NCAA GOALS). Due to these demanding schedules, previous research has indicated that student-athletes experience higher levels of academic stress compared to their non-athlete peers (Humphrey et al., 2000a; Pritchard et al., 2007a). Additionally, academic stress has been linked to athletic outcomes, with heavier academic loads being associated with nearly twice as high injury rates among collegiate football players throughout the season (Mann et al., 2016a). The interplay of academic demands, rigorous training schedules, and performance pressures likely imposes considerable mental and physical strain on student-athletes, potentially impacting their performance across both academic and athletic domains. Although the nuances of these relationships are yet to be fully examined, exploring several key areas could enhance understanding of this distinct population. This includes capturing the perspectives of various stakeholders on the academic stress and physical demands of the sport. Therefore, the aim of this study was to explore the perceptions of elite student-athletes regarding their academic and athletic experiences, with the goal of better understanding the potential presence and manifestations of mental fatigue.

7.3. Methods

7.3.1. Participant Recruitment

Purposive sampling was used to recruit elite male student-athletes with at least year's experience (i.e., Sophomore-year and higher) within elite collegiate basketball. Athletes were screened for eligibility based on current academic enrolment and scholarship status at a Division I University. First-year (Rookie) athletes were excluded due to their limited academic and athletic experience at collegiate level. Invitations to participate were delivered to participants in person, with the Participant Information Sheet providing the research aims and an overview of the interview questions. Based on prior interview research in elite sport (Braun & Clarke, 2021b) and the relatively homogenous sample of the present study, it was estimated that a sample size of approximately 10 participants would be sufficient to achieve data saturation. This study was granted ethics approval (ETH23-8107) by the University of Technology Sydney Human Research Ethics Committee and complied with the Declaration of Helsinki. No incentives were offered for participation.

7.3.2. Data Collection

An interview guide consisting of open-ended questions was developed to address relevant topics related to the research question and objectives. The interview guide was developed by members of the research team with input from expert performance coaches and reviewed by an experienced qualitative researcher. The guide was then pilot tested for validity and timing on two former Division I basketball players (both having participated in the collegiate setting within the last 5 years), with revisions made to improve relevance. The topics included were student-athlete experience, sources of fatigue for student-athletes, and role of academics for student-athletes. The interview questions are presented in Table 1. Recruitment and data collection occurred in summer (June), during the basketball offseason and between academic semesters.

The semi-structured interviews were conducted by a single researcher though in person interviews, to allow for a standardised approach when addressing the topics. The interviewer, whilst a novice qualitive researcher, was a PhD candidate with a research and sports science background as well as having extensive experience as a sports performance coach in the collegiate setting.

The researcher was permitted to employ follow-up questions to explore the participants responses for greater understanding and detail. Each discussion was recorded via video call at a convenient time selected by the participant. The expected duration of the interview was approximately 30 minutes; however, no limits were placed on duration other than participant availability.

Table 7-1: Interview guide with primary and follow up questions.

1) Tell me about yourself and your current role as a student-athlete?
2) What do you enjoy most about being a student-athlete?
   a) What comes to mind when I say “student-athlete”?

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3) As a student-athlete what are the biggest sources of stress ***within the sport***; mentally?
   a) What are the biggest sources of stress ***within the sport*** Physically?
   b) What are the biggest sources of stress ***within the sport*** Emotionally?
4) As a student-athlete what are the biggest sources of stress ***outside of the sport***; mentally?
   a) What are the biggest sources of stress ***outside of the sport*** Physically?
   b) What are the biggest sources of stress ***outside of the sport*** Emotionally?
5) As a student-athlete if you were to experience feelings mental fatigue, when would that be most prevalent?

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6) From your perspective, what is the role of academics as a part of being a student-athlete?
7) When are the most stressful times academically throughout the year?

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8) How might the stressors you face impact your sport performance?
9) As you think ahead what do you need to do to optimize your success both academically and athletically?
10) From your perspective what is the most important part of our discussion today?

7.3.3. Data Analysis

For each interview an audio recording was logged and then transcribed verbatim using PARROT AI (Artificial Intelligence) (Concord, MA, United States). Any identifying information (e.g., names) was redacted from the transcripts to deidentify the data. Once transcribed the interviews were then synchronously read with the audio recordings to ensure correct language was documented. Transcribed manuscripts were checked for approval and participants were offered the opportunity to confirm meaning, any contradicting information was redacted. This process also allowed the interviewer to become familiar with the data sets for further analysis and coding (Braun & Clarke, 2012).

We conducted Thematic Analysis (TA) of the data, following the method developed by Braun and Clarke (Bhaskar & Hartwig, 2016; Braun & Clarke, 2021a), to identify recurring patterns in the participants' experiences and perspectives. The analysis was based on a critical realist standpoint, which recognises a realist view of the world (it exists as it is) and a relativist understanding (our knowledge depends on how we observe and measure)(Wiltshire, 2018a). Furthermore, it is acknowledged that what is observed or experienced is influenced by both observable and unobservable events, guided by underlying causal structures and mechanisms (Bhaskar & Hartwig, 2016; Gorski, 2013). Additionally, our capacity to measure reality evolves over time and is constrained by our methods and language (Wiltshire, 2018b). In our analysis, we aimed to understand the explanations behind the events described by the student-athletes, using a inductive analysis (e.g., identifying concepts, categories and themes)(Azungah, 2018). This perspective takes into consideration the sociocultural factors that impact the participants' experiences and interpretations of events (Ussher, 1999). Previous studies have shown that critical realism is compatible with TA (Wiltshire & Ronkainen, 2021). Coding and analysis were carried out using MAXQDA (VERBI GmbH, Berlin, Germany). Two members of the research team conducted the coding and analysis for the entire transcription, both transcriptions were then compared to confirm interpretation. Researchers then combined the findings to reveal parallels in the student-athletes' perspectives and experiences. Codes were generated through an inductive process and refined during multiple readings of the data. Once coding was completed, individual codes were grouped into subthemes based on their similar meanings and then further organised into predominant themes. To ensure a comprehensive evaluation of the themes' relevance within the overall structure, directory containing themes, subjects, and quoted segments was maintained (Azungah, 2018).

7.4. Results

Six collegiate athletes (age: 20.2 ± 1.2 years) participated in the study. All participants were active members of the same Division I NCAA basketball team with at least 2 years of experience at the Division I level. All participants had previously participated in 4 years of high-school basketball as well as Amateur Athletic Union (AAU) basketball prior to attending college. Although, it was estimated that 10 participants would allow for data saturation, in the applied setting the sample population fitting the outline criteria is often limited. Furthermore, some recent research has questioned the imprecise use and unchallenged acceptance of data saturation for qualitative inquiry (Braun & Clarke, 2021c). Additionally, it has been suggested that "researchers should then make an in-situ decision about the final sample size, shaped by the adequacy (richness, complexity) of the data for addressing the research question (but with a pragmatic 'nod' to sample size acceptability)" (Braun & Clarke, 2021c). Therefore, recognising that sample size alone is not the only factor, value would still be garnered from the data collected.

Three distinct yet interconnected themes emerged from the interview data, each with relevant subtopics:

Pressure on and off the court: This theme addresses the dual demand for excellence in both academic and athletic realms that is necessary for maintaining one's status on the team.

Execute under pressure: This highlights specific times and events throughout the year that intensify the focus on academics, underscoring the periods when academic pressure peaks.

A good game plan: emphasises the critical importance of an individual's ability to effectively manage the distinct yet interconnected stressors inherent to the student-athlete experience.

Together, these themes elucidate the complex interplay between the pressures faced by student-athletes and their strategies for navigating these challenges.

7.4.1. Pressure On and Off the Court

Collegiate athletes must juggle two primary roles, that of a university student and an athlete. The academic aspect component already presents a considerable stress of most college students, a pressure that is likely compounded for athletes who must excel in both arenas.

> *"You gotta perform like every day and make sure you stay on top of that… both on the court and in the classroom. There is a lot of pressure from the outside and within the team." (Athlete 4)*

Throughout the interviews, the student-athletes described a pressure to perform both academically and athletically. Student-athletes believed that they need to "perform well" and often stress about "maintaining good grades" and "playing well" in order to satisfy themselves and those around them.

> *"You gotta do the homework, make sure your grades are good, if you want to play on the court... you just have to stay on top of the classroom." (Athlete 2)*

Moreover, collegiate student-athletes often prioritize sports development over academic pursuits. This prioritization could lead to student-athletes focusing on athletic commitments, potentially neglecting academic responsibilities. This dynamic likely results in increased pressure and stress as scholarships require athletes to maintain both academic and athletic excellence. This tension is highlighted in some of the responses of some of the student-athletes who perceive academics more as a mandatory obligation than primary focus, with basketball or their sport taking precedence.

> *"So, if I wanna keep on playing basketball, I gotta go to school. I gotta do well in school. So, it's like it's pretty much 50/50." (Athlete 3)*

These reflections highlight the presence of increased stress associated with the duality of their role as a student-athlete, recognising the need for balance and understanding the differences between the two roles.

7.4.2. Execute Under Pressure

Student-athletes emphasised that academic pressure fluctuated throughout the year and sports season, with peaks in academic demands occurring during midterm and final exams periods. These times are characterised by increased "time demands" and "significance" leading to increased stress.

> *"The most stressful times academically throughout the year for me are finals weeks" (Athlete 5)*

These stressful times around exams create added pressure, as the assessments typically cover a significant portion of the course material and carry considerable weight in determining final grades. The challenge of reviewing large volumes of information, coupled with pressure to perform well, leads to heightened stress levels.

> *"Obviously finals, it brings some stress and need to study… I know with me, I put pressure on myself to try and get the best grades I can." (Athlete 1)*

Student-athletes expressed that the periods around exams heightened the academic demands and emphasised the importance of academic success. Additionally, the timing of mid-term and final exams coincides with increased pressures during the basketball season, amplifying the stress experienced. For example, the finals exam week typically falls at the start of the conference season (playing regional teams within the same conference), while midterm exams occur during the postseason championship tournaments. The convergence of stressors from both academic and athletic realms are reflected in the student-athletes' subjective feelings that "success across academics and athletics" canters around crucial intervals, that can dramatically alter grades in a limited time.

> *"In order for me to get to where I want to get to, I mean, you gotta go to class, you gotta get good grades, and a big part of that is exams" (Athlete 6)*

In addition to periods of increased academic demand, the participants also identified times throughout the year when they felt mentally fatigued. While these times were not solely centred around exams, student-athletes were mindful of the fluctuations throughout the year.

> *"I would say during the season because you know, obviously you're ..... it's during the school year. So you have games, you have practice and then you have to on top of that do your*

homework, you have test, quizzes, exams and stuff like that. It is tough sometimes." (Athlete 2)

Furthermore, the student-athletes also felt mental fatigue was often associated with monotonous or recurring schedules. During those times the required activities created feelings of frustration and dissatisfaction, leading to lowered production and feelings of accomplishment.

"I feel like every year around January and February is when I start getting bogged down. It just seems really repetitive and that's when I struggle mentally probably the most." (Athlete 3)

Student-athletes encounter many stressors as they try to succeed in their sports and academic endeavours. The athletes reported increases in academic stress and mental fatigue occurred throughout the year at different times, suggesting these are independent of each other. Although academic stress and mental fatigue appear to be independent given that academic stress peaks around exam periods, mental fatigue is reported when activities are "repetitive and boring". However, both may appear at specific times during the year, especially around times of peak academic activity such as final exams. As such, particular care should be taken during these times as it may have a detrimental effect on their ability to perform athletically and academically.

7.4.3. A Good Game Plan

Student-athletes emphasised the critical importance of managing stress effectively. They identified a pressing need to cultivate "coping skills" to navigate periods of increased stress, highlighting the perceived need for greater attention and consideration to the mental components of performance both in the classroom and on the court.

"I'd say I have a good game plan, like create a game plan, a strategy of how I'm gonna make sure I'm still getting better on

> *my own, still doing what I supposed to do in practice and then and in games and also like in the classroom as well." (Athlete 4)*

The student-athletes are very conscious of the need to handle multiple concurrent and demanding commitments and, as Athlete 4 above sums up their reflection, they all agree that *"time management is critical"*. According to the student-athletes, maintaining a structured schedule is vital for effective time management as it brings organization and clarity to their daily routines. By allocating specific time to complete different tasks, student-athletes felt reassured that essential tasks were completed in a timely manner. This approach fostered a sense of efficiency, helping to avoid procrastination or time-wasting. They also believed it boosted their productivity by enabling them to tackle important tasks when they feel most alert and focused. These schedules were developed in collaboration with academic advisers and coaching staff; however, fluctuating circumstances and last-minute changes frequently heightened stress levels and left the students feeling "uneasy" and "anxious" about completing their tasks completed.

> *"Just have to have a good schedule. I'm a very scheduled person. When school starts like the first two weeks, the way I do it is probably the way I'm gonna do it the rest of the year. So having structure from the start is important." (Athlete 1)*

Additionally, it was noted that developing strategies to mentally compartmentalize study and athletics can optimise success in both areas, while also recognising that maintaining a strong academic performance can carry over into athletic performance.

> *"Compartmentalizing school, when I'm in the classroom, I'm in the classroom, I'm not worrying about the stuff on the court. But when I'm on the court, I'm worrying about the stuff on the court and not in the classroom. It takes a lot of effort keeping them separate, but that helps me manage both." (Athlete 6)*

The student-athletes recognise that academics and athletics go "hand in hand," noting that excelling in academic studied can positively impact performance on the court. However, many student-athletes believe that compartmentalizing academic studies and athletics would optimise success in both areas. Stress in one area of life can often spill over or "creep into" other areas, affecting various aspects of the student-athletes performance and well-being. This stress “spill-over” predominantly occurred when stress experienced in one domain, such as academics, affected performance in another, namely athletics. During times of stress, student-athletes often had difficulty concentrating, making decisions, or problem-solving effectively. This impairment can extend beyond the specific stressor, affecting performance and productivity in other tasks or responsibilities, specifically athletics.

7.5. Discussion

For the first time, this study has explored elite basketball student-athletes’ perspective in relation to sport and academics. The findings revealed a range of factors that influence the overall student-athlete experience. These were: *Pressure on and off the court* (the need to excel in both academic and athletic domains simultaneously), *Execute under pressure* (emphasising specific occasions and moments during the year with heightened academic pressure), and *A good game plan* (the significance of and individuals’ capacity to handle stress factors inherent to the student-athlete). Critically, each theme highlighted the perpetuation of stressors both from within and outside the high-performance environment of elite student-athletes. As such, the findings provide valuable insight for practitioners, coaches, and athletes to better understand the stressors and mental fatigue experienced by student-athletes, in order to address potential areas of concern in the pursuit of optimising performance.

The student-athletes emphasised feeling pressure to perform both in their academic studies and athletic pursuits. They often felt this was a source of stress and reported that their performance in both academics and athletics were equally important. This concept was often reinforced by family and friends and also from coaches and other staff members in their support teams. Previous studies that have interviewed student athletes have confirmed both the importance and influence of family members and coaches when establishing their priorities and focus. Notably however, it was reported that many placed a greater “emphasis on athletic success” over academic success (Woodruff & Schallert, 2008). Still others reported that outside support stressed “best of both” emphasising the need for student athletes to succeed in athletics and academic studies (Woodruff & Schallert, 2008). The tension of these competing priorities can further exacerbate the stress experienced by student athletes as they are pushed to invest in different areas.

Notably others have reported that student athletes express increased stress from relationships when compared to non-student athletes (Wilson & Pritchard, 2005). While all students must successfully navigate these competing social and academic demands, student-athletes have additional stress from athletic responsibilities. One of those additional athletic stressors was maintaining eligibility requirements (i.e., grade point average and progress toward degree), which was highlighted as being a primary source of stress as failure to meets these requirements can lead to dismissal from the team and loss of financial support. The student-athletes expressed concern about the constant pressure to eligibility requirements within their sport, and that academic requirements were the largest source of stress outside of basketball. Failure to meet eligibility requirements carries significant financial ramification for athletes. Players must maintain eligibility to continue to receive scholarship stipends for living expenses during college, but it may also impact the potential for employment from professional teams in the future. The increases in perceived stress from academic and athletic performance expectations coupled with outside influences from family and friends, create a challenging environment for the student-athletes.

The most challenging academic periods, as expressed by the student-athletes, come during the midterm and final exams. Certainly, previous literature has outlined physical ramifications during exam periods with increased injury rates among university football athletes, showing that higher academic demands coupled with sport participation led to twice as many injuries when compared to non-exam periods (Mann et al., 2016b). For basketball athletes particularly, these stressful periods commonly occurred at specific times (i.e., exam periods and major competitions) during the 5-month competitive season. These stressful timepoints were confirmed by other student-athletes who have communicated experiencing stress during “Big Moments” one of which was conference games and post season tournaments (Madrigal & Robbins, 2020). This combination of increased academic stress during exams and increased sport stress overlapping during conference play, presents reason for concern.

Players reported that these time points around exams are often accompanied with feelings of increased mental fatigue. Increased mental fatigue was also suggested to occur later in the year when the monotony of the schedule from both academics and athletics becomes high. One possible rationale for this, as suggested by Anderson and Butzin (Anderson & Butzin, 1974), is that fatigue resulting from training and competition may alter the athlete’s motivation to engage in challenging academic endeavours. Indeed, motivation has previously been suggested as a central component and indicator of mental fatigue (Boksem et al., 2006b), however, the athletes interviewed in the present investigation did not report physical fatigue as a constraint, only academic stress. Nevertheless, the potential for altered motivation should still be considered as it has previously been associated with changes in psychological stress in university students (Murad, 2021). As such, it is important for the coaches and performance staff members to be familiar with, and responsive to, the changes in academic demands during the season. Strategies such as subjective questionnaires or vigilance tests could be implemented to monitor fluctuations in the student-athletes mental load from academics or motivation throughout the year.

In addition to monitoring strategies, the need for developing tactics to cope with stressors of academics and athletics was also valued by the student-athletes. To achieve this, the athletes suggest the desire to implement a set schedule to manage academic and athletic responsibilities effectively, rather than last-minute obligations or agenda changes. This concept of consistent schedules contrasts with the negative feelings associated with monotony throughout the season, but that was not the case. The athletes welcomed a schedule, "knowing what the day/week holds" so that they were organised. However, the specifics of the practice sessions and academic demands seemed repetitive as the year progressed, leading to feeling of mental fatigue. These findings support previous research uncovering similar problems with time availability and management in youth soccer populations (Christensen & Sørensen, 2009). Creating times specifically, centred around academics and athletics separately may assist in proper time management and coping techniques. Moreover, it is important for coaching staff to understand that although academics and athletics are interrelated, developing strategies to compartmentalize them may allow for better "balance". Likewise, the student-athletes should be encouraged to utilise resources on campus (i.e., tutors, academic advisors) to maintain a strong academic performance, which has been observed in other student populations (Malik, n.d.; Reinheimer & McKenzie, 2011) and could potentially improve academic performance and reduce overall stress in student-athletes. Another supportive approach coaches can take is establishing an "open-door policy", encouraging team members to feel comfortable seeking assistance from the staff in coping with stress-related challenges. Practitioners may also consider introducing student-athletes to fundamental lifestyle concepts, such as mindfulness training, practicing deep breathing techniques, engaging in positive self-talk, and cultivating healthy sleep habits (such as limiting screen time before bed and aiming for 8 hours of sleep nightly)(Radcliffe et al., n.d.). Ultimately, coaches can play a pivotal role in facilitating management strategies for student-athletes, guiding them in managing both mental and physical stressors, crucial for optimal performance.

7.6. Conclusion

This study offers valuable insight into perspectives and experiences of elite collegiate basketball athletes. It classifies unique characteristics of top-level athletes as it relates to their experiences both academically and athletically. Special consideration should be given around periods of heightened academic demands and to developing skills to aid in stress management. Conversely, inconsistencies exist surrounding the degree of stress that is generated from the sport itself, suggesting that performance within the sport might not create subjective stress for all athletes. As such, it provides practitioners, basketball coaches and student-athletes opportunities to emphasises areas of concern to improve performance.

CHAPTER 8

DISCUSSION

8.1. Thesis Findings

In the United States, higher education institutions offer a broad array of scholastic, sports-related, philanthropic, and social engagement opportunities for students. Collegiate sports are amongst the most sought-after opportunities for many students. A student-athlete is an individual who is enrolled full-time or part-time in a university or college and concurrently takes part in an organised and competitive athletic activity sponsored by the institution. Student-athletes must balance the dual responsibilities of meeting academic and performance standards. This duality of responsibilities requires demanding schedules that include academic classes, training sessions, and high-pressure sports competitions.

To fully appreciate the stressors associated with being a student-athlete it is important for coaches and practitioners to understand the wholistic requirements of this unique group. Chapter 2 identified that while the physical and physiological demands of most college sports are well documented, there is a paucity of evidence examining the cognitive demands of the college student-athletes. Additionally, there is also a poor understanding of the presence and/or the impacts of cognitive fatigue in this specific group. When assessing the impacts of both the academic and athletic requirements, it is also important to consider the perspectives of student–athletes who have lived experience balancing these dual roles. Once better understood, areas of concern can be further explored, providing the opportunity to develop strategies to more effectively support athlete health and performance.

To address these gaps in understanding, a series of studies were conducted to examine different academic and athletic demands and student-athlete responses in Division I collegiate basketball student-athletes. This work included specific focus on how acute and seasonal stressors may impact mental fatigue as well as basketball-specific performance. To explore these concepts specific in the context of basketball performance, Study 1 was designed to develop a valid and reliable shooting performance assessment that could be feasibly applied in the collegiate basketball setting. The second study (Chapter 5) then used this newly developed performance assessment (the SST) to gain insight into the acute effect of mental fatigue on basketball shooting performance. To do this, mental fatigue was induced using traditional experimental methods (i.e., a Stroop task) and fatigue was also examined following a standardised basketball film session, which is a common coaching tool used in collegiate basketball. The third study (Chapter 6) assessed mental fatigue and shooting performance over the course of a NCAA

Division I basketball season, focusing on specific periods of different academic, training and competition demands. Finally, the fourth study (Chapter 7) was a qualitative exploration of the student-athletes' academic and athletic experiences, to better understand their perceptions around the potential presence and manifestations of mental fatigue. The collective results of these studies provide new information for coaches, practitioners, and athletes that can be used to better understand the presence, sources and effects of mental fatigue on high performing student athletes. This work can be used to inform the development and application of innovative strategies to enhance student-athlete health and sports performance.

The main findings of this thesis were:

i) The novel standardised shooting task (SST) for basketball, developed in study 1, demonstrated sufficient measurement reliability and sensitivity to detect meaningful changes in basketball shooting performance. It also has adequate construct validity, providing an ecologically valid measurement that can feasibly be incorporated to athlete monitoring strategies in elite basketball players.

ii) Mental fatigue levels were significantly increased in elite student-athletes following sustained cognitive vigilance during a 30-min Stroop task and 30-min sport-specific film sessions. Basketball shooting performance was significantly reduced following the Stroop task, and there was a large, but non-significant reduction in shooting performance following the film sessions. These findings suggest that periods of sustained vigilance increase mental fatigue, and this can have a detrimental effect on subsequent basketball shooting performance.

iii) Basketball shooting performance was significantly reduced following increased levels of mental fatigue stemming from added academic stress. However, an increase in sport-specific training or games had no effect on subsequent basketball shooting performance.

iv) Student-athletes perceive pressure to perform both academically and athletically. and commonly reported that their most challenging times are during peak periods of academic assessment, including midterm and final exam weeks.

8.1.1. Developing a Basketball-Specific Performance Test

The finding from the first study can directly be applied by to help practitioners and coaches as a method for assessing basketball shooting performance. This type of skill-based test could prove useful in tracking changes in athlete performance and may offer an alternative to typical athlete 'monitoring tools', which tend to be focused on physiological outcomes. The newly developed SST is a sport specific, skill-based test, that not only shows adequate reliably, but also appears sensitive to change following basketball specific stress, such as a typical practice. Furthermore, the test, developed in collaboration with elite coaches, demonstrated both ecological and construct validity, in that outcomes show a significant positive correlation between shooting accuracy in real match play. The integration of sport specific skill assessments, such as the SST, that align with regular technical training session goals, may create minimal interruption while assist practitioners and coaches in developing evidence-informed individualised programs, to optimise player development and performance.

8.1.2. SST Performance and Mental Fatigue

The utility of the SST in understanding sport-specific impacts of mental fatigue is highlighted in studies 2 and 3. The key finding in study 2 was that the Stroop task led to a noticeable rise in perceived mental fatigue, coinciding with a decrease in shots made during the SST. Similarly, engaging with a basketball-specific film session resulted in student-athletes reporting increased mental effort, and led to a large, but non-significant increase in perceived mental fatigue. Following this film session, there were also decrements in shooting performance during observed during the SST. Although these effects were non-significant, they did exceed the minimal detectable change established in study 1. As such, practitioners should consider film sessions of 30 minutes or longer could result in increased levels a mental fatigue that may have deleterious effects on basketball shooting performance.

Study 3 demonstrated elite student-athletes exhibit increased subjective feelings of mental fatigue at the end of a week with high academic demands, as well as impaired SST shooting performance. Objective measures of cognitive performance - assessed through the PVT-B showed no changes in following any of the weeks examined in Study 3. Notably however, after completing the PVT-B at the end of the ACADEMIC week, players reported increased perceptions of mental effort and mental fatigue, an effect that was not present in any other week. This suggests that increases in academic stress can result in a reduced resiliency for the short tasks of sustained vigilance. Furthermore, the PVT-B results throughout the season showed a trend towards increased reaction times. This result may suggest that cumulative fatigue may lead to increased reaction times over the course of the season, but the exact contributors to this result remain unclear, particularly as no direct measures of cumulative fatigue were included in the study.

In addition to the increased mental effort and fatigue during the ACADEMIC week in study 3, results from the REST-Q showed that student-athletes exhibited heighten stress levels during this week, particularly in the areas of Social Stress, Fatigue, Disturbed Break and Exhaustion. The increase in stressors coincided with no change in recovery scores, indicating a poorer stress/recovery balance compared to the other weeks investigated. Interestingly, student-athletes also reported increased levels in Social Stress during the TYPICAL week, which was a pivotal part of the regular season, conference play. These conference games are the most critical to overall team success over the course of the season, as these games not only affect overall win-loss record (like all other games), but also independently contribute to the teams designated league/conference standings. As such, the outcome of these games holds greater significance as only these games directly affect standings and seeding for conference tournaments and postseason play. This rise in stress exhibited by student-athletes during this period may therefore be associated with heightened pressure to perform during a critical part of the season, however, these changes in stress warrant further investigation in the future.

8.1.3. Student-Athlete Perceptions

Study 4 explored the lived experiences of student-athletes, and the primary finding was that student-athletes feel a strong pressure to perform both academically and athletically. This finding supports previous reports that show student-athletes experience heightened stress compared to non-student-athlete counterparts. It was also notable that the student athletes reported that their greatest source of stress is related to academic studies, and not basketball. This finding is interesting to consider in the context of results from Study 3, where decrements in shooting performances were observed around exam periods. In contrast, an increase in sport specific requirements, such as higher number of practices and games, had no effect on SST outcomes. Taken collectively, the result in SST performance and student-athlete perception studies suggest that student-athletes are resilient to intensifications in basketball exposure, but not increases in mental fatigue centred around academics. It is likely that student-athletes spend more time and focus on basketball, potentially creating disproportionate emphasis and motivation for their sport compared to their academics. To further highlight this concept, in studies 2 and 3, participants reported high levels of motivation to complete the basketball task.

One possible explanation for this may be the athlete's attraction to the sport rather than the classroom. However, the student-athletes also acknowledged the importance of academic success as a part of their role. Nevertheless, academics seem to play a major role in the student-athlete experience and stress from this realm may influence basketball shooting performance.

8.2. Summary of Key Findings

Prior to the series of studies conducted in this thesis, the presence, sources and effects of mental fatigue on basketball performance were not well documented. This thesis has developed new knowledge about mental fatigue in student-athletes by exploring how various stressors in collegiate basketball, including sport-specific (cognitive and physical) and academic demands, impact skill performance and self-reported, mental fatigue.

Specifically, the SST was utilized to demonstrate a link between acute mental fatigue and reductions in shooting performance in elite student-athletes. This measure was then integrated into a Division I basketball season to show that academic load may also impact shooting outcomes. The knowledge provided by these studies can be used by practitioners, coaches, and student-athletes to better plan and strategize to optimize performance. Consistent sport-specific monitoring tasks could also enable informed decisions regarding training and interventions to address stressors throughout the season. The findings of this thesis provide evidence that mental fatigue negatively impacts basketball shooting performance and is highest for student-athletes during periods of increased academic stress.

8.3. Limitations

This research for was conducted in an applied collegiate athletics setting, and although this design strengthens the ecological validity, it also creates several inherent limitations that should be considered when interpreting the results. In developing the SST, the research team collaborated closely with expert coaching staff to create an ecologically valid assessment of shooting performance that could be practically implemented. To enhance specificity, the expert recommendations for developing this test included ensuring that each athlete should not attempt the same selection of shots (i.e. 2-point vs 3-point shots). Consequently, athletes were separated into two groups (2-point or 3-point shots), this was necessary due to a relatively small sample and a need maintain test specificity, a challenge when investigating elite athletes.

Moreover, to improve reliability, the SST focused solely on jump shooting performance, which does not replicate all shooting situations in basketball and, therefore, may not be reflective of various stimuli encountered during game play.

Another challenge was that all the data collected was within one university and therefore may not be reflective of other collegiate basketball teams or professional basketball populations. Furthermore, the results from study 4 focused on student-athletes' perceptions; thus, the data should be interpreted with caution as other universities may have different expectations or standards in student-athlete requirements and care. Additionally, the results from Study 3 may even vary within the same team from season to season based upon scheduling and logistical timing of events. All studies were exclusively conducted on male participants, thus limiting the generalizability of the findings to females, as physiological and psychological responses to interventions may differ. This lack of diversity restricts the applicability of the results to broader populations and could overlook sex-specific variations critical to the research outcomes.

Results from study 3 and 4 focused directly on the duality of the student-athlete experience. However, these findings may not be reflective of other levels of basketball and, therefore, may not be applicable to them. In Study 3, because the student-athletes were in competition season, basketball and academic workloads for each week were not controlled experimentally and are therefore not perfectly matched. Variations in physical demands might influence shooting performance outcomes, however, our method of selecting "experimental weeks" during the season improves ecological validity. Study 3 also has the potential for an ordered effect since the "experimental weeks" were not selected by the research team. Nevertheless, efforts were made to reduce this likelihood of this through pre/post measurements for each week.

Study 4 was conducted after the previous investigations due to the constraints and availability of the student athletes. In retrospection, conducting this study first may have provided insight into areas exploration, however, the information garnered still provides valuable understanding into the perceptions of student-athletes surrounding mental fatigue.

Lastly, there are limitations surrounding our assessment of mental fatigue. In Study 2, the basketball film duration was limited to 30 minutes to standardise duration across experimental groups. It should be recognised that film times are highly variable within and across basketball team settings. Additionally, the conversations during the film sessions were not scripted verbatim. However, to limit variability, the same video, coaching concepts, questions and administering coach were all consistent. In study 2 and 3, despite increases in subject's mental fatigue and effort, as well as changes in objective cognitive performance, the exact mechanisms contributing to these responses remain unclear.

Despite these limitations, the collective work presented in this thesis makes a significant contribution to progressing the understanding of the effects of mental fatigue on elite basketball student-athletes.

8.4. Practical Applications

The findings emerging from this thesis can be immediately translated into practice to have a meaningful impact on student-athlete programming and experiences in elite basketball, which are summarised in Figure 8.1.

The results from the first study provide a valid and reliable sport specific assessment for basketball, the SST. Practitioners can use this tool to regularly quantify sport-specific performance, offering a more game-relevant monitoring method compared to common physical-focused monitoring protocols. The results from studies 3 and 4 provide insight to the ramifications of mental fatigue on basketball shooting performance from both acute stressors (e.g., film sessions) and more chronic stressors (e.g., heavy academic periods). Coaches and practitioners should be conscious of these findings when planning their programs, adjusting stressors where possible, and adapting other parts of the program when stressors are unavoidable (e.g., exam periods). The findings from investigating student-athletes' perceptions also highlighted the need to consider non-sport-related stressors, specifically academic demands, and their potential impact on basketball performance.

To enhance the academic success and well-being of student-athletes, several policy changes are proposed. Firstly, scheduling adjustments will be made to limit competition and games around final exams, ensuring students can focus on their academic responsibilities during this critical period. Additionally, coping strategies centered around academics will be integrated to help student-athletes manage their dual roles more effectively. These strategies might include time management workshops, academic counseling, and stress relief techniques. Lastly, creating consistent schedules that harmonize athletic and academic commitments throughout the season will provide student-athletes with a stable routine, reducing conflicts between their sports and academic obligations and promoting a balanced lifestyle.

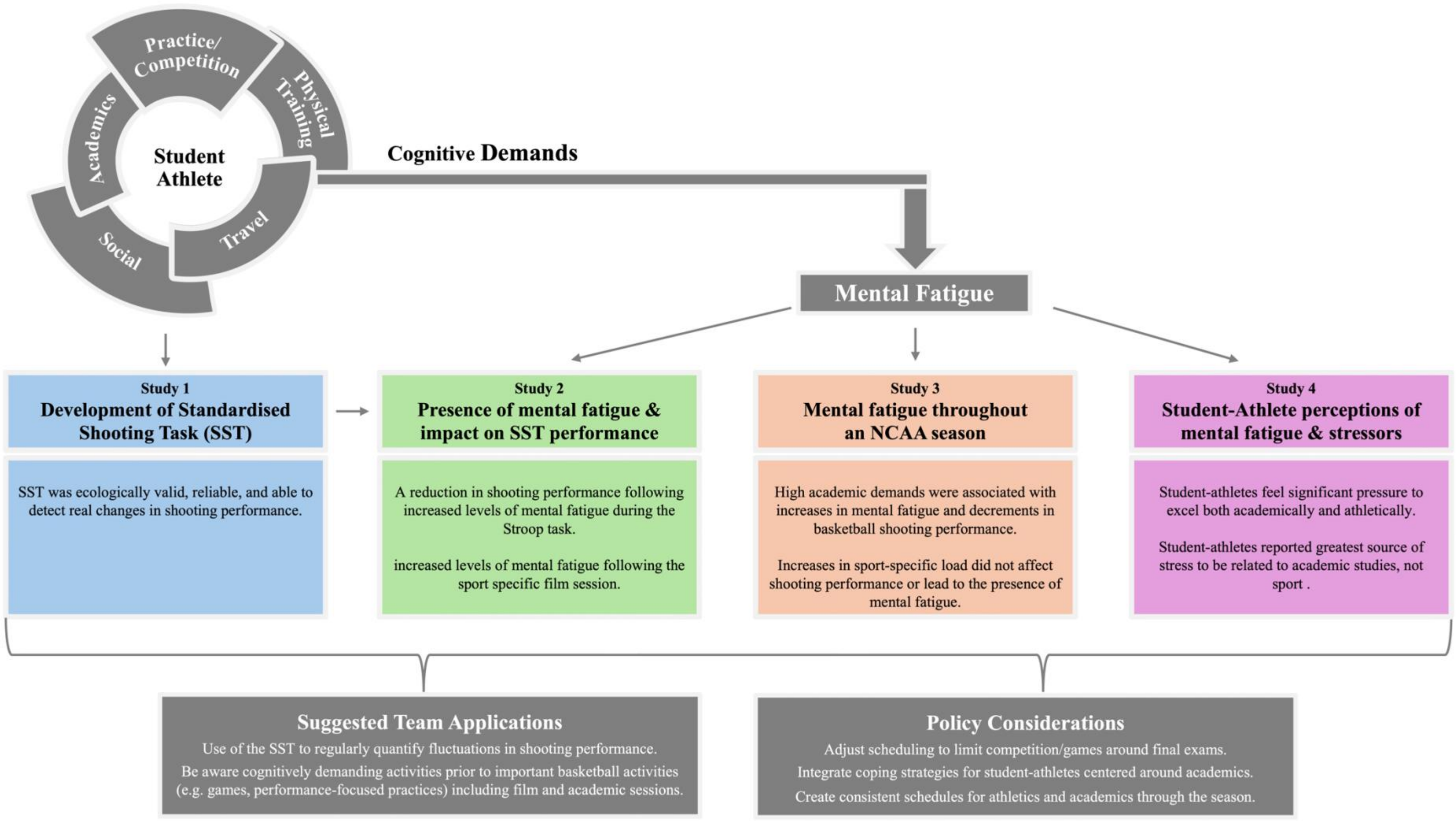

Figure 8-1: Summary of findings from the studies investigated in this thesis

This work is already having a real-world impact, as the suggestions outlined above have already begun to be incorporated directly into the collegiate setting in which the data was collected. Specifically, film times have been limited and practice schedules allow for extra time between the end of class and the start of basketball activities. Additionally, the findings of this thesis have assisted in promoting a culture of research focused on not only improving athlete performance but also enhancing overall student-athlete welfare.

8.5. Future Research Recommendations

This thesis has enhanced knowledge about the relationship between mental fatigue and basketball performance in student-athletes. However, to gain a more comprehensive understanding of these effects further research is required. The SST used in this work focused on jump shooting performance, which is only one aspect of the game of basketball. Researchers should consider other basketball assessments to understand holistic impact of mental fatigue on the game of basketball.

This thesis also specifically addressed to elite collegiate basketball student-athletes. Future research is warranted for other populations, such as amateur or professional basketball athletes, as these groups face different stressors in their respective environments.

Mental fatigue decreases basketball shooting performance in elite collegiate student-athletes. Therefore, future research should explore a a dose-response relationship of mental fatigue to better understand the minimum thresholds that lead to decrements in shooting performance. Additionally, while some other investigations have considered free throws and jump shots, future research should consider the effects of mental fatigue on different types of basketball shots (e.g. with and without opponent pressure).

The research conducted in this thesis emphasised basketball specific film sessions and academics as two of the cognitively demanding tasks commonly faced by student-athletes. However, it is possible that stressors from social interactions, team obligations, public perception, and other factors could impact performance and should therefore be explored.

CHAPTER 9
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APPENDICES

Appendix 1: Ethic Approval

UTS Human Research @Ethics Committee Approval – (ETH20-4635)

research.ethics@uts.edu.au
to Aaron.Coutts, Blake.McLean, Bryce.D.Daub

Sun, May 10, 2020, 9:18 PM

Dear Applicant,

Re: ETH20-4635 - "Mental Fatigue and Effect on Basketball Specific Skill Performance"

Your local research office has reviewed your application and agreed that it now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH20-4635

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.

- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

UTS Human Research Ethics Committee Approval – (ETH21-6665)

Research.Ethics@uts.edu.au — Wed, Jun 1, 2022, 12:38 AM

to Research.Ethics, Aaron.Coutts, Blake.McLean, Bryce.D.Daub, aaronheishman

Dear Applicant

Re: ETH21-6665 - "Mental Fatigue and Effect on Basketball Performance"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH21-6665.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents and submit any required

amendments prior to implementation. Instructions on how to submit an amendment application can be found here.

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- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

UTS Human Research Ethics Committee Approval – (ETH23-8107)

research.ethics@uts.edu.au

Thu, Mar 30, 9:22 PM

to Aaron.Coutts, Bryce.D.Daub, Blake.McLean, Research.Ethics

Dear Applicant,

Re: ETH23-8107 - "Elite Coaches and Athletes perspectives of fatigue in Division I college basketball."

Your local research office has reviewed your application and agreed that it now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any conditions detailed in this document.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH23-8107

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required

amendments prior to implementation. Instructions on how to submit an amendment application can be found here.

- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible Conduct of Research and National Statement on Ethical Conduct in Human Research.

Appendix 2: Evidence of Research Integrity Modules

Graduate Research School

Research Integrity for Students

Certificate of Completion

This is to certify that

Bryce Daub

has successfully completed

Module 1: Research Integrity and Code of Conduct

Production Note:
Signature removed prior to publication.

Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: 18/02/2020

UTS

Graduate Research School

Research Integrity for Students

Certificate of Completion

This is to certify that

Bryce Daub

has successfully completed

Module 2: Plagiarism and Misconduct
Module 3: Risk Assessment
Module 4: Risk Management and Health & Safety
Module 5: Project Management

Production Note:
Signature removed prior to publication.

Professor Lori Lockyer,
Dean, Graduate Research School

University of Technology Sydney

Date: 18/02/2020