[redacted]

Prifysgol Abertawe
Swansea University

The Effect of Morning Exercise on Afternoon Performance in Professional Cricketers

Fergus Nutt

[redacted]

Abstract

Introduction: Match play within professional cricket commences at a variety of times during the day, with the shorter 'white ball' formats often starting anywhere from 11:00 to 19:30. This presents large windows of opportunity for pre-competition strategies to be utilised to improve performance. Salivary hormones, in particular testosterone, exhibit a circadian rhythm over the waking day, falling up to ~50% to a nadir at ~20:00. With salivary testosterone concentrations showing strong links with neuromuscular, cognitive and motivational benefits, the ability to optimise those natural levels could be a way to improve an athlete's match day performance. Engaging in a bout of exercise prior to competition has been used by sports teams to prime the body, with the purpose to enhance performance. ***Methods:*** In this study, a group of 21 professional male cricket players (aged: 26 ± 6 years, body mass: 88.1 ± 4.4 kg, height: 184 ± 3.6 cm) engaged in an investigation with the aim to compare the effects of 2 morning priming protocols on markers of afternoon performance. Following a randomised-counterbalance design, the players were split into groups of 4. The control day consisted of the players reporting for the afternoon tests (Readiness To Perform questionnaire [RTP], Stroop Test, countermovement jump [CMJ] and Run-two sprint at ~ 15:00, with 30min slots for each group. The experimental trials consisted of groups arriving at ~ 9:00 with 30min slots, to engage in either the Trap bar deadlift protocol (4 reps at 50%, 70%, 80%, 3 x 4 at 85% 1RM) or repeated Sprint session (6 x 35.4m with a 180° turn at the midpoint) with a 30s recovery, roles were reversed following a 7-day break; participants then rested for ~5h and returned to completed the afternoon performance tests. ***Results:*** Run-two sprint time was significantly reduced ($p < 0.001$) (CON = 5.99 ± 0.17s, Sprint = 5.94 ± 0.17s, Trap bar = 5.91 ± 0.17s), Trap bar saw further reductions when compared to the Sprint ($p = 0.032$). Only the Trap bar protocol saw a significant increase in CMJ Jump height (JH) ($p = 0.021$) (CON = 43.8 ± 6.8cm, Sprint = 45.0 ± 7.3cm, Trap bar = 45.2 ± 6.5cm). There was no significant correlation between absolute ($p > 0.05$) or relative strength ($p > 0.05$) and the effectiveness of the priming strategies on neuromuscular performance. Both Sprint and Trap bar expressed significant reductions in time to complete the Stroop test ($p < 0.05$) (CON – 51.1 ± 4.7s, Sprint – 48.4 ± 3.6s, Trap bar – 47.9 ± 2.8s), with Trap bar again reporting further reductions compared to Sprint ($p < 0.05$). Whilst the trials demonstrated a significant impact on the athletes' afternoon neuromuscular and cognitive performance, their readiness to perform scores were unaffected ($p > 0.05$). ***Conclusion:*** Performing morning exercise is associated with afternoon neuromuscular and cognitive performance benefits, with no detriment to the readiness to perform.

Acknowledgements

When I first embarked on my MSc I knew that the next year, which turned out to be two, would be a different and more challenging University experience. In hindsight, I underestimated quite how different it would be. The last 18 months have been testing for most, the circumstances made collecting data for my MSc at times impossible. I would like to take a moment to thank a few people who have gone above and beyond to make this process possible.

Firstly, while they had the fortune of avoiding me during several 'lockdowns' my family have been incredibly supportive during my entire time at University, particularly during my MSc. Often providing calm on the end of the phone during numerous frustrating moments. They motivated me to remain on top of my write up during several stale months, then gave gentle reminders about completion during busier times when starting my full time job - for all of your support I am beyond grateful.

Special mentions go to Phil Scott and Jonty Norris who both dedicated huge amounts of time and effort into the project. Both were extremely adaptable surrounding meetings and the data collection, while their own work commitments were rapidly changing. Phil was always contactable to provide his expert insight, even when travelling around the world. I am particularly appreciative of Jonty's dedication to the investigation during numerous setbacks from government restrictions, without this we certainly wouldn't have completed the project we set out to do.

Finally, to Prof. Liam Kilduff, being my tutor for my entire time at Swansea University is probably an achievement in itself. Over the last 5 years, I have appreciated your no-nonsense approach (Russell et al., 2015) – which at times was particularly necessary. Your work ethic and depth of knowledge in elite sport are things that I hope to learn from and take with me thoughout my career. I already miss my fearful weekly walks to engineering east to have our progress (or lack of) meetings, thank you for all the support, occasional laughs and countless emails over my time here.

Table of Contents

List of Abbreviations

T - Testosterone
C - Cortisol
T20 - Twenty Over Match
CMJ - Countermovement Jump
DJ - Drop Jump
RSI - Reactive Strength Index
PPO - Peak Power Output
FSH - Follicle-Stimulating Hormone
LH - Luteinizing Hormone
RM - Repetition Maximum
$pgml^{-1}$ - Picogram Per Millilitre
Kg - Kilograms
ms^{-1} - Metres Per Second
h - Hour
AM - Morning
PM - Afternoon
RTP – Readiness to Perform
SD - Standard Deviation
CON - Control
Ca^{2+} - Calcium
~ - Approximately
° - Degrees
s - Seconds

Declarations and Statements

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed: [redacted]
Date: 16/08/21

Statement 1:
This thesis is the result of my own investigations, except where otherwise stated. In this instance references are provided in text with a reference list provided after the final chapter.

Signed: [redacted]
Date: 16/08/21

Statement 2:
I hereby give consent for my thesis, if accepted, to be available for photocopying and inter-library loan, and for the title and summary to be made available to outside organisations.

Signed: [redacted]
Date: 16/08/21

The University's ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

Signed: [redacted]

Date:16/08/21

List of Figures

List of Tables

Chapter 1.0 - Introduction

Over recent decades of professional cricket, a variety of formats have emerged with the limited overs games enjoying a dramatic rise in popularity (Petersen, Pyne, Portus, & Dawson, 2008). The demand from spectators and the media, together with a condensed fixture load due to seasonal limitations, has resulted in matches taking place throughout the week with a variety of start times, from mid-morning to early evening. Typically, the majority of limited overs games start in the afternoon creating a window of opportunity on competition day to influence overall player performance (Cook, Kilduff, Crewther, Beaven, West, 2014).

Matchday success in cricket relies on the ability to score runs when batting, take wickets and restrict runs in the field (Carr, McMahon & Comfort, 2015). The significance of sprint performance has been highlighted in; batting (Duffield & Drinkwater, 2008), bowling (Duffield, Carney & Karppinen, 2009; Glazier, Paradisis & Cooper, 2000) and fielding, particularly in the limited overs format (Petersen, Pyne, Portus & Dawson, 2009). A player's cognitive ability, expressed through reaction time and decision-making, acts as a precursor to their neuromuscular performance. Glazier et al. (2000) concluded that elite fast bowlers typically bowl at speeds between 129-146km.h^{-1}, providing the batsman with a limited timeframe to track the ball then conduct a response for a successful interception. It has been proposed that both sprint performance and cognitive function decrease over the waking day (Chang, & Etnier, 2009; Cook et al., 2014; Cooper, Bandelow, Nute, Morris & Nevill, 2012). However, the same studies demonstrated that a bout of morning exercise could halt, or even improve the afternoon decline in the performance parameters. A morning exercise session is a feasible pre-competition strategy that may suit most elite teams, where such improvements might positively affect key aspects of performance.

Steroidal hormones Testosterone (T) and Cortisol (C) diurnally fluctuate in a cyclic nature, where concentrations typically peak ~08:00 then drop by 40-50% to a trough ~22:00 (Cook et al., 2014; Guignard, Pesquies, Serrurier, Merino & Reinberg, 1980; Kreamer et al., 2001; Piro, Fraioli, Sciarra & Conti, 1973; Teo, McGuigan & Newton, 2011). It is well-established that

that the natural concentrations of T can be acutely affected by a bout of resistance (Cook et al., 2014; Kreamer et al., 1990, 1991, 1999; Russell et al., 2016), jump (Bosco et al., 1998) and sprint training (Cook et al., 2014; Russell et al., 2016). Moreover, these elevations in T have been linked to increases in peak power output (PPO) (r = 0.66) (Bosco et al., 1998), jump height (r = 0.61) (Cardinale & Stone, 2006), and speed (r = 0.65) (Crewther, Lowe, Weatherby & Gill, 2009b). Enhanced athletic performance was particularly significant in elite populations where Crewther et al. (2012) used T to predict squat (r = 0.92) and sprint performance (r = 0.87).

In addition to the above, the non-genomic effects of T have been shown to extend further than neuromuscular performance, where research on top level athletes has linked T concentrations to motivation and willingness to perform (Carré & McCormick, 2008; Cook & Crewther, 2012; Cook, Crewther & Kilduff, 2013, 2018). Using self-selected workout loads as a marker for motivation Cook et al. (2013) reported a strong relationship with Salivary T (r = 0.81). The aforementioned studies would imply that T has an effect on the cognition of athletes. However, there is a lack of research linking T to reaction time and decision making, particularly in the sporting population. Muller et al. (2005) showed that the addition of exogenous T may increase competitive decision making in winning scenarios, but is yet to be determined in a sporting context. More commonly investigated, reductions in T have been linked to a decline in cognitive abilities in the aging population (Cherrier et al. 2005; Kenny, Bellantonio, Gruman, Acosta & Prestwood, 2002; Kenny, Fabregas, Song, Biskup & Bellantonio, 2004).

Competition day strategies have been recently assessed in an attempt to maximise performance (Kilduff, Finn, Baker, Cook & West, 2013), in particular the use of morning exercise to elevate afternoon parameters (Cook et al., 2014; Ekstrand, Battaglini, McMurray & Shields, 2013; Mason, Argus, Norcott & Ball, 2017; McGowan, Pyne, Thompson, Raglin & Rattray 2017; Russell et al., 2016). Initial work from Ekstrand et al. (2013) used a morning resistance session to seek improvements in afternoon throwing measures. While performance benefits were evoked, it was suggested that similarities in movement and muscle recruitment patterns between the exercise modes explained the reported effects. Cook et al. (2014) gave further evidence of a potential ‘priming’ effect observed in the afternoon following a morning resistance (3x50% 3RM, 3x80% 3RM, 3x100% 3RM for back squat and bench press) and sprint session (50%, 80%, 3x100% of maximal effort with 45s rest between sets). Notably, the study found that typical afternoon concentrations of T had been attenuated - indicating that morning exercise may have off-set the natural diurnal decline. Russell et al. (2016) went further, investigating the involvement of T in elevations in afternoon performance. While a significant rise in T prompted afternoon performance benefits in the sprints trial. The cycle trial did not lead to rises in T but elicited benefits in jumping performance and PPO. This may be indicative of other secondary mechanisms at play as well as the non-genomic effects of T. Tsoukos et al. (2018) advanced this thought when neuromuscular improvements were seen 24h post resistance session, a timeframe supposedly unable to affect an athlete's circadian rhythm. Many secondary mechanisms have been proposed, including: stimulation of high frequency motor neurons (De Villareal et al., 2007; Sale, 2002), mechanical stiffness (Bojsen-Møller, Magnusson, Rasmussen, Kjaer & Aagaard, 2005; Tsoukos et al., 2018) and muscle temperature (Harrison, James, McGuigan, Jenkins & Kelly, 2019; Kenny et al., 2003). While the effects of these mechanisms on muscular performance are known to be temporary, their involvement cannot be discounted.

The pre-conditioning strategies focusing on bouts of morning exercise have evoked positive results in jump and sprint performance (Cook et al., 2014; De Villareal et al., 2007; Ekstrand et al., 2013; Russell et al., 2016). While hormonal 'priming' has been successful in power athletes, applying similar principles to an intermittent sport such as cricket would provide a novel approach to the area. Therefore, using a group of professional cricketers, the aim of this study was to investigate the effect two differing morning protocols on afternoon measures of performance, cognition and motivation. It was hypothesised that a morning session would influence afternoon performance markers.

Chapter 2.0 - Review of Literature

2.1 - Physiological Demands and Aspects of Performance in Cricket

2.1.1- Background of Cricket

Professional cricket is played worldwide, across 4 main formats. Longer formats such as 5-day test matches, played by the international sides, and 4-day domestic cricket matches between counties are termed ‘red ball cricket’. Shorter formats, played within a day, 50 over (one-day) and 20 over (T20) matches, are played with and subsequently referred to as ‘white ball cricket’. The shorter format games, particularly T20 matches, can only take up to 3h to complete leading to an increase in interest from spectators, resulting in T20 cricket becoming the most profitable format of the game (Petersen et al., 2008). Due to its condensed format, the result of a T20 match can often depend on the outcome of a single ball, making the execution of key skills arguably more important in the shorter format. Players are categorised into batters and bowlers, (where bowlers deliver seam or spin), all players are required to field (Johnstone & Ford, 2010).

2.1.2 - Physiological Demands of a Limited Overs Match

Often in professional sport the physical demand is proportional to the length of the game. Petersen, Pyne, Portus, and Dawson (2009) were the first to quantify the movement patterns and demands cricketers across differing formats, as shown in *Table 2.1*. Using forty-two State level males, T20 cricket significantly increased the amount of all physical efforts, particularly ‘high-intensity efforts’ and ‘sprints’ in batsmen, bowlers and fielders. It was concluded that, contrary to most sports, cricket becomes more physically demanding in shorter formats. This aligns with work from Tallent et al. (2017) which also demonstrated the demanding nature of a T20 fixture, reporting that the relative cost (high-intensity running and dynamic stress load) of an over (6 balls) was in excess of 100% greater during a match than training. Both studies highlight the importance of sprint performance and repeatability in short format cricket. Most recently, Webster, Comfort and Jones (2020) investigated the relationship between physical fitness parameters and the demands of a 50 over match. Moderate relationships were reported between CMJ and distance covered (r = 0.585), maximal velocity (r = 0.567) and sprinting distance (r = 0.554). While the total distance covered by fast bowlers was notably lower than previous studies (Petersen, Pyne, Portus, Karppinen & Dawson, 2009; Petersen, Pyne, Portus & Dawson, 2011), which used international cricketers, therefore opposition quality and ground dimensions may explain the drop in values.

Table 2.1 – Movement patterns of cricketers over differing formats (Petersen et al., 2009 pg 278-281)

Game format and playing position	No. of sprints per hour	Mean sprint Distance (m)	Maximum sprint distance (m)	No. of efforts per hour	Recovery ratio (1 : *x*)
Twenty20					
Batsmen (*n* = 26)	15 ± 9[b]	13 ± 4[1]	19 ± 6[1]	45 ± 16[1,c]	38 ± 13[2,c]
Fast bowlers (*n* = 18)	23 ± 10[1,b]	17 ± 4[b]	35 ± 13[2,b]	61 ± 25	25 ± 18
[redacted]					
Wicketkeeper (*n* = 6)	2 ± 1	16 ± 9	22 ± 11	23 ± 4[+]	64 ± 18[+]
Multi-day					
Batsmen (*n* = 9)	8 ± 3	13 ± 7	21 ± 8	28 ± 6	61 ± 10
Fast bowlers (*n* = 10)	17 ± 11	13 ± 1	28 ± 5	56 ± 29	38 ± 31
Fielders (*n* = 20)	3 ± 2	16 ± 7	26 ± 14	19 ± 8	90 ± 52
Spin bowlers (*n* = 0)					
Wicketkeeper (*n* = 4)	2 ± 4	11 ± 19	12 ± 9	12 ± 6	167 ± 73

Note: A sprint is defined as movement above 5 $m \cdot s^{-1}$ for at least 1 s.
[1]Small, [2]moderate, [3]large and [4]very large magnitudes of difference within position between Twenty20 and One Day: [a]Small, [b]moderate, [c]large and [d]very large magnitudes of difference within position between Twenty20 and multi-day: [+]Small, [‡]moderate, [†]large and [*]very large magnitudes of difference within position between One Day and multi-day cricket.

2.1.3- Lower-Body Power as a Determinant of Performance

As highlighted above, sprint performance is crucial in all three determinants of success; run scoring, run restriction and wicket taking (Carr et al., 2015). Batsmen can score by completing a 17.68m run from one crease to another. Multiple runs can be completed, highlighting the importance of a player's repeated sprint ability. Johnstone and Ford (2010) also showed the importance of CMJ and RSI performance in batsman, which were respectively (10% and 19%) greater than that of the bowlers. Both performance tests were likely markers for the acceleration and deceleration required during the change in direction when turning for multiple runs. Effective running between the wickets is likely to increases a batter's run scoring potential and match day success (Duffield & Drinkwater, 2008). Conversely, a fielder's sprint ability can directly negate that of a batsman. A fielder's running speed can not only decrease the chance of a batsman scoring a boundary, but also reduce the time available to run between the wicket. The importance of fielders' sprint ability increases in the shorter formats of the game, Peterson et al. (2009) demonstrates this in *Table 2.1* where fielders are required to increase all of their sprint determinants.

A bowler's success is often dependent on their ability to take wickets – dismissing a batsman. Bowling speed is regarded as a desirable skill for a fast bowler and their team. Glazier, Paradisis and Cooper (2000) showed that in the elite population fast bowlers typically deliver the ball between 129-146km.h^{-1}, with the very top fast bowlers breaking 150km.h^{-1}. By principle, the faster the release speed of the ball the less time the batsman has to react, heightening the chance of taking a wicket. Increasing a bowler's lower body performance is likely to affect ball release speed. Whilst a fast bowler's run up is often unique and rhythmical, Glazier et al. (2000) found horizontal run-up velocity had a moderate correlation ($r = 0.7$) with ball speed upon release. Similarly, Duffield, Carney and Karppinen (2009) similarly reported the positive correlation ($r = 0.7$) but suggested that the final 5m of a bowler's run-up was more influential on ball speed. Ferdinands, Marshall and Kersting (2010) reported that the deceleration of a bowler's centre of mass accounted for 43.1% of bowling velocity in 34 premier grade fast bowlers further demonstrating the influence of a bowler's lower-body power on cricketing performance.

2.1.4 - Role of Cognition in Performance

As well as high levels of physical skill, cricket depends on mental aptitude; moreover, the ability to focus intensely for long bouts of time where physical fitness cannot compensate (Noakes & Durandt, 2000). Cricket is known for its unique match day tactics, such as bowling plans and fielding set-ups, where each ball is delivered and then played with a plan in mind. In a game where the ball travels at such high-speed players rely on reaction time and cognitive performance for skill success. There is limited research on bowlers' cognition, primarily because they deliver the ball. Batters and fielders typically face ball speeds of over 40ms^{-1}, subsequently having 2.5ms to react to environmental cues (Regan, Beverley & Cynader, 1979).

Batters also need to process deviations in ball flight such as swing or spin (Stretch, Bartlett & Davids, 2000), highlighting the importance of cognitive function; specifically, reaction time and decision making. Anticipation and reaction time allow players time to move the body into the most effective position possible, increasing the chance of a positive interception and a successful outcome (Hopwood, Mann, Farrow & Nielsen, 2011). Mental strategies such as anticipation are a crucial skill in fast-paced striking sports (Abernethy & Zawi, 2007). Anticipation allows the athlete to bypass temporal restrictions like bat-to-ball interception when batting or ball-to-hand interception when fielding. Land and McLeod (2000) investigated how batsmen track the ball at high velocities. This suggests that a batsman typically pursuit tracks, actively watches, the ball 50-80% of the time, implying that a large amount of ball flight is anticipated and flight pattern presumed. The study compared the changes in ball tracking in a professional batsman and a variety of amateur players. As expected the elite batsman showed significantly more pursuit tracking, implying that more proficient players pick up visual cues significantly earlier than amateurs (Renshaw & Fairweather 2000). Similarly, Thomas, Harden and Rogers (2005) who showed that elite cricketers have significantly faster visual evoked potential (VEP), acting as a marker for cognitive stimulation. However, there were no significant differences in basic reaction time between the elite and control group. Though the use of a non-cricket specific test when comparing elite players and non-players may explain the result. A cricket specific test would be more likely to exploit differences in reaction time between playing and non-playing populations. Further importance of an athletes cognitive importance is often exaggerated when playing a cognitive demanding sport like cricket, Tallent et al. (2017) reported cognitive impairment following a spell of bowling in T20 cricket. Furthermore, (Veness, Patterson, Jeffries & Waldron, (2017) showed a reduction in cricket related performance markers following induced mental fatigue.

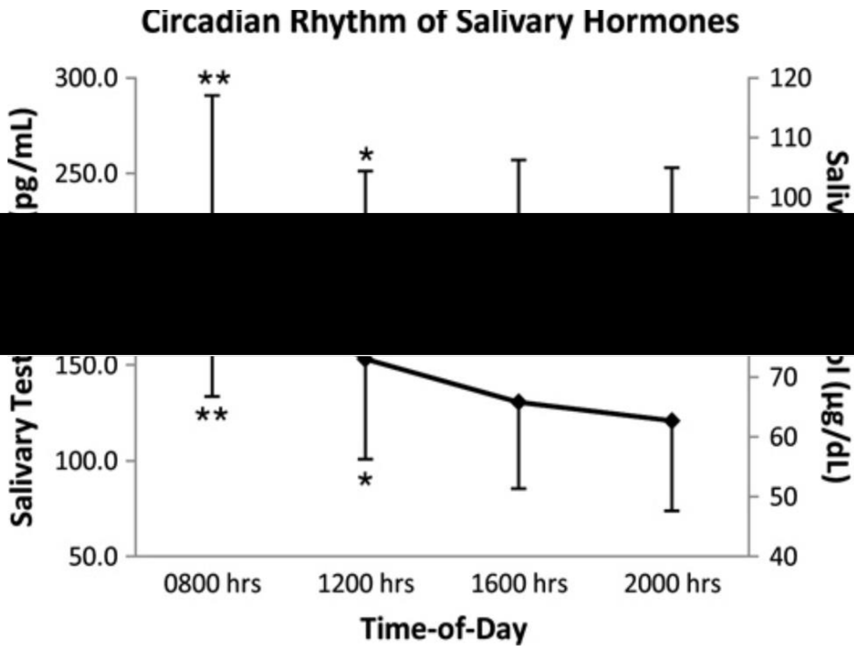
2.2 - The Role of Testosterone in Athletic Performance

2.2.1- Basal Production

Due to its proposed anabolic nature, T is one of the primary hormone associated with athletic performance. In a healthy adult male, the gonadotropic-releasing hormone (GnRH) secreting neuroendocrine cells, located in the hypothalamus, release a small wave of action potentials upwards of every 90 minutes, inducing the production of GnRH (Widmaier, Raff & Strang, 2004). GnTH then travels, via the hypothalamopituitary portal vessel, to the anterior pituitary. Once detected, an endocrine response causes the secretion of follicle-stimulating hormone (FSH) and luteinizing hormone (LH). While the production of FSH and LH may not be equal, they are proportional to the strength of the action potential and subsequent GnRH detection. Both FSH and LH travel to the testes where they undertake differing roles. FSH acting on the Sertoli cells stimulating spermatogenesis. LH interacts with the Leydig cells directly stimulating the production of T from acetate and cholesterol (Devlin, 2010). Males typically produce 4-10mg/day, most of which passes into the bloodstream as a lipid soluble steroid hormone (Pocock, Richards & Richards, 2018). T also acts as a paracrine agent further stimulating spermatogenesis inside the Sertoli cells. T is then regulated using negative feedback mechanisms by inhibiting LH, and by definition its own production, via a protein hormone called inhibin produced by the Steroli cells (Widmaier et al., 2004).

2.2.2 - Circadian Rhythm of Testosterone

The circadian rhythm of T refers to the diurnal changes in the bodily production and concentrations of the hormone. It is well documented that T concentrations fluctuate throughout the day often peaking early morning ~08:00 and then slowly staggering to a nadir in the evening ~20:00. Concentrations have been shown to drop ~40-50% over the course of the day before regeneration overnight (Cook et al., 2014; Guignard, Pesquies, Serrurier, Merino & Reinberg, 1980; Kreamer et al., 2001; Piro, Fraioli, Sciarra & Conti, 1973; Teo, McGuigan & Newton, 2011).

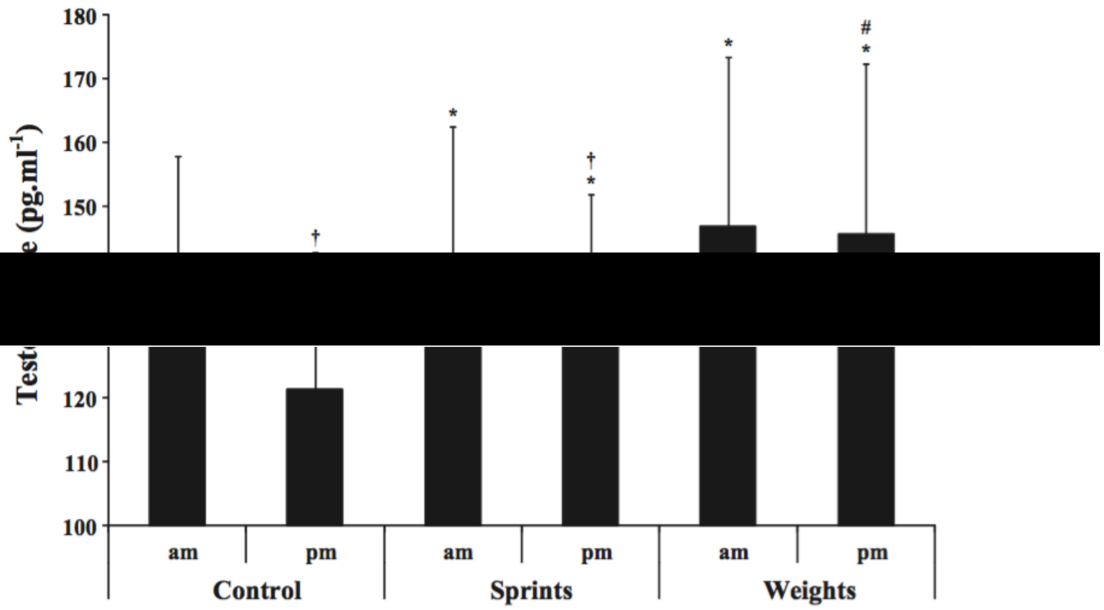


[redacted]

Figure 2.1 – Circadian rhythm of salivary T and C concentrations (Teo et al., 2011 pg. 1538-1545)

Early work by Piro et al. (1973) investigated the rhythm of plasma T concentrations over a 24h period in thirteen males, reporting significant diurnal variations of T, with the highest values at 08:00 and the lowest at 22:00, providing evidence of a rhythmical cycle in T production. Interestingly, concentrations of T regulating gonadotropins, FSH and LH, did not show the same gradual decline. FSH and LH levels fluctuated although mean values were lower in the evening when compared to the morning. Guignard et al. (1980) concurred with the work of Piro et al. (1973) by demonstrating T concentrations follow a similar cyclic trend whilst also suggesting cortisol levels to mirror that of T. Later research from Teo et al. (2011) also found concentrations of T fell over the day by ~40%, whilst showing the catabolic hormone cortisol replicated the decline of T, but not to the same extent.

Kreamer et al. (1990, 1991) both showed that a high-volume resistance session is likely to acutely elicit a substantial increase in T. Following this, Kreamer et al. (2001) investigated the effect of a similar resistance protocol on the circadian rhythm of salivary T using 10 weight-trained males. Despite earlier discoveries on the effect of exercise on T, there was no significant difference between the circadian rhythm of the control day compared to the experimental trial. It was suggested that T levels had normalized within 1h and the resistance protocol had no later effect on the cyclic nature of afternoon decline in T. Conversely, Cook et al. (2014) investigated the effect of a morning weights session on afternoon performance, reporting that salivary T concentrations significantly fell from AM to PM in the control (-10.9 ± 2.4 pgm^{-1}) as shown in *Figure 2.2*, with a smaller reduction in the repeated sprints protocol (-6.2 ± 7.1 pgm^{-1}) and almost no reduction in the weights protocol (-1.2 ± 5.5 pgm^{-1}). Afternoon jumping was significantly improved, which was attributed to off-set circadian decline, seemingly as a result of the resistance protocol. Possible reasons for the contrasting results of Kreamer et al. (2001) and Cook et al. (2014) may lie in the exercise protocols. Cook et al. (2014) used a power-based weights session with significantly high loads than the hypertrophic session used by Kreamer et al. (2001). Notably, differences in participant training status could also contribute, where the ‘professional rugby union players’ used by Cook et al., (2014) are likely to be of a higher training status than the ‘recreationally weight-trained men with resistance training experience of at least 1 year’. This could be explained by linking work by Crewther et al. (2012) which investigated the concentrations of salivary free T on predicting squat and print performance, showing strong and significant correlations between the T levels of the ‘good squatters’ for squat performance (r = 0.92) and sprint times (r = -0.87). No significant correlations were found for ‘average squatters’. This suggests that training/strength status of an athlete is important when linking hormonal responses and performance.



[redacted]

Figure 2.2 – Changes in salivary T concentrations AM-PM (Cook et al., 2014)

2.2.3 - The Effect of Testosterone on Lower-Body Performance

It is well-documented that the anabolic hormone T contributes to the long-term hypertrophy of type II muscle fibres, motor unit recruitment, and subsequent performance (Crewther, Cronin & Keogh, 2006; Hakkinen, Pakarinen, Alen, Kauhanen & Komi, 1988; Raastad, Glomsheller, Bjøro & Hallén, 2001). It is now suggested that T may acutely enhance neuromuscular performance in sprint and power events (Viru & Viru, 2005). The exact mechanism behind this proposed benefit in force production is still unclear (Crewther, Cook, Lowe, Weatherby & Gill, 2011). As previously mentioned, it is proposed that T may have non-genomic effects on skeletal muscle. T is thought to elicit rapid elevations in intracellular Ca^{2+} in the sarcoplasmic reticulum whilst also regulating electrophysiological contractile properties (Ekstrand, Battaglini, McMurray & Shields, 2003; Estrada, Liberona, Miranda & Jaimovich, 2000; Passaquin, Lhote & Rüegg, 1998). The action of T has expressed increases in peak force production in rodents (Hamdi & Mutungi, 2010), while this study provides evidence for the possible mechanism for the non-genomic effect of T, the effect in humans remains unclear. With that said, a systemic review by Dent, Fletcher and McGuigan (2012) concluded that the changes within the contractile process, brought about by T, may enhance the muscles ability to produce power.

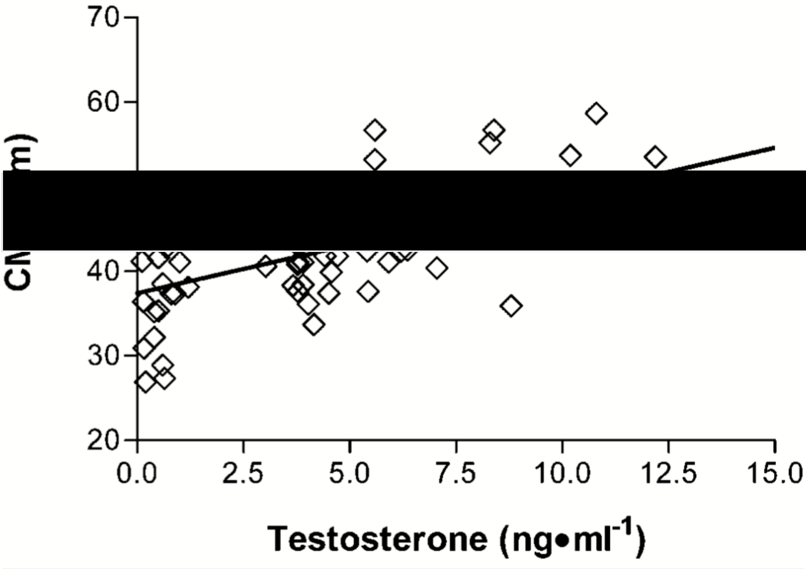


Figure 2.3 – Relationship between T concentrations and CMJ jump height (Cardinale & Stone, 2006)

Early work by Bosco et al. (1998) found a 30% rise in serum T concentrations following a 60s jumping protocol. The elevations in T significantly correlated with the average power output (r = 0.61) and jump height (r = 0.66) of sixteen male professional footballers. It was suggested that the exercise protocol was too short to provoke the T response and acutely enhance jumping performance. However, Obminski et al. (1998) similarly reported seeing rises in T and performance after such short time periods reporting improvements in leg power in the second of two 10s-cycle sprints where a rise in T was seen following the first. More recently, Cardinale et al. (2006) also associated T concentrations with jumping performance finding a significant correlation (r = 0.61, $p < 0.001$) between CMJ jump height and T concentrations in both men and women, as shown in *Figure 2.3.*

Using thirty-four professional male rugby players Crewther et al. (2009b) gave further evidence for the involvement of T in muscular performance. Using an array of lower-body performance parameters, there were numerous correlations with salivary T. The stronger correlations were typically associated with the 'backs' who demonstrated high sprint speeds and jumping performance when compared to the 'forwards'. One of such correlations linked salivary T concentrations to 10-20 m, 10-30 m and 20-30 m sprint times (r = 0.65). Crewther et al. (2009b) highlighted the importance of using salivary T as an indirect measure of free testosterone, providing a more sensitive endocrine marker than that of total T.

As previously mentioned, T concentrations rhythmically fluctuate. Over the waking day T typically peaks ~08:00 and steadily declines to a nadir ~20:00 (Cook et al., 2014; Guignard, Pesquies, Serrurier, Merino & Reinberg, 1980; Kreamer et al., 2001; Piro, Fraioli, Sciarra & Conti, 1973). Recent work from Teo et al. (2011) looked into the circadian rhythmicity of salivary T and markers of lower-body performance. When testing at four intervals across the day (08:00, 12:00, 16:00, 20:00) there was no significant relationships between salivary T concentrations and peak force or power across the time intervals. Critically, the participants only needed one year of recreational lifting to take part in the study. As earlier discussed, Crewther et al. (2012) showed how training status of an athlete can significantly change the interaction between T concentrations and lower body performance tests. Cook, Crewther and Smith (2012) showed that elite female athletes can exhibit double the concentration of T when compared to non-elite athletes ($87pgml^{-1}$ v $41pgml^{-1}$), when considering the aforementioned performance benefits of T, the training and competitional status of an athlete may significantly affect free T and its interaction with performance parameters.

In summary, while not conclusive it appears that T may have an effect on muscular performance. Particularly on the force production mechanism by influencing the availability of Ca^{2+} in the contractile process. This could directly enhance the speed and power of an athlete, increasing the chance of success.

2.2.4 - Performance Motivation

As well as enhancing an athletes' neuromuscular performance, T has been shown to have an effect on motivational behavior which is a complex construct portraying elements of task, situational and environmental specificity (Vallerand, 2004). The influence of T on motivation has been investigated in a variety of settings, showing that individuals with higher T concentrations are likely to make larger financial risks (Coates, Gurnell & Sarnyai, 2010). Dose administration of T has been linked with a reduction in unconscious fear (van Honk, Peper & Schutter, 2005) and an increase in motivation to engage in primed action concepts (Aarts & van Honk, 2009). More pertinently, acute changes in T have been shown to predict competitive motivation (Carré & McCormick, 2008).

Using 12 highly trained males, Cook et al. (2012) investigated the T responses when viewing themed video clips and how they affect voluntary squat performance. The themes of the videos were: erotic, aggressive, sad, motivational, and humorous. The participants watched a 4-minute video and then performed a workout aimed at finding their 3RM back squat, which was used as a well-regulated marker of motivation. Both the erotic and aggressive videos elicited a significant rise in T concentrations when compared to the control (6.9% and 13% respectively). The rise in T resulted in significantly increased back squat load - erotic (2.1%) and aggressive (5.4%). A strong correlation between relative changes in T and 3RM (r = 0.85) highlight the obvious link in this investigation. A follow up study by Cook et al. (2013) also suggested the link between salivary T and voluntary workloads, where a strong correlation (r = 0.81) affirmed the potential association of T and athletic motivation.

Most recently, Cook et al. (2018) evaluated the link between self-perceptual motivation and salivary T in elite and non-elite women athletes. The study showed that on average over the month the elite group had significantly more T than the non-elite, highlighting the hormones importance in sporting success. Stronger within-subject relationships were seen between basal salivary T significantly correlated with self-rated motivation (r = 0.70-0.75) in the elite group than the non-elite group (r = 0.41-0.50). The same pattern continued for the muscular performance tests suggesting that the T concentrations of the elite group were more consistently related to motivation and muscular performance, aligning with the aforementioned suggestion of Crewther el al. (2012).

2.2.5 - Cognitive Performance

Following the effect of T on aspects of athlete motivation, a theorised causal influence on competitive decision making is plausible. There is a lack of research on T and its association with cognitive enhancement, especially regarding elite sport. Large proportions of current literature are based on clinical populations; which hypothesise that the decline of T in older males may correlate with the age-related reduction in cognition (Cherrier et al. 2005; Kenny et al. 2002; 2004). Furthermore, low concentrations of T may be an indirect risk factor in developing Alzheimer’s disease (Ramsden et al., 2003). Muller, Aleman, Grobbee, De Haan & van der Schouw (2005) revealed a positive curvilinear association between T and a variety of cognitive tests, where higher concentrations were associated with greater cognitive performance. The males in the lowest quintile for T concentrations performance significantly worse overall than males in the top quintile; where the cognitive tests were designed to measure memory, processing speed and executive function. Whilst the study used an age range of 40-

80 years the proposed mechanism of T effect on cognition still remain uniform. The motion of T influence on cognition was additionally enhanced when exogenous T was supplemented (Cherrier et al., 2005; O'Connor, Archer, Hair & Wu, 2001). Reporting elevations of 20-40 nmol/L in T levels, further improved cognition - posed questions over the existence of an optimal concentration.

The mechanism which T influences activity in the brain mirrors those in the reproductive and muscular skeletal system. As previously mentioned, T is synthesized from cholesterol in the testes and adrenal gland. T can then be (1) converted to estradiol by aromatase in the brain (2) metabolized to dihydrotestosterone (DHT), enabling the molecule to bind to androgen receptors. Subsequently, T has the ability to act as both an androgen and estrogen in both sexes. Due to T engaging in differing pathways when acting in the brain it can affect a variety of regions: prefrontal cortex (Finley & Kritzer, 1999), amygdala (Abdelgadir, Roselli, Choate & Resko, 1999) and hippocampus (Sarrieau et al., 1990). All of which play an important role in memory and crucial cognitive tasks.

Early work from Muller (1994) associated lower salivary T with slower mean reaction times and a higher number of passive avoidance reactions, aligning with previously discussed theories of T influence on motivation and dominance. Later, Muller et al. (2005) revealed a curvilinear association between T and a variety of cognitive tests, where higher concentrations were associated with greater cognitive performance. Most recently, 54 female participants were administrated 0.5mg of exogenous T and then tested for their competitive decision making following a victory and a loss scenario. Competitive decision making increased but only following a winning scenario. In contrast, all participants' showed reductions in decision making after a losing scenario. While this investigation concluded that T had enhanced competitive decision making the study only used competition regarding social status adding to previous work surrounding social dominance (Muller & Wrangham, 2004; Wingfield, Hegner, Dufty & Ball, 1990), rather than providing a novel approach involving decision making during a sporting contest.

Morning exercise has been linked with improving afternoon performance in a number of cognitive tests (Chang, & Etnier, 2009; Cooper, Bandelow, Nute, Morris & Nevill, 2012). Both studies demonstrated reductions in response times during a computer-based Stroop test while diminishing the relative fall in accuracy across the day when compared to the control. As earlier mentioned T exhibits a circadian rhythm, declining throughout the day (Kreamer et al., 2001). Cook et al. (2014) suggested that following an acute bout of exercise in the morning, afternoon decline of T can be off-set. To date no study has looked into the plausible link between morning exercise attenuating the afternoon decline in T and subsequent cognitive performance.

2.3 - Priming Literature

2.3.1- Critical Review

Early work by Mason et al. (2007) investigated improving afternoon power output following a morning priming session in thirteen State level rugby players. The study used a test-retest protocol with a counterbalanced crossover design. The priming session attempted to effect both upper- and lower-body potentiation using 4x3 for both barbell back squat and bench press; while using an unloaded bar with resistance applied using bands which totalled 46.8kg. An improvement in upper-body performance was reported, with rises of 8.5 ± 5.8% and 13.9 ± 7.0% in bench press throw PPO and peak force respectively. These improvements weren't replicated in lower body performance; with a mean fall of 3.4 ± 4.9% in CMJ PPO reported. The variability in neuromuscular responses among the same population suggests possible inconsistencies in the stimulus, specifically the use of identical priming loads for the upper and lower-body was likely to produce contrasting results due to the differing strength levels of the muscle groups. In addition to the low stimulus, this was the only study not to use individualised load calculations for their priming session. Similarly, the priming protocol may have lacked the required volume or intensity to induce a significant hormonal response. The session was neither hypertrophic nor power based. Work by Kraemer et al. (1990; 1991; 1999) showed a hypertrophic design (240 total repetitions) could elicit a 72% increase in T and 27% following a strength session (155 total repetitions). With a total volume of 12 repetitions, at a minimal load, the variable results could be due to a lack of stimulus. Notably, there was only 1h and 45minutes between the priming session and performance tests, the shortest rest period for a priming protocol to date. Raastad and Hallen (2000) found performance and fatigue markers took up to 3h to return to baseline following a 'moderate-load weight session', due to the 22% decrement in electrically evoked force production it was concluded that peripheral fatigue was a main contributing factor, although central fatigue wasn't excluded. The equivocal results throughout the field has led to differing theories on priming session structure and how they affect possible physiological mechanisms. Fry, Stone, Thrush and Fleck (1995) suggested that athletes fall into 'responders' and 'non-responders' when testing afternoon performance following a bout of low volume Olympic lifting in the morning. Out of 19 male lifters, 6 were identified as 'responders' and demonstrated mean increases in vertical jump (4.5%), snatch (6%) and clean (5.2%) 5h and 30mins post resistance session, while the other 13 lifters saw small reductions. Interestingly, those 6 'responders' were associated with having significantly higher perceptions of anxiety compared to the 'non-responders', suggesting the possible involvement of the endocrine system in the differing results.

Focusing on the structure of the priming session, De Villarreal, González-Badillo & Izquierdo (2007) investigated the neuromuscular effects of differing priming protocol (PP) over a 6h recovery period using twelve trained volleyball players. Five priming protocols were conducted, as shown in *Table 2.2*, ranging from ballistic movements to strength sessions. Significant improvements in leg performance 6h post warm up were reported; PP2 resulted in 2.48% rise in DJ height, PP3 elicited a larger 5.47% rise, whilst the strength-based protocols both found positive effects on performance after 6h recovery. A ballistic protocol saw the greatest benefit in lower leg power output. PP1 showed a 9.03% increase in DJ PPO and 4.18% elevation in DJ height, across the same 6h period. The variety in the PP of the study gave insight into the differing effects on performance.

***Table 2.2* –** Priming protocols, (De Villarreal et al., 2007)

Session	**Protocol**
PP1	3x5 optimally loaded CMJ
PP2	2x4 at 80% , 2x3 at 85% 1RM
PP3	2x4 at 80% , 2x2 at 90% , 2x1 at 95% 1RM
PP4	3x5 optimal height DJ
PP5	Volleyball specific warm up
PP6	3x5 at 30% 1RM half squat

Whilst volume did not differ significantly between protocols, the results of this study suggest an load-dependent relationship where using higher loads demonstrated the greatest influence. Interestingly, this was also the case following PP1 which used high specificity to enhance jumping performance. In agreement with findings of Mason et al. (2007), protocols using low-load sessions (i.e. 30% 1RM back squat) seem to have limited effect on delayed muscular performance.

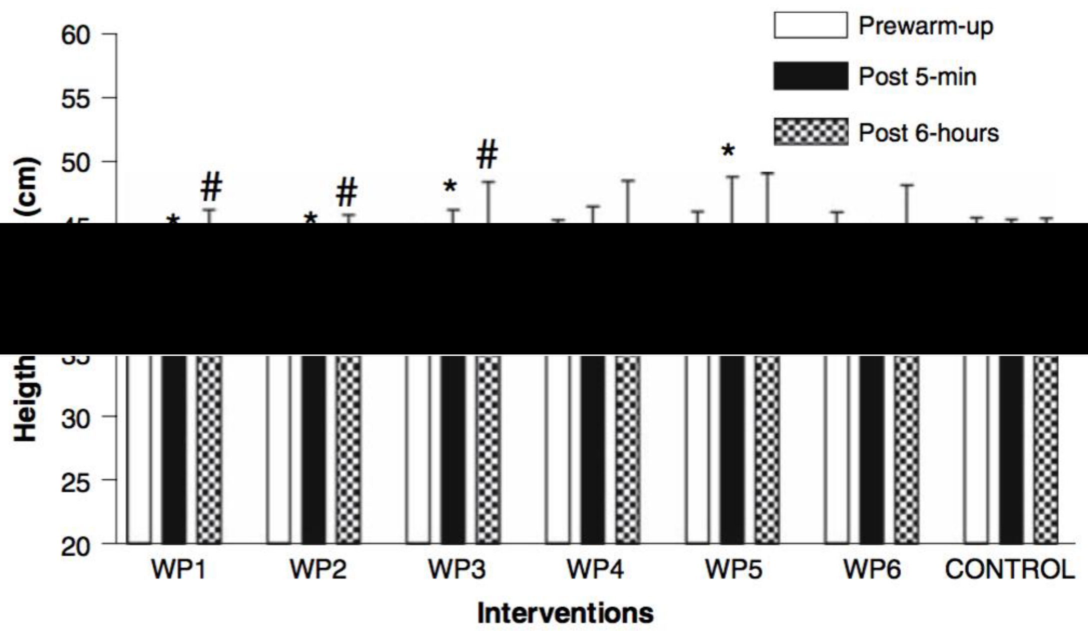


Figure 2.4 - Maximal DJ height (cm) **P* < 0.05 = significant difference from prewarm-up to post-5 min. # *P* < 0.05 = significant difference from prewarm-up to post-6 h (De Villarreal et al., 2007)

Later work from Ekstrand et al. (2013) investigated the effect of a morning weights session on afternoon jumping and backwards overhead shot throw (BOST). The protocol for the priming session consisted of 4x6 at 35%1RM power cleans followed by 1x6 at 50%, 1x1 at 85% back squat. This study used loaded protocols similar to Mason et al. (2007) and De Villarreal et al. (2007) which both appeared not to contain enough stimulus to elicit a performance benefit. The low volume of back squats led to no significant change in vertical jump height 4-6h later. However, a significant increase of 2.6% in afternoon BOST distance was reported. It was noted that the similarity in movement pattern and muscle recruitment of a power clean and a BOST may have influenced the positive result. While this paper intended to investigate the effects of morning exercise on afternoon performance, the afternoon performance tests for the control and experimental trials were completed at different time. The control tests were completed between 13:00-15:00 and the experimental tests at 14:00-16:00. Therefore, the same athlete could have their test times differ by 3h which could ultimately affect performance, particularly if diurnal hormone changes are believed to be involved.

Cook et al. (2014) also set out to investigate the effect morning weights has on afternoon performance. Using eighteen semi-professional rugby players in a repeated measures design. The players completed a control trial and then one of two possible priming sessions. Weights- 3x50% 3RM, 3x80% 3RM, 3x100% 3RM for back squat and bench press. Sprints- 50%, 80%, 3x100% of maximal sprint with 45s rest between sets. This was the first study to measure hormonal responses to a priming session, utilizing both salivary T and C levels. It was reported that T levels significantly dropped from am to pm in the control (-10.9 ± 2.4 $pgml^{-1}$). In the sprint trial T levels also dropped from am to pm (-2 ± 7.1 $pgml^{-1}$) but significantly less than the control. Crucially, in the weights trial, T levels remained the same from am to pm (-1.2 ± 5.5$pgml^{-1}$) suggesting the weights session offset the natural circadian decline in T.

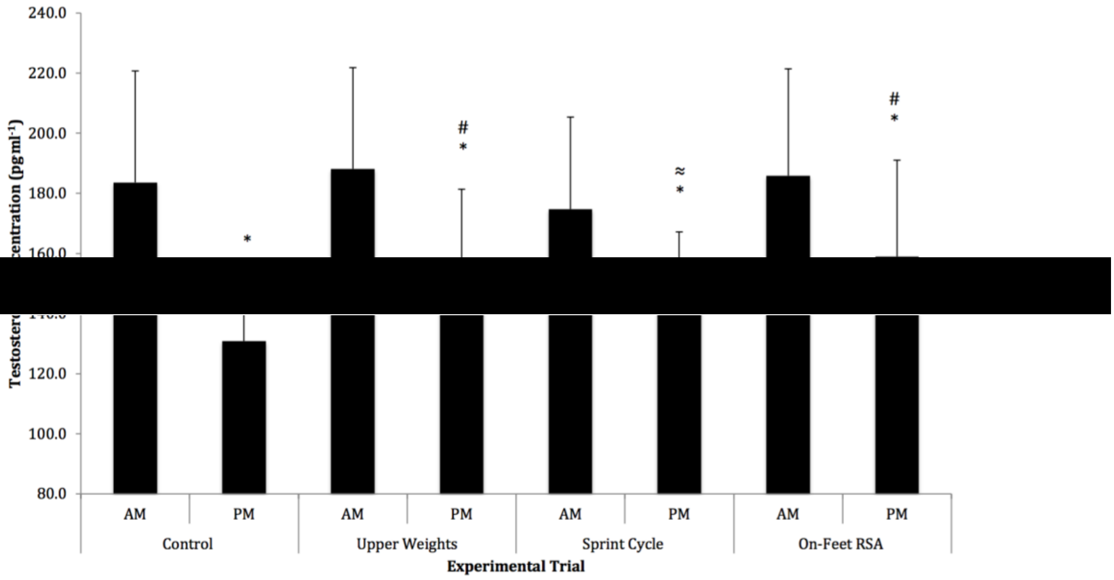
Table 2.3 **–** Player performance in response to the trials (Cook et al., 2014)

Condition	Performance			
	3RM BBP (kg)	3RM Squat (kg)	40 m (s)	CMJ PPO (W)
[redacted]				
Weights	144 ± 14[b]	175 ± 13[b]	5.16 ± 0.16[a,b]	4408 ± 378[b]

RM, repetition maximum; BBP, barbell bench press; PPO, peak power output.
[a] Indicates different to Control trial.
[b] Indicates different to all other conditions.

Shown in *Table 2.3*, the weights protocol saw increases in the 3RM for both bench press and back squat, improvements in 40m sprint times and elevated PPO in the CMJ; all of which were significantly different to the control. The Sprint protocol reported significant improvements in the sprint tests but not the 3RM or CMJ. The Weights protocol was similar to PP2,3 used by De Villarreal et al. (2007) which also reported improvements in lower leg performance, indicating both used adequate stimulus to obtain a hormonal response. Cook et al. (2014) attributed the augmented performance to the offsetting of the natural circadian decline - the first study to link the concepts.

Following on from the proposed involvement of T in priming, Russell et al. (2016) also investigated the effect of morning exercise on afternoon performance. Using 15 elite male rugby union players who first completed a control trial, then one out of three possible priming protocols. The weights session consisted of 5x10 70-75% 1RM of bench press, with 90s rest between sets. With the variable tests measuring lower body performance, this protocol was aiming to obtain a hormonal response. The other two priming protocols were as followed: Sprint- 6x40m repeated sprints, and Cycle - 6x6s maximal effort sprints with 7.5% bodyweight resistance). As seen in *Figure 2.5* there was an increase in pm T levels compared to the control for both weights (17.33 ± 17.5%) and sprint (22.34 ± 20.32%) but not cycle.



[redacted]

Figure 2.5 - Salivary testosterone responses to trials. * significant decline from AM time point ($p < 0.001$); # significant difference to Control at respective time point ($p < 0.01$); ≈ significant difference to Upper Weights and On-Feet RSA ($p < 0.05$) (Russell et al., 2016)

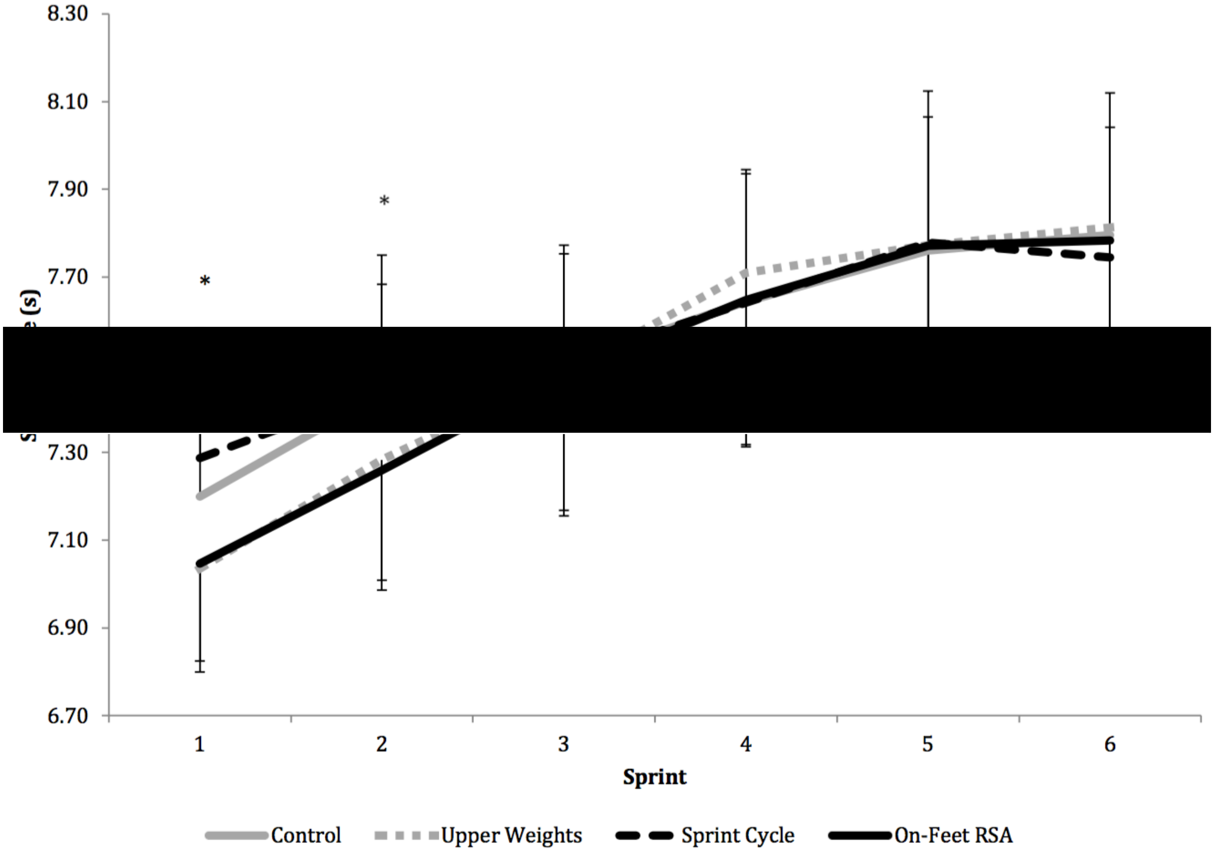


Figure 2.6 - Individual repeated-sprint times in response to trials. * Indicates significant main effect of trial ($p < 0.05$) at the corresponding time-point (Russell et al., 2016)

Despite the insignificant rise in T, the cycle protocol saw improvements in CMJ PPO and JH while the weights trial did not, suggesting the involvement of other mechanisms in combination with diurnal hormone changes. As shown in *Figure 2.6***,** the sprint protocol saw improvements in both CMJ parameters and the first two sprints of the RSA test – whereas, weights only saw similar improvements for the RSA test. As the sprint protocol reported the greatest responses in T and improvements in performance tests it would imply that combining specificity and an adequate stimulus for a T response would evoke the greatest performance benefit. This approach aligns with work by McGowan et al. (2017), who investigated the effect of a morning priming session on afternoon swim performance 6h later. Using thirteen competitive swimmers and two different priming protocols; swim only and swim dry (consisting of typical swimming specific resistance session). Time trial performance for a 100m afternoon swim was shown to significantly improve in the swim only trial (1.6 ± 0.6%) and swim dry trial (1.7 ± 0.7%) but not in the control. Similar improvements were seen in split times and stroke rate throughout the swim.

Tsoukos et al. (2018) looked into the 24h responses to a ballistic priming session. Using seventeen well-trained team sport athletes. The ballistic protocol comprised of a 5x4 jumps squats at 40% 1RM. Jumping performance was improved 6h post priming session, reporting rises in RSI (10.7 ± 2.1%) and CMJ height (5.1 ± 1.0%). Notably, an increase in CMJ height at 24h (3.0 ± 0.7%) suggests alternative neuromuscular mechanisms are at play. Most recently, Donghi et al. (2021) decided to investigate the effect of a morning priming session on afternoon performance of a younger population of elite soccer players (Age : 17 ± 1 years). Using the heavily adopted repeated sprint protocol, afternoon T was elevated above the control – but not to a similar extent as Russell et al. (2016). The lack of significant performance benefits were associated with the low baseline and negligible afternoon increase in T. This difference between previous work (Cook et al., 2014; Russel et al., 2016) was likely due to the contrasting age and training status of the athletes. However, with the progression of academy athletes into senior squads becoming more prevalent in professional sport, particularly cricket, this study highlighted that a morning priming session could be detrimental to afternoon performance.

2.3.2 - Priming Mechanisms

The potential mechanisms responsible for the positive effects as a result of priming remain unclear. It has been suggested that an athlete's T concentrations can be an effective predictor of performance, where higher concentrations are associated with elevations in squat strength, sprint speed (Crewther, Cook, Gaviglio, Kilduff & Drawer, 2012), motivation (Cook, Crewther & Kilduff, 2012, 2018) and cognition (Muller, Aleman, Grobbee, De Haan & van der Schouw, 2005). This aligns with previous research that also links testosterone to speed and power production, aiding an athletes' jump and sprint ability (Bosco et al., 1998; Cardinale & Stone, 2006; Crewther, Lowe, Weatherby, Gill & Keogh, 2009). T also seems to influence cognition acting as both a mental and physical ergogenic aid being positively linked with an athletes' motivation and readiness to perform, which could transfer to physical performance (Cook, Crewther, & Kilduff, 2013; Crewther, Carruthers, Kilduff, Sanctuary & Cook, 2016; Fry & Lohnes, 2010). As highlighted above Cook, Kilduff, Crewther, Beaven and West (2014) investigated the effect of morning resistance training on afternoon performance and attributed the improvement to diurnal hormone changes. They suggested a morning strength session could off-set the natural circadian decline in T, supporting the theory of T concentrations impacting performance as a viable mechanism for same day muscle priming. In addition, Russell et al. (2016) also suggested T had a role in the improvements of afternoon performance following a morning exercise bout. A morning upper body weights session significantly increased afternoon T (+17.33 ± 17.50 %, $p < 0.01$) and elicited an initial increase in sprint speed during the repeat ability test. This implies the rise in T as the most likely explanation for the elevation of afternoon performance as the athletes' legs had not been primed. However, findings from Russell et al. (2016) validate earlier speculation that neuromuscular mechanisms may also be at play. The cycling sprint protocol resulted in no significant increase in afternoon T when compared to the control but showed increases in PPO in the CMJ test 6h post session. The involvement of other secondary mechanisms would explain results of papers that found increased performance after 24-48h of recovery (Raastad & Hallén, 2000; Tsoukos, Veligekas, Brown, Terzis & Bogdanis, 2018). As aforementioned, Fry et al. (1995) debated the involvement of an athlete's psychological state, specifically anxiety levels - suggesting it could not only effect their neuromuscular performance but ability to harness afternoon benefits following a morning priming session. It is widely accepted that an athlete's psychological stress during competition is likely to have an impact on their performance (James & Collins, 1997). Early work by Filaire, Sagnol, Ferrand, Maso and Lac, (2001) suggested that the stress of competition brought about lower self-confidence and a rise in salivary C. More recently, Papacosta, Nassis and Gleeson, (2016) also concluded that higher levels of anxiety were linked to a C response but was more commonly observed in winners, suggesting that such a psychophysiological response could give a competitional advantage. T has also been shown to respond to pre-competition stress. Arruda, Aoki, Paludo and Moreira, (2017) observed higher levels of salivary T prior to matches that were of perceived high importance to the player. While some studies have shown no link between anxiety and T or C responses (Haneishi et al., 2007; Thatcher, Thatcher & Dorling, 2004), their interaction and possible effect on performance outcome is of note.

When considering alternative mechanisms for priming, the timeframe that they could affect performance is often unclear. De Villarreal et al. (2007) debate the stimulation of high frequency motor neurons, which have been shown to improve the rate of force development (Güllich & Schmidtbleicher, 1996; Sale, 2002). However, the improvements have only been shown to last several minutes (French, Kraemer & Cooke, 2003) making its involvement in afternoon performance following a morning session doubtful. Peripheral mechanisms such as an increase in Ca^{2+} sensitivity in the actin-myosin interaction as a result of phosphorylation of regulatory light chains (Tillin & Bishop, 2009). While there is a bank of evidence supporting the acute increase of regulatory light chain phosphorylation in animal models, (Manning & Stull, 1982; Moore & Stull, 1984; Szczesna et al., 2002) its role in human performance remains undetermined. Tsoukos et al. (2018) made reference to mechanical stiffness as a possible reason for the increase in performance 24h after a plyometric resistance session. Mechanical stiffness has been associated with vertical jump height and isometric force development (Bojsen-Møller et al., 2005). Comyns, Harrison, Hennessy and Jensen (2007) elicited a temporary rise of 10.9% in leg stiffness 4 minutes after 1 set of 93% of a 1RM back squat, showing the potential enhancement following a priming session, the length of time that mechanical stiffness is acutely enhanced by resistance training remains unclear.

Kenny et al. (2003) found muscle temperature to be 3.2°C above baseline 40 minutes after an exercise session. Significant elevations were maintained to the last testing time at 75 minutes showing the possibility of these elevations lasting much longer. To date, no study has investigated the link between muscle or core temperature and priming. Every 1°C rise in temperature leading to a 4% increase in power output (Sargeant, 1987). If the rises in temperature are sustained, then its role in performance would be plausible.

Table 2.4 **-** Summary of priming literature

Author(s)	Participants	Exercise Protocol	T Response ($pgml^{-1}$) (am-pm)	Neuromuscular Response
Cook et al., (2014)	Eighteen semi-professional rugby union males	W - 3x50% 3RM, 3x80% 3RM, 3x100% 3RM S- 50%, 80%, 3x100%	W- ↓ 1.2 ± 5.5 S - ↓ 6.2 ± 7.1 Con - ↓ 10.9 ± 2.4	↑ 3RM for BP + BS (W, S) ↑ 40m Sprint performance (S,W)
De Villarreal et al., (2007)	Twelve trained volley ball males	WP 1- 3x5 jumps with optimal loaded CMJ WP2- 2x4 at 80% 1RM, 2x3 at 85% 1RM) WP3- 2x4 at 80% 1RM, 2x2 at 90% 1RM, 2x1 at 95% 1RM WP 4- 3x5 DJ from optimal height WP 5- Specific warm-up for volleyball match WP6- 3x5 at 30% 1RM		WP1- ↑ 9.03% in DJ PPO ↑ 4.18% in DJ height WP2- ↑ 2.48% in DJ height WP3- ↑ 5.47% in DJ height
Ekstrand et al., (2013)	Fourteen experienced shot put throwers	4x6 at 35%1RM- PC 1x6 at 50%, 1x1 at 85%-BS		↑ 2.6 % BOST No sig. VJ
Mason et al., (2007)	Thirteen state level rugby union males	4x3- BP, BS Resistance banded (46.8kg)		↑ 8.5 ± 5.8% BP throw ↑ 13.9 ± 7.0% BP PF ↓ 3.4 ± 4.9% CMJ PPO
Russell et al., (2016)	Fifteen elite rugby union males	W- 5x10 70-75% 1RM- BP S- 6x40m Cy- 6x6s	(Relative to control) W- ↑ 21.60 ± 22.69 S - ↑ 28.12 ± 25.53	Cy - ↑ 2.37 ± 1.70 % CMJ JH S- ↑ 3.92 ± 1.74 % CMJ JH ↑ in Sprint performance (W,S)
Tsoukos et al., (2018)	Seventeen well trained team sport athletes	5x4 at 40% 1RM- JS		↑ 10.7 ± 2.1% RSI ↑ 5.1 ± 1.0% CMJ JH

Note: T= Testosterone W= Weights S= Sprint WP= Warm up protocol RM= Repetition maximum Cy= Cycling JS= Jump squat JH= Jump height BP= Bench press BS= Back squat DJ= Drop jump RSI= Reactive strength index PF= Peak force PPO= Peak power output PC= Power clean Con= Control ↑= Increase ↓= Decrease

Chapter 3.0 - Methods

3.1 - Experimental Approach to the Investigation

This study investigated afternoon performance in response to a morning priming session, following a repeated-measures design. Afternoon performance parameters included: neuromuscular, mood and cognitive responses. All participants were required to attend the testing venue associated with their County on three separate occasions. Over a three week period each athlete completed a control and two experimental priming trials (Weights, On Feet Sprint) where tests were separated by at least 7 days to ensure full muscle recovery. Counties were asked to enforce a rest day 24h prior to testing. The study was completed during the pre-season block, where participants were familiar with regular weight training.

3.2 - Procedures Overview

The afternoon readiness to perform questionnaire, cognitive test, countermovement jumps (CMJ) and finally, 'run-two' sprint. A ~5h gap between priming protocols and re-testing was chosen to align with previous work in the field (Cook et al., 2014; Russell et al., 2016) whilst remaining feasible and consistent with current pre-competition strategies used in county and international cricketers.

3.3 - Participants

21 male professional cricket players were recruited (aged: 26 $\pm$ 6 years, body mass: 88.1 $\pm$ 4.4 kg, height: 184 $\pm$ 3.6 cm). All participants were given information sheets which outlined the procedures of the study. Initial consent was given by the coaches, then on the first day of testing the consent forms were signed by the players. All the participants had been engaging in recent training sessions leading up to the study and were declared fit to engage in the study by the medical staff employed by each County. Participants were also informed of the possible risks that were associated with partaking in the study and told they could withdraw at any time. Ethical approval was granted by Swansea University's ethical advisory board.

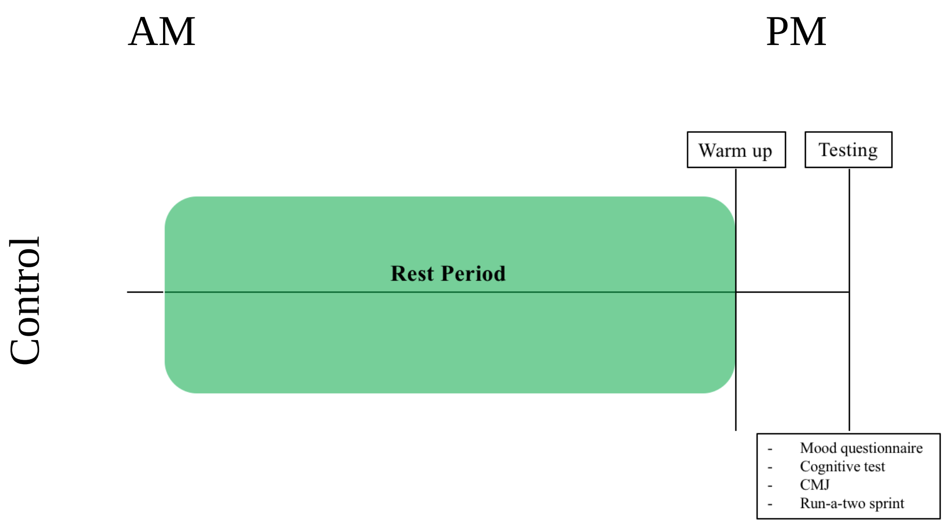


Figure 7 – Control procedure schematic

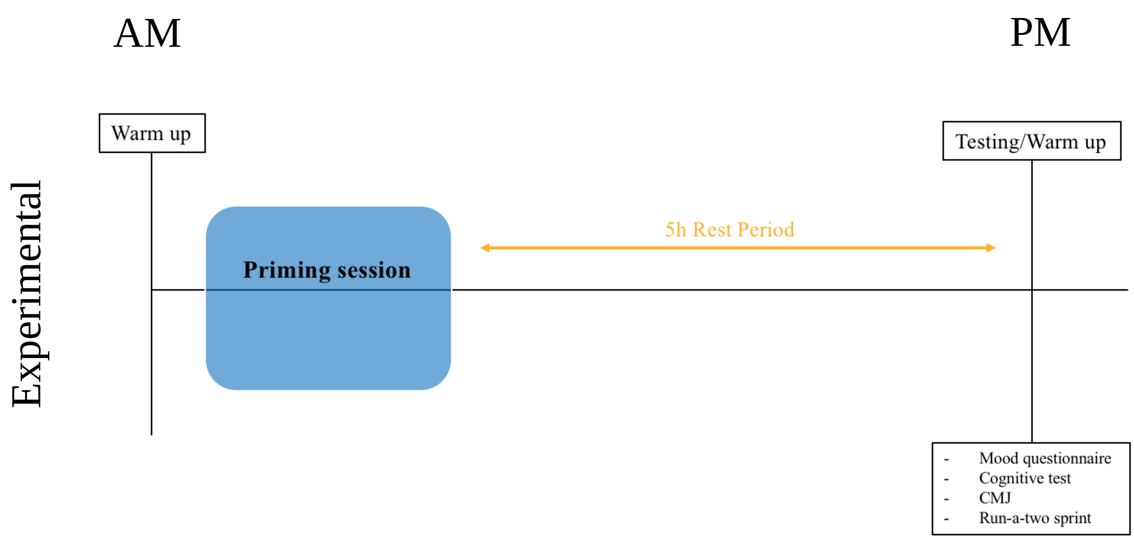


Figure 8 – Experimental procedure schematic

3.4 - Priming Protocols

Both priming protocols were completed in the morning of the experimental trials following a standardised 5-minute warm up. All participants completed at least one priming session and a control trial, sixteen participants completed both priming protocols.

3.4.1 - Lower-Body Weights

The Lower-body Weights protocol consisted of a trap bar deadlift session, completing one set of four repetitions at 50%, 70%, 80% then three sets of four repetitions at 85% of the participants one repetition maximum (1RM), totalling six sets (24 repetitions) where each set used 120s rest intervals. All participants were engaging in multiple weight training sessions per week, all were familiar with the trap bar deadlift. This weights session was based off similar loads to (Cook et al., 2014), which reported significant elevations in T and power-based performance tests.

3.4.2 - On-Feet Repeated Sprint Ability (RSA)

An adapted on-feet RSA protocol comprised of six sets of 35.36m sprints, each sprint required a 180° change in direction after the first 17.68m, where each set was separated by 30s passive rest. The distance of 17.68m aligns with the standard ‘Run-two’ English Cricket Board (ECB) test, coinciding with the afternoon performance parameter.

3.5 - Afternoon Performance Tests

Following the ~5h rest, all participants were required to complete the afternoon measures of performance. To avoid acute fatigue affecting the results the measures were conducted in order of perceived exertion, with the test likely to tax the participants the most positioned last. Participants were assessed for their readiness to perform, cognitive function, completed a CMJ to quantify lower-limb function and finally, a ‘run-a-two’ as a cricket specific marker of sprint performance.

3.5.2 - Readiness to Perform Questionnaire

Using an adapted version of the readiness to perform questionnaire (Appendix-) measuring the self-perceptual indicators of fatigue, aggression, soreness, mood and motivation- first used by (Mason et al., 2017). The questionnaire uses a 5-point Likert scale where participants mark on a scale from 0 (least) to 5 (Most) which derives an overall score based on the numerical values of the 5 subscales. The participants were instructed to isolate and complete the questionnaire without corroboration.

3.5.3 – Cognitive Function

All participants were asked to complete an app based Stroop test (EncephalApp Stroop).They were encouraged to remove themselves to a quiet space, with no corroboration. A total of 10 practice rounds were included (5 'Stroop off', 5 'Stroop on') following this, an assessed 'Stroop on' test was administered. Total time was automatically calculated as a sum of the time taken to completed the 5 individual rounds. Any mistakes resulted in the round being restarted, the additional time was not added onto the total time to complete.

3.5.4 - Assessment of Neuromuscular Performance

Participants were all familiar with the protocol; a maximal effort with arms akimbo (isolating leg drive). Mistakes were discounted and repeated. 10 participants used the force plate system; With the sample frequency set at 1000Hz, participants were instructed to step onto the platform (Kistler Instrumented, Type AG 5691A, Switzerland) and remain motionless for a minimum of 1s, enabling the collection of body weight via ground reaction forces. Vertical reaction force traces were analysed in Bioware and used to determine PPO following methods from Owen, Watkins, Kilduff, Bevan and Bennett (2014). Additionally, the CMJ has been expressed as the most reliable measure of lower body power r = 0.87 (Markovic, Dizdar & Cardinale, 2004) with a re-test reliability of r = 0.97 (Ostrowski et al. 1997). Jump height was determined as the difference in vertical displacement from toe-off to maximal vertical displacement, calculated by multiplying the sampling points by the time intervals. 11 participants completed the same CMJ protocol using the Optojump next (Microgate). Optojump uses photoelectric cells, which lie along two parallel bars (one transmitter and one receiver). The bars were set up ~1 m apart. The bars were connected to portable laptop (Optojump software, version 1.12.1.0). The Optojump system measured the flight time of vertical jumps with an accuracy of 1/1000 seconds (1 kHz). Jump height was then estimated as $9.81 \times \text{flight time}^2/8$. The test-retest reliability has been reported as 0.98-0.99 (Attia et al., 2017).

3.5.5 - Sprint Performance (Run-Two)

The cricket 'Run-two' is an established ECB standard test where the participants are required to replicate completing two runs; sprinting the distance of 17.68m with a standard cricket bat in either hand, slide the bat over the crease line, turn 180° and sprint back across the start line (ECB revised testing protocols, *unpublished).* Any occasion the participants bat failed to pass the crease line would be discounted. Sprint times were recorded using electronic timing gates (Brower Timing Systems, Salt Lake City, USA). Sprint times were recorded using electronic timing gates (Brower Timing Systems, Salt Lake City, USA), which have been show to exhibit intra-class correlations of 0.99 with coefficients of variance of 0.9% (Shalfawi, Enoksen & Tønnessen, 2012). The participants were able to push off from their preferred foot, ~50cm behind the start line, with bat in hand and waited for the command "3-2-1-GO". Three full splits (35.36m) were recorded per participant; The fastest of the three times was reported. Each county used their own indoor facilities with a rubber floor. Players were encouraged to use their normal footwear and training apparel, which was to be kept consistent through all trials.

3.6 - Statistical Analysis

Data are reported as mean ± SD, analysis was performed using IMB SPSS (Version 26; SPSS Inc., Chicago, IL, USA) with the level of significance set a $p < 0.05$. A repeated measures ANOVA was used, revealing any interactions between the trials across timepoints. Paired samples T-tests were applied where significant condition effects were reported in order to locate where the differences lay. Pearson's Correlation Coefficient was performed on absolute and relative strength levels, when compared to changes in physical performance. Data was checked for normality, Mauchly's test of sphericity was consulted and if sphericity values were exceeded then Greenhouse-Geisser corrections were applied. Hedge's effect sizes (ES) were calculated for post-hoc comparisons.

Chapter 4.0 - Results

4.1 - Run-Two Sprint Time

There was a significant condition effect for Run-two sprint times from the trials (p = 0.001 (*Figure 4.1)* Sprint (p = 0.013 ES: 0.26), Trap bar (p = 0.001 ES: 0.43),. The mean sprint times following the priming protocols were both significantly improved compared to the control; moreover, the Trap bar protocol saw a further significant reduction from the Sprint trial (p = 0.032 ES: 0.18) (CON = 5.99 ± 0.17s, Sprint = 5.94 ± 0.17s, Trap bar = 5.91 ± 0.17s). There was no significant correlation between absolute baseline strength and change in performance for either protocol (Sprint: r = 0.338, p = 0.221; Trap Bar: r = 0.302, p = 0.132). When baseline strength was reported relative to bodyweight, significance was still not found (Sprint: r = 0.259, p = 0.32 ; Trap Bar: r = 0.252, p = 0.251).

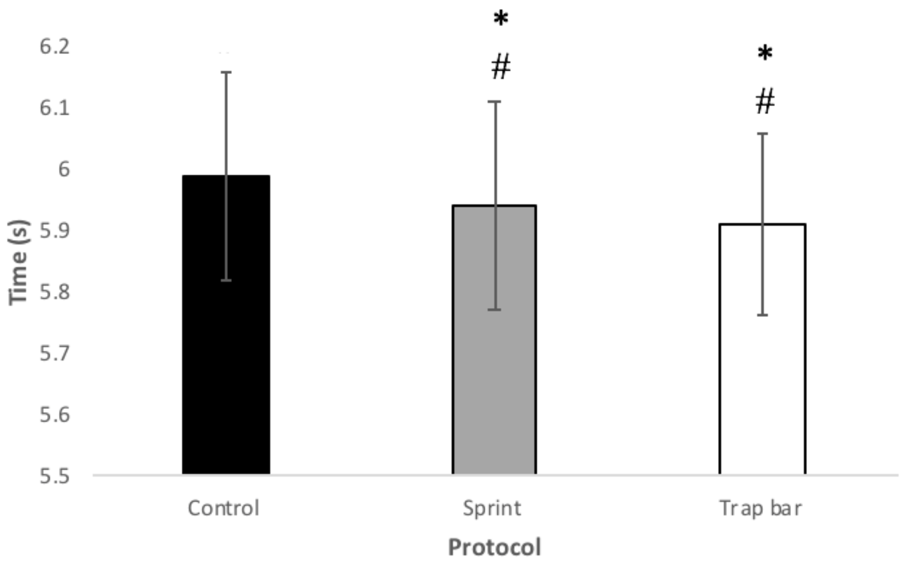


Figure 4.1 – Run-two sprint time response to priming protocols. * indicates significant decline from the control (p < 0.05). # indicates significant from the respective protocol (p < 0.05).

4.2 - Countermovement Jump Height

There was a significant condition effect for countermovement JH from the trial (p = 0.041)((*Figure 4.2)*. Both the Sprint and Trap bar protocol were elevated above the mean control JH (CON = 43.8 ± 6.8cm, Sprint = 45.0 ± 7.3cm, Trap bar = 45.2 ± 6.5cm) respectively. The mean JH of the Trap bar protocol was significantly elevated when compared to the control (p = 0.021 ES: 0.15), No significant correlation was found between absolute (Sprint: r = -0.225, p = 0.312 ; Trap Bar: r = -0.1, p = 0.170) or relative (Sprint: r = 0.115, $p > 0.05$; Trap Bar: r = -0.338, p = 0.246) baseline strength levels and change in jump performance following either priming protocol.

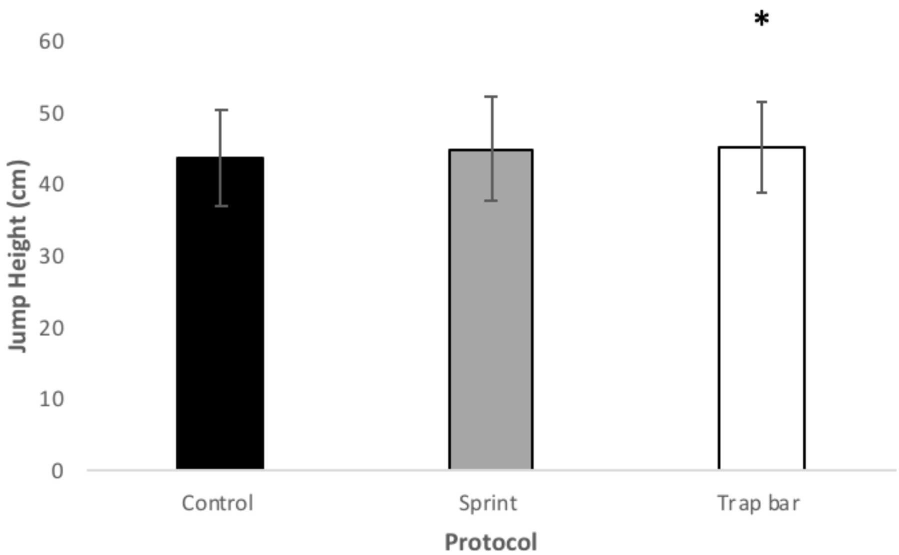


Figure 4.2 – Countermovement jump height response to priming protocols.. * indicates significant increase from the control ($p < 0.05$).

4.3 - Cognitive Function

Figure represents the participants total time to complete a Stroop test as a marker of cognitive function. Time for completion was significantly reduced by the priming protocols, reporting a condition effect with the trials (p = 0.001), the Trap bar (p = 0.003 ES: 0.56) and Sprint (p = 0.023 ES: 0.90) protocol saw significant reductions when compared to the control. The total mean times for completion were reported as CON – 51.1 ± 4.7s, Sprint – 48.4 ± 3.6s, Trap bar – 47.9 ± 2.8s.

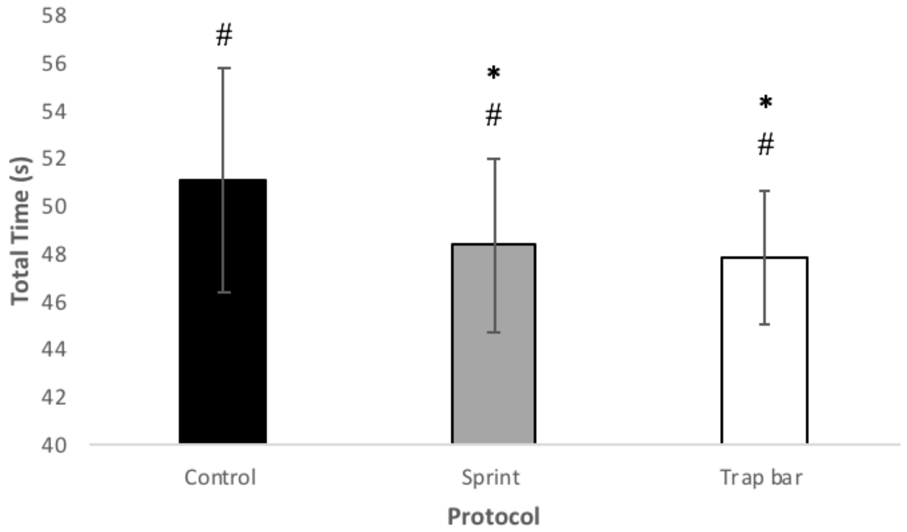


Figure 4.3 – Time to completion of a Stroop test in response to priming protocols. * indicates significant decline from the control ($p < 0.05$). # indicates significant from the respective protocol ($p < 0.05$).

4.4 - Readiness to Perform

No interaction effect was seen between the trials and the athletes readiness to perform in the afternoon (*p = 0.130)* Individual mood characteristics of the questionnaire were assessed, highlighting a significant rise in the participants aggression following the Trap bar protocol when compared to the control ($p = 0.011$).

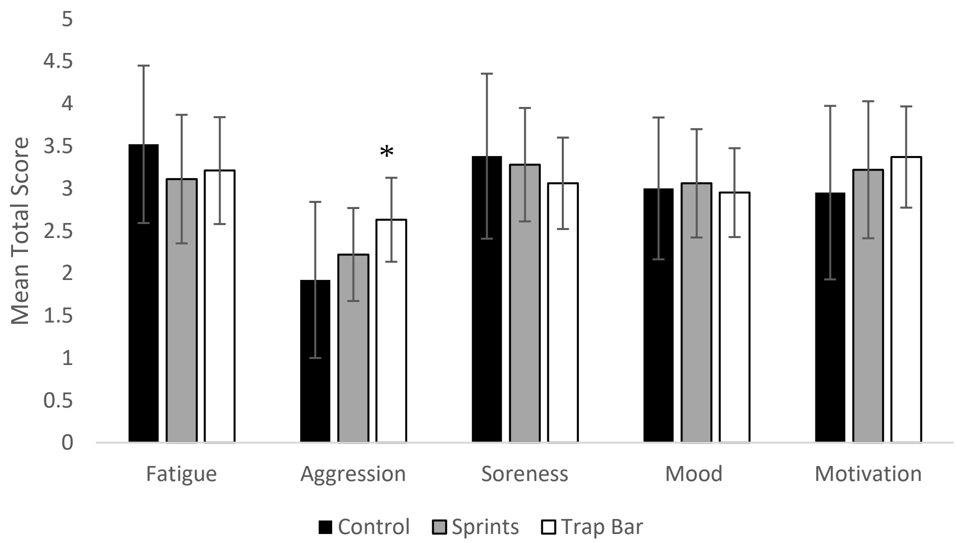


Figure 4.4 – Mean score for each mood characteristic. * indicates significant increase from the control ($p < 0.05$).

Chapter 5.0 – Discussion

This study investigated the efficacy of differing morning exercise protocols on afternoon neuromuscular, mood and cognitive performance in professional cricket players. Aligning with our hypothesis, morning exercise protocols elicited a beneficial effect in the afternoon - across all performance parameters. Both protocols (Trap bar and Sprint) saw significant reductions in afternoon Run-two sprint times, ~5h post a morning priming session. Moreover, the Trap bar session resulted in further significant improvements in performance when compared to Sprint. This finding was in agreement with Cook et al. (2014) who also found a morning weights session to have a greater impact on afternoon sprint performance when compared to a morning Sprint (on-feet) protocol. The trend in responses in both studies may be as a result of the larger T response from the weights session, aligning with (Cook et al. 2014; Russell et al. 2016), as T positive effect on sprint performance is well documented (Crewther et al. 2009b; Cook et al. 2014; Viru & Viru, 2005). The proposed non-genomic effects skeletal muscle is thought to have a positive effect on the contractile process (Dent et al., 2012) specifically, T evoking elicit rapid elevations in intracellular Ca^{2+} in the sarcoplasmic reticulum whilst also regulating electrophysiological contractile properties (Ekstrand et al., 2003; Estrada et al., 2000; Passaquin et al., 1998). Sprint performance underpins key determinants of success in all the facets of cricket; Batting (Duffield & Drinkwater, 2008), bowling (Duffield et al., 2009; Ferdinands et al., 2010; Glazier et al., 2000) and fielding (Carr et al., 2015). While this study showed the proposed benefit of a morning priming session on afternoon sprint times, Russell et al. (2016) only noted a significant improvement in performance for the first 2 bouts of a 40m repeated sprint test. This suggests the potential benefit of priming could diminish over repeated bouts of high intensity exercise; the effectiveness of the pre-competition strategy in cricket may be limited to the early efforts in a game, such as the start of a bowling spell or batting innings. While this study did not investigate the effectiveness of priming on repeated run-two sprint times, this could provide a meaningful finding for further research.

Contrary to Cook et al. (2014), this study aligns with Russell et al. (2016) by observing a meaningful change in afternoon sprint performance following the Sprint (on-feet) protocol; Russell et al. (2016) attributes the differing results to the lack of afternoon T attenuation. This study, similar to Russell et al. (2016) followed a Sprint protocol encompassing a 180° turn at the mid-point of the bout. It is documented that a change in direction during a sprint will increase time spent in acceleration, potentially resulting in greater elevations of blood lactate (Akenhead, French, Thompson & Hayes, 2015). With increased concentrations of blood lactate being linked to secretion of T (Crewther et al., 2011; Lin et al., 2001), it is plausible that the change in direction in combination with the greater bouts of maximal sprint efforts in this study and Russell et al. (2016) aided the afternoon performance benefit. Improvements across afternoon JH were in conjunction with former research (De Villarreal et al., 2007; Russell et al., 2016), more notably (Cook et al., 2014) who also saw only significant improvements following the weights trial – with a marginal rise following the Sprint (on-feet) protocols. Other studies (Harrison et al., 2019) have suggested that factors such as muscle temperature could also be influencing the increase in neuromuscular performance following a morning priming session. The studies in the area have only suggested that this elevation and subsequent improvement in peak power output would express a temporary effect (Kenny et al., 2003) – and therefor any positive thermal effect is unlikely to extend to 5 ½ hours post exercise protocol.

Along-side the ergogenic physical effects of morning exercise, this study adds to the growing research on morning exercise enhancing afternoon cognitive performance (Chang, & Etnier, 2009; Cooper, et al., 2012), potentially supporting the notion of the beneficial role of T on cognitive performance, in particular decision making and reaction-based tasks (Crewther, Cook, Cardinale, Weatherby & Lowe, 2011; Muller et al., 2005). Both protocols saw significant reductions in the time to complete the Stroop test compared to the control, with the Trap bar session seeing even further significant reductions than the Sprint. This could be a marker of the Trap bar session evoking a larger T response, as seen by Cook et al. (2014), demonstrating a dose dependent response on cognition. The mechanism of action of T on cognition is still to be fully understood. Janowsky (2006) suggested that T is readily converted to estradiol in the brain by the aromatase, the result of this can positively impact stimulation in the hippocampus and amygdala - structures which are vital to learning and memory. (Hopwood et al., 2011; Regan et al., 1979; Stretch et al., 2000) noted the importance of reaction time and decision making in professional cricket, particularly when batting and fielding, this exaggerates the finding of a morning exercise session not only attenuating the usual decline in cognitive task but further significantly improving it.

When evaluating a pre-competition strategy like priming, balancing the positive neuromuscular performance benefits and fatigue, specifically the athletes readiness to perform, is crucial to its practical implementation. This is the first study to evaluate an athlete's self-perceived readiness to perform in the afternoon, following a morning priming session. Whilst the RTP scores were not reported to be significantly elevated above the control, the marginal increase when having completed a morning exercise session would be considered a main finding. Gill (2014) noted that athletes often report an anecdotal 'feel good' period following a bout of exercise and it was speculated that a ~5h gap would diminish this effect with the onset physical and mental fatigue. Aggression, as an individual factor of the questionnaire was significantly raised following the Trap bar protocol, which may also be a marker of this session eliciting a greater T response.

Interestingly, there were 3 potential ‘non-responding’ individuals who didn’t see any increase in either the run-two or CMJ tests. This has been previously discussed by Fry et al. (1995), who associated non-responders with having significantly higher levels of perceived anxiety, furthering the perceived involvement of the endocrine system as a primary mechanism. Priming responses have often been to be individualised, determining factors that may influence and predict success was investigated. Seitz & Haff (2016) suggested that stronger athletes may elicit a greater priming response, in this study it was concluded that neither absolute or body weight relative strength levels have any influence on the priming performance outcomes in professional cricketers - this warrants further investigation. As mentioned throughout this study, diurnal changes can have a significant effect on athletic performance (Cook et al., 2014). When investigating individualised responses to priming, protocols can be adapted to optimise the physiological state of an athlete during competition. An athletes chronotype has been shown to have a significant impact on the time of an individual’s peak performance, impacting cognition, neuromuscular performance and mood (Facer-Childs, Boiling & Balanos, 2018), this is of particular importance in professional cricket as matches commence at a variety of times – dependent of the competition format. Individuals can often be split into early chronotypes (ECT) or late chronotypes (LCT), ECT have reported improvements in performance parameters in the morning, peaking ~14:00 thereafter declining over the day. The less prevalent LCT (~ 10% of elite athletes) have expressed improvements in performance parameters in the evening, typically peaking ~22:00 (Brown, Neft & LaJambe, 2008). While the expression of an athletes chronotype may not explain the variation in responders, it may influence the magnitude of the response. As previously discussed, partaking in a morning priming session may off-set the circadian decline in T and subsequently cognitive and athletic performance. With ~90% of elite athletes being classified as ECT (Lastella, Roach, Halson & Sargent, 2016), evening fixtures may not coincide with the typical ~14:00 peak in performance of the chronotype subset. Engaging in a morning priming session may prove beneficial by eliciting an attenuation of the afternoon decline in T as expressed in (Cook et al., 2014) and consequently, neuromuscular performance, cognition and mood as demonstrated from this study – this could allow for an improved window of peak performance while working in conjunction with the natural chronotype of the athlete.

Naturally, this study contains some limitations. Due to government restrictions, saliva samples could not be collected and analysed for T + C concentrations in response to the priming protocols. The same restrictions lead to tightly managed groups of participants partaking on a rotational basis – due to these restrictions it wasn't feasible to use a random cross-over design, all athletes were made to complete the control and then the experimental trials on following weeks. The lack of a randomised order may have led to an order effect, where the athletes could have increased their performance in the testing parameters over the study due to increasing levels of familiarisation. Minimising this, the athletes were all familiar with the CMJ and run-two sprint protocols – regularly partaking in both as part of their training and as progression markers for their teams. None of the athletes had previously engaged in a Stroop test before partaking in this study, so it is possible a level of familiarisation bias could led the results of the Stroop test to improve following each attempt. To limit this, the athletes engaged in 5 practice rounds before their results were recorded.

Future directions of research could incorporate salivary T + C samples as originally planned in this study – to provide further clarity into the mechanisms at play when a priming effect is observed. Factoring in athletes chronotypes could also provide novel research to professional cricket, to aid optimal performance in a sport where fixtures have a wide variety of start times. Involving further cognitive tests to evaluate the effect of priming on cricket specific reaction times or visual analysis of picking up subtle cues of bowlers during delivery.

5.1- Conclusion

In professional cricket, this study demonstrates that a bout of morning exercise can be integrated as a strategy to evoke significant elevations in neuromuscular and cognitive performance whilst improving the athletes readiness to perform. Specifically 4 reps at 50%, 70%, 80%, 3 x 4 at 85% 1RM of Trap bar deadlift saw the greatest elevations across the afternoon performance tests. Whilst the use of a repeated 'Run-two' sprint protocol (6 x 35.36m with a 180° turn at the midpoint) also offered afternoon performance benefits. The use of the sprint protocol might prove a more viable protocol for away travel when access to gym equipment may be limited; whilst providing an option to interchange the sessions if game days are back to back with no rest day in between.

References

Aarts, H., & van Honk, J. (2009). Testosterone and unconscious positive priming increase human motivation separately. *Neuroreport, 20*(14), 1300-1303.

Abdelgadir, S. E., Roselli, C. E., Choate, J. V., & Resko, J. A. (1999). Androgen receptor messenger ribonucleic acid in brains and pituitaries of male rhesus monkeys: studies on distribution, hormonal control, and relationship to luteinizing hormone secretion. *Biology of reproduction*, *60*(5), 1251-1256.

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of motor behavior*, *39*(5), 353-367.

Akenhead, R., French, D., Thompson, K., & Hayes, P. (2015). The physiological consequences of acceleration during shuttle running. *International journal of sports medicine, 36*(04), 302-307.

Arruda, A. F., Aoki, M. S., Paludo, A. C., & Moreira, A. (2017). Salivary steroid response and competitive anxiety in elite basketball players: Effect of opponent level. *Physiology & behavior, 177*, 291-296.

Attia, A., Dhahbi, W., Chaouachi, A., Padulo, J., Wong, D. P., & Chamari, K. (2017). Measurement errors when estimating the vertical jump height with flight time using photocell devices: the example of Optojump. *Biology of sport*, *34*(1), 63.

Beyenburg, S., Watzka, M., Clusmann, H., Blümcke, I., Bidlingmaier, F., Elger, C. E., & Stoffel-Wagner, B. (2000). Androgen receptor mRNA expression in the human hippocampus. *Neuroscience letters*, *294*(1), 25-28.

Bojsen-Møller, J., Magnusson, S. P., Rasmussen, L. R., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. *Journal of applied physiology*, *99*(3), 986-994.

Bosco, C., Cardinale, M., Tsarpela, O., Colli, R., Tihanyi, J., Von Duvillard, S., & Viru, A. (1998). The influence of whole body vibration on the mechanical behaviour of skeletal muscle. *Biol Sport*, *153*, 157-164.

Brown, F. M., Neft, E. E., & LaJambe, C. M. (2008). Collegiate rowing crew performance varies by morningness-eveningness. *The Journal of Strength & Conditioning Research*, *22*(6), 1894-1900.

Cardinale, M., & Stone, M. H. (2006). Is testosterone influencing explosive performance? *The Journal of Strength & Conditioning Research*, *20*(1), 103-107.

Carré, J. M., & McCormick, C. M. (2008). Aggressive behaviour and change in salivary testosterone concentrations predict willingness to engage in a competitive task. *Hormones and behavior*, *54*(3), 403-409.

Carr, C., McMahon, J. J., & Comfort, P. (2015). Relationships between jump and sprint performance in first-class county cricketers. *Journal of Trainology*, *4*(1), 1-5.

Chang, Y. K., & Etnier, J. L. (2009). Effects of an acute bout of localized resistance exercise on cognitive performance in middle-aged adults: A randomized controlled trial study. *Psychology of Sport and Exercise*, *10*(1), 19-24.

Coates, J. M., Gurnell, M., & Sarnyai, Z. (2010). From molecule to market: steroid hormones and financial risk-taking. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1538), 331-343.

Comyns, T. M., Harrison, A. J., Hennessy, L., & Jensen, R. L. (2007). Identifying the optimal resistive load for complex training in male rugby players. *Sports Biomechanics*, *6*(1), 59-70.

Cook, C. J., & Crewther, B. T. (2012b). Changes in salivary testosterone concentrations and subsequent voluntary squat performance following the presentation of short video clips. *Hormones and behavior*, *61*(1), 17-22.

Cook, C. J., Crewther, B. T., & Smith, A. A. (2012a). Comparison of baseline free testosterone and cortisol concentrations between elite and non-elite female athletes. *American Journal of Human Biology*, *24*(6), 856-858.

Cook, CJ., Crewther, BT., and Kilduff, LP. (2013). Are free testosterone and cortisol concentrations associated with training motivation in elite male athletes? *Psychology of Sport and Exercise*, 14(6): 882-885.

Cook, C. J., Kilduff, L. P., & Crewther, B. T. (2018). Basal and stress-induced salivary testosterone variation across the menstrual cycle and linkage to motivation and muscle power. *Scandinavian journal of medicine & science in sports*, *28*(4), 1345-1353.

Cook, CJ., Kilduff, LP., Crewther, BT., Beaven, M., and West, DJ. (2014). Morning based strength training improves afternoon physical performance in rugby union players. *Journal of Science and Medicine in Sport*, 17(3): 317-321.

Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity*, *5*(2), 183-190

Cherrier, M. M., Asthana, S., Plymate, S., Baker, L., Matsumoto, A. M., Peskind, E., ... & LaTendresse, S. (2001). Testosterone supplementation improves spatial and verbal memory in healthy older men. *Neurology*, *57*(1), 80-88.

Cherrier, M. M., Matsumoto, A. M., Amory, J. K., Ahmed, S., Bremner, W., Peskind, E. R., ... & Craft, S. (2005). The role of aromatization in testosterone supplementation: effects on cognition in older men. *Neurology*, *64*(2), 290-296.

Cherrier, M. (2009). Testosterone effects on cognition in health and disease. In *Advances in the Management of Testosterone Deficiency* (Vol. 37, pp. 150-162). Karger Publishers.

Crewther, B. T., Carruthers, J., Kilduff, L. P., Sanctuary, C. E., & Cook, C. J. (2016). Temporal associations between individual changes in hormones, training motivation and physical performance in elite and non-elite trained men. *Biology of sport*, *33*(3), 215.

Crewther, B. T., Cook, C. J., Gaviglio, C. M., Kilduff, L. P., & Drawer, S. (2012). Baseline strength can influence the ability of salivary free testosterone to predict squat and sprinting performance. *The Journal of Strength & Conditioning Research*, *26*(1), 261-268.

Crewther, B. T., Cook, C., Cardinale, M., Weatherby, R. P., & Lowe, T. (2011). Two emerging concepts for elite athletes. *Sports medicine*, *41*(2), 103-123.

Crewther, B. T., Cook, C. J., Lowe, T. E., Weatherby, R. P., & Gill, N. (2011). The effects of short-cycle sprints on power, strength, and salivary hormones in elite rugby players. *The Journal of Strength & Conditioning Research*, *25*(1), 32-39.

Crewther, B., Cronin, J., & Keogh, J. (2006). Possible stimuli for strength and power adaptation: acute metabolic responses. *Sports Medicine*, *36*(1), 65-79.

Crewther, B. T., Lowe, T., Weatherby, R. P., & Gill, N. (2009a). Prior sprint cycling did not enhance training adaptation, but resting salivary hormones were related to workout power and strength. *European journal of applied physiology*, *105*(6), 919.

Crewther, B. T., Lowe, T. I. M., Weatherby, R. P., Gill, N., & Keogh, J. (2009b). Neuromuscular performance of elite rugby union players and relationships with salivary hormones. *The Journal of Strength & Conditioning Research*, *23*(7), 2046-2053.

Dent, J. R., Fletcher, D. K., & McGuigan, M. R. (2012). Evidence for a non-genomic action of testosterone in skeletal muscle which may improve athletic performance: Implications for the female athlete. *Journal of sports science & medicine*, *11*(3), 363.

Devlin, TM. (2010). *Textbook of Biochemistry with Clinical Correlations.* 7th ed. United States: John Wiley & Sons. 916-928.

Donghi, F., Rampinini, E., Bosio, A., Fanchini, M., Carlomagno, D., & Maffiuletti, N. A. (2021). Morning Priming Exercise Strategy to Enhance Afternoon Performance in Young Elite Soccer Players. *International Journal of Sports Physiology and Performance*, *16*(3), 407-414.

Duffield, R., Carney, M., & Karppinen, S. (2009). Physiological responses and bowling performance during repeated spells of medium-fast bowling. *Journal of Sports Sciences*, *27*(1), 27-35.

De Villarreal, E. S. S., González-Badillo, J. J., & Izquierdo, M. (2007). Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *European journal of applied physiology*, *100*(4), 393-401.

Ekstrand, L. G., Battaglini, C. L., McMurray, R. G., & Shields, E. W. (2013). Assessing explosive power production using the backward overhead shot throw and the effects of morning resistance exercise on afternoon performance. *The Journal of Strength & Conditioning Research*, *27*(1), 101-106.

Estrada, M., Espinosa, A., Müller, M., & Jaimovich, E. (2003). Testosterone stimulates intracellular calcium release and mitogen-activated protein kinases via a G protein-coupled receptor in skeletal muscle cells. *Endocrinology*, *144*(8), 3586-3597.

Estrada, M., Liberona, J. L., Miranda, M., & Jaimovich, E. (2000). Aldosterone-and testosterone-mediated intracellular calcium response in skeletal muscle cell cultures. *American Journal of Physiology-Endocrinology And Metabolism*, *279*(1), E132-E139.

Facer-Childs, E. R., Boiling, S., & Balanos, G. M. (2018). The effects of time of day and chronotype on cognitive and physical performance in healthy volunteers. *Sports medicine-open*, *4*(1), 1-12.

Fry, A. C., & Lohnes, C. A. (2010). Acute testosterone and cortisol responses to high power resistance exercise. *Human physiology*, *36*(4), 457-461.

Fry, A. C., Stone, M. H., Thrush, J. T., & Fleck, S. J. (1995). Pre-competition training sessions enhance competitive performance of high anxiety junior weightlifters. *The Journal of Strength & Conditioning Research*, *9*(1), 37-42.

French, D. N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *The Journal of Strength & Conditioning Research*, *17*(4), 678-685.

Ferdinands, R., Marshall, R. N., & Kersting, U. (2010). Centre of mass kinematics of fast bowling in cricket. *Sports Biomechanics*, *9*(3), 139-152.

Filaire, E., Sagnol, M., Ferrand, C., Maso, F., & Lac, G. (2001). Psychophysiological stress in judo athletes during competitions. *Journal of Sports Medicine and Physical Fitness*, *41*(2), 263-268.

Finley, S. K., & Kritzer, M. F. (1999). Immunoreactivity for intracellular androgen receptors in identified subpopulations of neurons, astrocytes and oligodendrocytes in primate prefrontal cortex. *Journal of neurobiology*, *40*(4), 446-457.

Gierczuk, D., & Bujak, Z. (2014). Reliability and accuracy of batak lite tests used for assessing coordination motor abilities in wrestlers. *Polish Journal of Sport and Tourism*, *21*(2), 72-76.

Gill, N. (2014). Coach's insight: priming. *High-performance Training for Sports. Joyce D, Lewindon D, eds. Champaign, IL: Human Kinetics*, 308.

S. Glazier, P., Paradisis, G. P., & Cooper, S. M. (2000). Anthropometric and kinematic influences on release speed in men’s fast-medium bowling. *Journal of Sports Sciences*, *18*(12), 1013-1021.

Guignard, M. M., Pesquies, P. C., Serrurier, B. D., Merino, D. B., & Reinberg, A. E. (1980). Circadian rhythms in plasma levels of cortisol, dehydroepiandrosterone, δ4-androstenedione, testosterone and dihydrotestosterone of healthy young men. *European Journal of Endocrinology*, *94*(4), 536-545.

Güllich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New studies in athletics*, *11*, 67-84.

Haneishi, K., Fry, A. C., Moore, C. A., Schilling, B. K., Li, Y., & Fry, M. D. (2007). Cortisol and stress responses during a game and practice in female collegiate soccer players. *Journal of Strength and Conditioning Research*, *21*(2), 583.

Hamdi, M. M., & Mutungi, G. (2010). Dihydrotestosterone activates the MAPK pathway and modulates maximum isometric force through the EGF receptor in isolated intact mouse skeletal muscle fibres. *The Journal of physiology*, *588*(3), 511-525.

Hakkinen, K., Pakarinen, A., Alen, M., Kauhanen, H., & Komi, P. V. (1988). Neuromuscular and hormonal adaptations in athletes to strength training in two years. *Journal of applied physiology*, *65*(6), 2406-2412.

Harrison, P. W., James, L. P., McGuigan, M. R., Jenkins, D. G., & Kelly, V. G. (2019). Resistance priming to enhance neuromuscular performance in sport: evidence, potential mechanisms and directions for future research. *Sports Medicine*, 1-16.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers?. *International Journal of Sports Science & Coaching*, *6*(4), 523-535.

Janowsky, J. S. (2006). Thinking with your gonads: testosterone and cognition. *Trends in cognitive sciences*, *10*(2), 77-82.

James, B., & Collins, D. (1997). Self-presentational sources of competitive stress during performance. *Journal of Sport and Exercise Psychology*, *19*(1), 17-35.

Johnstone, J. A., & Ford, P. A. (2010). Physiologic profile of professional cricketers. *The Journal of Strength & Conditioning Research*, *24*(11), 2900-2907.

Kenny, A. M., Bellantonio, S., Gruman, C. A., Acosta, R. D., & Prestwood, K. M. (2002). Effects of transdermal testosterone on cognitive function and health perception in older men with low bioavailable testosterone levels. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *57*(5), M321-M325.

Kenny, A. M., Fabregas, G., Song, C., Biskup, B., & Bellantonio, S. (2004). Effects of testosterone on behavior, depression, and cognitive function in older men with mild cognitive loss. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *59*(1), M75-M78.

Kenny, G. P., Reardon, F. D., Zaleski, W., Reardon, M. L., Haman, F., & Ducharme, M. B. (2003). Muscle temperature transients before, during, and after exercise measured using an intramuscular multisensor probe. *Journal of applied physiology*, *94*(6), 2350-2357.

Kilduff, L. P., Finn, C. V., Baker, J. S., Cook, C. J., & West, D. J. (2013). Preconditioning strategies to enhance physical performance on the day of competition. *International journal of sports physiology and performance*, *8*(6), 677-681.

Kraemer, W. J., Marchitelli, L., Gordon, S. E., Harman, E., Dziados, J. E., Mello, R., ... & Fleck, S. J. (1990). Hormonal and growth factor responses to heavy resistance exercise protocols. *Journal of Applied Physiology*, *69*(4), 1442-1450.

Kraemer, W. J., Gordon, S. E., Fleck, S. J., Marchitelli, L. J., Mello, R., Dziados, J. E., ... & Fry, A. C. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *International journal of sports medicine*, *12*(02), 228-235.

Kraemer, W. J., Häkkinen, K., Newton, R. U., Nindl, B. C., Volek, J. S., McCormick, M., ... & Putukian, M. (1999). Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *Journal of applied physiology*, *87*(3), 982-992.

Kraemer, W. J., Loebel, C. C., Volek, J. S., Ratamess, N. A., Newton, R. U., Wickham, R. B., ... & Rubin, M. R. (2001). The effect of heavy resistance exercise on the circadian rhythm of salivary testosterone in men. *European journal of applied physiology*, *84*(1-2), 13-18.

Land, M. F., & McLeod, P. (2000). From eye movements to actions: how batsmen hit the ball. *Nature neuroscience*, *3*(12), 1340-1345.

Lane, A. R., & Hackney, A. C. (2015). Relationship between salivary and serum testosterone levels in response to different exercise intensities. *Hormones*, *14*(2), 258-264.

Lastella, M., Roach, G. D., Halson, S. L., & Sargent, C. (2016). The chronotype of elite athletes. *Journal of human kinetics*, *54*, 219.

Lin, H., Wang, S. W., Wang, R. Y., & Wang, P. S. (2001). Stimulatory effect of lactate on testosterone production by rat Leydig cells. *Journal of cellular biochemistry*, *83*(1), 147-154.

Manning, D. R., & Stull, J. T. (1982). Myosin light chain phosphorylation-dephosphorylation in mammalian skeletal muscle. *American Journal of Physiology-Cell Physiology*, *242*(3), C234-C241.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research*, *18*(3), 551-555.

Mason, B. R., Argus, C. K., Norcott, B., & Ball, N. B. (2017). Resistance training priming activity improves upper-body power output in rugby players: implications for game day performance. *Journal of strength and conditioning research*, *31*(4), 913-920.

McGowan, C. J., Pyne, D. B., Thompson, K. G., Raglin, J. S., & Rattray, B. (2017). Morning exercise: enhancement of afternoon sprint-swimming performance. *International journal of sports physiology and performance*, *12*(5), 605-611

Mehta, P. H., van Son, V., Welker, K. M., Prasad, S., Sanfey, A. G., Smidts, A., & Roelofs, K. (2015). Exogenous testosterone in women enhances and inhibits competitive decision-making depending on victory–defeat experience and trait dominance. *Psychoneuroendocrinology*, *60*, 224-236.

Moore, R. L., & Stull, J. T. (1984). Myosin light chain phosphorylation in fast and slow skeletal muscles in situ. *American Journal of Physiology-Cell Physiology*, *247*(5), C462-C471.

Müller, M. J. (1994). Salivary testosterone and simple reaction time parameters. *Neuropsychobiology*, *30*(4), 173-177.

Muller, M. N., & Wrangham, R. W. (2004). Dominance, aggression and testosterone in wild chimpanzees: a test of the ‘challenge hypothesis’. *Animal Behaviour*, *67*(1), 113-123.

Muller, M., Aleman, A., Grobbee, D. E., De Haan, E. H. F., & van der Schouw, Y. T. (2005). Endogenous sex hormone levels and cognitive function in aging men: is there an optimal level?. *Neurology*, *64*(5), 866-871.

Noakes, T. D., & Durandt, J. J. (2000). Physiological requirements of cricket. *Journal of sports sciences*, *18*(12), 919-929.

O'Connor, D. B., Archer, J., Hair, W. M., & Wu, F. C. (2001). Activational effects of testosterone on cognitive function in men. *Neuropsychologia*, *39*(13), 1385-1394.

Ostrowski, K. J., Wilson, G. J., Weatherby, R., Murphy, P. W., & Lyttle, A. D. (1997). The effect of weight training volume on hormonal output and muscular size and function. *Journal of strength and Conditioning Research*, *11*, 148-154.

Papacosta, E., Nassis, G. P., & Gleeson, M. (2016). Salivary hormones and anxiety in winners and losers of an international judo competition. *Journal of sports sciences*, *34*(13), 1281-1287.

Passaquin, A. C., Lhote, P., & Rüegg, U. T. (1998). Calcium influx inhibition by steroids and analogs in C2C12 skeletal muscle cells. *British journal of pharmacology*, *124*(8), 1751-1759.

Petersen, C., Pyne, D. B., Portus, M. J., & Dawson, B. (2008). Analysis of Twenty/20 cricket performance during the 2008 Indian Premier League. *International Journal of Performance Analysis in Sport*, *8*(3), 63-69.

Petersen, C., Pyne, D. B., Portus, M. R., & Dawson, B. (2009). Quantifying positional movement patterns in Twenty20 cricket. *International Journal of Performance Analysis in Sport*, *9*(2), 165-170.

Petersen, C., Pyne, D. B., Portus, M. R., Karppinen, S., & Dawson, B. (2009). Variability in movement patterns during One Day Internationals by a cricket fast bowler. *International Journal of Sports Physiology and Performance*, *4*(2), 278-281.

Petersen, C. J., Pyne, D. B., Portus, M. R., & Dawson, B. T. (2011). Comparison of player movement patterns between 1-day and test cricket. *The Journal of Strength & Conditioning Research*, *25*(5), 1368-1373.

Piro, C., Fraioli, F., Sciarra, P., & Conti, C. (1973). Circadian rhythm of plasma testosterone, cortisol and gonadotropins in normal male subjects. *Journal of steroid biochemistry*, *4*(3), 321-329.

Pocock, G., Richards, CD., and Richards, DA. (2018). *Human Physiology*. 5th ed. New York: Oxford University Press. 768-770

Raastad, T., Glomsheller, T., Bjøro, T., & Hallén, J. (2001). Changes in human skeletal muscle contractility and hormone status during 2 weeks of heavy strength training. *European journal of applied physiology*, *84*(1-2), 54-63.

Raastad, T., & Hallén, J. (2000). Recovery of skeletal muscle contractility after high-and moderate-intensity strength exercise. *European journal of applied physiology*, *82*(3), 206-214.

Rampinini, E., Bishop, D., Marcora, S. M., Bravo, D. F., Sassi, R., & Impellizzeri, F. M. (2007). Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *International journal of sports medicine*, *28*(03), 228-235.

Ramsden, M., Nyborg, A. C., Murphy, M. P., Chang, L., Stanczyk, F. Z., Golde, T. E., & Pike, C. J. (2003). Androgens modulate β-amyloid levels in male rat brain. *Journal of neurochemistry*, *87*(4), 1052-1055.

Renshaw, I., & Fairweather, M. M. (2000). Cricket bowling deliveries and the discrimination ability of professional and amateur batters. *Journal of Sports Sciences*, *18*(12), 951-957.

Russell, M., King, A., Bracken, R. M., Cook, C. J., Giroud, T., & Kilduff, L. P. (2016). A comparison of different modes of morning priming exercise on afternoon performance. *International journal of sports physiology and performance*, *11*(6), 763-767.

Sale, D. G. (2002). Postactivation potentiation: role in human performance. *Exercise and sport sciences reviews*, *30*(3), 138-143.

Sargeant, A. J. (1987). Effect of muscle temperature on leg extension force and short-term power output in humans. *European journal of applied physiology and occupational physiology*, *56*(6), 693-698.

Sarrieau, A., Mitchell, J. B., Lal, S., Olivier, A., Quirion, R., & Meaney, M. J. (1990). Androgen binding sites in human temporal cortex. *Neuroendocrinology*, *51*(6), 713-716.

Seitz, L. B., & Haff, G. G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Medicine*, *46*(2), 231-240.

Shalfawi, S., Enoksen, E., & Tønnessen, E. (2012). Assessing test-retest reliability of the portable Brower speed trap II testing system.

Smirniotou, A., Katsikas, C., Paradisis, G., Argeitaki, P., Zacharogiannis, E., & Tziortzis, S. (2008). Strength-power parameters as predictors of sprinting performance. *Journal of Sports Medicine and Physical Fitness*, *48*(4), 447.

Spielberger, C. (2004). *Encyclopedia of applied psychology*. Academic press.

Szczesna, D., Zhao, J., Jones, M., Zhi, G., Stull, J., & Potter, J. D. (2002). Phosphorylation of the regulatory light chains of myosin affects Ca2+ sensitivity of skeletal muscle contraction. *Journal of applied physiology*, *92*(4), 1661-1670.

Tallent, J., Higgins, M. F., Parker, N., Waldron, M., Bradford, E., Keenan, J., & O'Neill, B. V. (2017). Quantification of bowling workload and changes in cognitive function in elite fast bowlers in training compared with twenty20 cricket.

Teo, W., McGuigan, M. R., & Newton, M. J. (2011). The effects of circadian rhythmicity of salivary cortisol and testosterone on maximal isometric force, maximal dynamic force, and power output. *The Journal of Strength & Conditioning Research*, *25*(6), 1538-1545.

Thatcher, J., Thatcher, R., & Dorling, D. (2004). Gender differences in the pre-competition temporal patterning of anxiety and hormonal responses. *Journal of sports medicine and physical fitness*, *44*(3), 300.

Thomas, N. G., Harden, L. M., & Rogers, G. G. (2005). Visual evoked potentials, reaction times and eye dominance in cricketers. *Journal of sports medicine and physical fitness*, *45*(3), 428.

Tillin, N. A., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports medicine*, *39*(2), 147-166.

Tsoukos, A., Veligekas, P., Brown, L. E., Terzis, G., & Bogdanis, G. C. (2018). Delayed effects of a low-volume, power-type resistance exercise session on explosive performance. *The Journal of Strength & Conditioning Research*, *32*(3), 643-650.

van Honk, J., Peper, J. S., & Schutter, D. J. (2005). Testosterone reduces unconscious fear but not consciously experienced anxiety: implications for the disorders of fear and anxiety. *Biological psychiatry*, *58*(3), 218-225.

Veness, D., Patterson, S. D., Jeffries, O., & Waldron, M. (2017). The effects of mental fatigue on cricket-relevant performance among elite players. *Journal of sports sciences*, *35*(24), 2461-2467.

Viru, A., & Viru, M. (2005). Preconditioning of the performance in power events by endogenous testosterone: in memory of Professor Carmelo Bosco. *Journal of strength and conditioning research*, *19*(1), 6.

Webster, T. M., Comfort, P., & Jones, P. A. (2020). Relationship Between Physical Fitness and the Physical Demands of 50-Over Cricket in Fast Bowlers. *Journal of Strength and Conditioning Research*.

Widmaier, EP., Raff, H., and Strang, KT. (2004). *Vanders, Sherman, & Luciano's Human Physiology: The Mechanisms of Body Functions.* 11th ed. New York: McGraw- Hill. 610-612.

Wingfield, J. C., Hegner, R. E., Dufty Jr, A. M., & Ball, G. F. (1990). The" challenge hypothesis": theoretical implications for patterns of testosterone secretion, mating systems, and breeding strategies. *The American Naturalist*, *136*(6), 829-846.

Ethical Approval

Fagan Aynsley.
Wed 22/04/2020 10:33
To: [redacted]

Dear Fergus,

Thank you for your recent ethics application.

This is to confirm that the ethics application "The neuromuscular, endocrine and cognitive responses to morning priming in professional cricket-ers." has been approved.

Your approval reference number is 2020-011 and the date of approval is 21.04.20.

Please keep note of this number for future reference.

Best of luck with your research.

Warm regards,
Aynsley Fagan
Programme Administrator

College of Engineering I Y Coleg Peirianneg
Swansea University I Prifysgol Abertawe
Fabian Way I Ffordd Fabian
Crymlyn Burrows
Swansea I Abertawe
Wales I Cymru
SA1 8EN

Phone I Ffôn [redacted]
Email I Ebost [redacted]

(Version 1.1, Date: XX /XX/20)

Project Title: The afternoon neuromuscular and cognitive responses to a morning priming session in professional cricketers.

Contact Details: [redacted]

1. Invitation Paragraph

I would like to invite you to take part in a research study that I am conducting with my supervisors, Prof. Liam Kilduff, Phil Scott (England cricket S&C), Dr Mark Waldron, and Prof. Mark Russell. We are interested in understanding more about muscular priming, the effect of a weights session on performance later in the day. We hope to be able to use these results in the future of match day preparation in professional cricket.

2. Why have I been chosen?

You have been chosen as a professional cricket player, the aimed population, that will hopefully benefit from the results of the study. You have the right to decline participation or withdraw at any point.

3. What will happen to me if I take part?

During this study you will be required to select a muscle priming exercise protocol from the protocols provided. Priming protocols have been discussed and amended with suggestions from team coaches. You will also be expected to partake in baseline and further testing following the resistance session. These tests include: Run-a-two, Countermovement and drop jumps, mood questionnaire and cognitive reaction tests.

4. What are the possible disadvantages of taking part?

The risks associated with this study include: Possible light fatigue following the resistance exercise and testing, mild muscular soreness in line with all weight sessions. As with all forms of training, there is a small possibility that the activities performed could lead to an unsuspected injury; however, the risk is no greater than that posed by your daily training regimes.

5. What are the possible benefits of taking part?

You are benefiting your and our understanding of match and training day competition, whilst engaging in a resistance training session.

6. Will my taking part in the study be kept confidential?

Any data collected will be kept strictly confidential and only accessed by the research team. Participants names will not be included in any presentations or reports; personal information will not be linked in any way to your data.

ECB S&C coach (Phil Scott) will also have access to non-anonymised data.

Data Protection and Confidentiality

Your data will be processed in accordance with the Data Protection Act 2018 and the General Data Protection Regulation 2016 (GDPR). All information collected about you will be kept strictly confidential. Your data will only be viewed by the researcher/research team.

All electronic data will be stored on a password-protected computer file. All paper records will be stored in a locked filing cabinet. Your consent information will be kept separately from your responses to minimise risk in the event of a data breach.

Please note that the data we will collect for our study will be made anonymous once the data has been collected, thus it will not be possible to identify and remove your data at a later date, should you decide to withdraw from the study. Therefore, if at the end of this research you decide to have your data withdrawn, please let us know before you leave.

Data Protection Privacy Notice

The data controller for this project will be Swansea University. The University Data Protection Officer provides oversight of university activities involving the processing of personal data, and can be contacted at the Vice Chancellors Office.

Your personal data will be processed for the purposes outlined in this information sheet. Standard ethical procedures will involve you providing your consent to participate in this study by completing the consent form that has been provided to you.

The legal basis that we will rely on to process your personal data will be processing is necessary for the performance of a task carried out in the public interest. This public interest justification is approved by the College of Engineering Research Ethics Committee, Swansea University.

The legal basis that we will rely on to process special categories of data will be processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes.

How long will your information be held?

We will hold any personal data and special categories of data for the duration of the study (24-36 months)

What are your rights?

You have a right to access your personal information, to object to the processing of your personal information, to rectify, to erase, to restrict and to port your personal information. Please visit the University Data Protection webpages for further information in relation to your rights.

Any requests or objections should be made in writing to the University Data Protection Officer:-

University Compliance Officer (FOI/DP)
Vice-Chancellor's Office
Swansea University
Singleton Park
Swansea
SA2 8PP
Email: dataprotection@swansea.ac.uk

How to make a complaint

If you are unhappy with the way in which your personal data has been processed you may in the first instance contact the University Data Protection Officer using the contact details above.

If you remain dissatisfied then you have the right to apply directly to the Information Commissioner for a decision. The Information Commissioner can be contacted at: -

Information Commissioner's Office,
Wycliffe House,
Water Lane,
Wilmslow,
Cheshire,
SK9 5AF
www.ico.org.uk

8. What if I have any questions?

Re-iterate that further information can be obtained from the researcher contact stated above. Also state that the project has been approved by the College of Engineering Research Ethics Committee at Swansea University. If you have any questions regarding this, any complaint, or concerns about the ethics of this research please contact Dr Andrew Bloodworth, Chair of the College of Engineering Research Ethics Committee, Swansea University. [redacted]. The institutional contact for reporting cases of research conduct is Registrar & Chief Operating Officer Mr Andrew Rhodes. Email: researchmisconduct@swansea.ac.uk. Further details are available at the Swansea University webpages for Research Integrity. http://www.swansea.ac.uk/research/researchintegrity/.

PARTICIPANT CONSENT FORM
(Version 1.1, Date: xx/xx/20xx)

Project Title:

The afternoon neuromuscular and cognitive responses to a morning priming in professional cricketers.

Contact Details:

[redacted]

Please initial box

1. I confirm that I have read and understood the information sheet dated 17/12/20 (version number 1.1) for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐
3. I understand that sections of any of data obtained may be looked at by responsible individuals from the Swansea University or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐

1. I understand that data I provide may be used in reports and academic publications in anonymous fashion ☐
2. I agree to take part in the above study. ☐

________________________________	_________________	__________________________
Name of Participant	Date	Signature
________________________________	_________________	__________________________
Name of Person taking consent	Date	Signature
________________________________	_________________	_______________________

READINESS TO PERFORM QUESTIONNAIRE

PRIVATE AND CONFIDENTIAL – FOR USE BY RESEARCH TEAM ONLY

Please circle to rate the following:

Name: ____________________ Date:_________ Time:_________

FATIGUE LEVELS				
1 Very Fatigued	**2** Fatigued	**3** Somewhat Fatigued	**4** Slightly Fatigued	**5** No Fatigue
LEVEL OF AGGRESSION				
1 Very Low	**2** Low	**3** Average	**4** High	**5** Very High
GENERAL MUSCLE SORENESS				
1 Very Sore	**2** Sore	**3** Somewhat Sore	**4** Slightly Sore	**5** No Soreness
MOOD				
1 Very Low	**2** Low	**3** Average	**4** High	**5** Very High
MOTIVATION TO COMPETE				
1 Very Low	**2** Low	**3** Average	**4** High	**5** Very High