Physiological and perceptual responses to training and competition in elite female netball players

Laurence Birdsey

[redacted]

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Abstract

Few studies have reported the physical demands of, and physiological responses to, training and competition in international netball players. This thesis set out to investigate this in female players via a series of studies. Study one characterised the playing demands of international match-play, and the physiological and perceptual responses to an international netball tournament. Mid-court performed at a higher Player Load^{TM} (mean difference ± standard deviation: 85.7% ± 49.6%), and internal intensity (mean heart rate: 3.7% ± 3.8%) than goal-based positions. Neuromuscular performance decreased after a single match (jump height: 4.0% ± 2.5%) whilst markers of muscle damage, soreness and perceived fatigue accumulated across the tournament. Study two characterised the physiological and perceptual responses to a regularly performed netball-training session. Neuromuscular performance was enhanced immediately post-exercise (Cohen's d effect size, percent change: peak power output: 0.47, 5%), returned to baseline two hours post, and was reduced 24 h post-training (peak power output: 0.27, 3%; jump height: 0.39, 6%). Study three investigated the effect of training-session order. Performing netball prior to strength training resulted in enhanced neuromuscular performance two hours post-training (peak power output: 1.2, 5%; jump height: 1.2, 9%; peak velocity: 1.0, 3%), whilst strength followed by netball reduced neuromuscular performance at 20 h post (peak power output: 1.1, 4%; jump height: 1.4, 10%; peak velocity: 1.4, 4%). This thesis provides a detailed investigation in to the responses to netball training and competition, as well as the impact of training-session order on neuromuscular, perceptual and endocrine responses over 20 h. Training should be individualised to condition players for the positional-specific external and internal demands of international match-play. To optimise training performance, two hours post-training could be a more favourable time to perform explosive training than the following day, whilst technical netball training should precede strength training when both sessions are performed within the same training day.

Declarations and statements

Declaration 1

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]………………..(candidate)

Date…………29/06/2021…..……………..

Declaration 2

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

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Statement 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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Statement 2

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

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List of abbreviations

20P: 20 hours post-session one
+0h: immediately post-training
+2h: two hours post-training
+24h: twenty four hours post-training
ATP: adenosine triphosphate
AU: arbitrary unit
BAM+: brief assessment of mood +
C: cortisol concentration
CK: creatine kinase
CV: coefficient of variation
dRPE: differential rating of perceived exertion
EMG: electromyography
HPA: hypothalamic-pituitary-adrenal
HR: heart rate
IPS1: immediately post-session one
IPS2: immediately post-session two
JH: jump height
MVC: maximal voluntary contraction
NET-STR: netball followed by strength session order
PPO: peak power output
PPOrel: peak power output relative to mass
Pre: baseline
PreS1: prior to training session one
PreS2: prior to training session two
PV: peak velocity
RPE-B: rating of perceived breathlessness
RPE-L: rating of perceived leg-muscle exertion
RPE-T: rating of perceived technical/ cognitive demand
RPE-U: rating of perceived upper-body muscle exertion
SD: standard deviation
sRPE: session rating of perceived exertion
STR-NET: strength followed by netball session order

T: testosterone concentration

T:C: testosterone to cortisol ratio

Chapter 1 General Introduction

1. Introduction

Netball is a team sport involving the performance of a 60-minute match, with international netball tournaments involving the performance of up to eight matches over a 10-day period. Competition demands are therefore not limited to that of a single match like many team sports, but rather high level performance across a series of matches with incomplete recovery. As such, players and teams alike must be conditioned to performing to a high level across a series of matches in order to gain success at the highest level, such as the Netball World Cup.

Characterising the movement demands of a sport permits provides a more detailed understanding, allowing the development of highly specific training programmes and ability to individualise training to individual or playing position (Young et al., 2016). The playing demands of netball have been assessed by the types of movements, distance covered and activities performed by use of notational analysis (Davidson & Trewartha, 2008; Fox, Spittle, Otago, & Saunders, 2013; Steele & Chad, 1992), accelerometry (Bailey, Gastin, Mackey, & Dwyer, 2017; Cormack, Smith, Mooney, Young, & O'Brien, 2014; Young, Gastin, Sanders, Mackey, & Dwyer, 2016), and more recently by use of an indoor positioning system (Brooks, Benson, Fox, & Bruce, 2020). All players have specified areas of the court in which they are able to play, with these court restrictions (along with positional specific roles) contributing to unique playing demands, including the types of movements (Fox et al., 2013), distance covered (Davidson & Trewartha, 2008), as well as type and frequency of activities (Bailey et al., 2017). However, whilst external playing demands of elite netball have been reported (Bailey et al., 2017; Brooks et al., 2020; Young et al., 2016), there are currently no reports in an elite or international tournament (involving several matches played on consecutive days) which may yield differences due to consecutive match demands. Additionally, demands are limited to external only, with no reports highlighting internal demands, such as heart rate or rating of perceived exertion at any playing standard. Load is determined by a combination of exercise volume and intensity (Foster et al., 2001) and can encompass both external and internal dimension. External loads are quantified through objective markers of physical work performed, such as speed, accelerations and distance whilst internal load refers to the associated response, and typically includes heart rate and perceived effort (Bourdon et al., 2017). External load of netball increases with playing standard, indicative of greater distance covered, and number and frequency of accelerations, decelerations and jumping movements (Cormack et al., 2014), highlighting the importance of optimal physical conditioning at an elite standard. Whilst reports of playing demands allow movements (including distance and types of movements) and external load to be replicated in training for specific playing positions, the physiological or perceptual responses are unknown, highlighting a significant limitation for coaches and conditioning coaches in the preparation of players for competition.

International netball tournaments require the performance of a series of matches performed over consecutive days. Therefore not only are the internal and external demands of match-play required to be known to prepare optimally, but also the fatiguing responses to and recovery from competition. Knowledge of the perceptual, physiological and endocrine responses to a netball match or series of matches assists coaches and conditioning coaches to optimally prepare players for these demands, and also highlights appropriate strategies which could be employed to aid recovery and improve subsequent performance (Reilly & Ekblom, 2005). For example, following a competitive soccer match impairments in nervous system function (Brownstein et al., 2017), and sprint performance (Rampinini et al., 2011) can be evident for up to 48 hours post-match. This can have considerable impact upon subsequent athletic performance if competition were to be repeated in this time frame, as is the case in international netball tournaments. However, at present there are no suitable studies of fatiguing responses following either a single match, or series of matches, highlighting a considerable gap in the literature. One study highlights the countermovement jump and perceptual responses to a competitive match (Wood, Kelly, & Gabbett, 2013), however this was following an 80 minute match (versus 60 min as played internationally) and players performed the entire match, which is not commonly employed, especially in tournaments. Additionally, there are no studies of the endocrine responses to match-play, which may have important implications for behaviour (Bateup, Booth, Shirtcliff, & Granger, 2002; Crewther & Cook, 2018; Grant & France, 2001; Sapienza, Zingales, & Maestripieri, 2009), neuromuscular performance (Cook, Kilduff, Crewther, Beaven, & West, 2014; Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011; Gaviglio & Cook, 2014; Teo, McGuigan, & Newton, 2011) and athletic performance (Balthazar, Garcia, & Spadari-Bratfisch, 2012; Bermon & Garnier, 2017).

Training is key for players and teams to optimally condition for match-play demands. Indeed, players perform training in order to develop strength, speed and endurance as well as technical and tactical components related to performance (C. Thomas, Comfort, Jones, & Santos, 2017). Activity and playing demands of elite-standard match-play have been well reported (Bailey et al., 2017; Brooks et al., 2020; Young et al., 2016), allowing coaches and conditioning coaches to effectively plan training to target the external demands of training. However, coaches must also plan training to carefully provide periods of overload and recovery, in order to maintain training performance across a given period of training (Meeusen et al., 2013). Whilst acute responses to various types of training have been reported, such as following isolated resistance (Linnamo et al., 2000; Linnamo, Pakarinen, Komi, Kraemer, & Häkkinen, 2005; McCaulley et al., 2009), speed (Johnston, Cook, Crewther, Drake, & Kilduff, 2015) and soccer training (Sparkes et al., 2018), highlighting the type of fatigue experienced, the magnitude of such responses, and recovery profiles, there are no reports following netball training. Knowledge of these responses permits coaches and conditioning coaches to balance training stress and recovery, prevent over-training (Meeusen et al., 2013) and maximise adaptations (Bishop, Jones, & Woods, 2008; García-Pallarés, Sánchez-Medina, Carrasco, Díaz, & Izquierdo, 2009).

Netball players train multiple times per day, in order to improve the physical, technical and tactical qualities required for performance (Simpson, Jenkins, Scanlan, & Kelly, 2020). Training session order has been demonstrated to be an important consideration in concurrent training programmes. Negative impact has been reported when endurance exercise precedes strength exercise on hypertrophy (Kraemer et al., 1995), strength (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000; Jones, Howatson, Russell, & French, 2017; Kraemer et al., 1995) and power development (Häkkinen et al., 2003; Kraemer et al., 1995; Lee et al., 2020). This has been termed the interference effect (Fyfe, Bishop, & Stepto, 2014), and may be due to impaired signalling (Fyfe et al., 2014), reduced training performance (Leveritt, Abernethy, Barry, & Logan, 1999), or nutritional status (Areta et al., 2013; McBride, Ghilagaber, Nikolaev, & Hardie, 2009). Indeed, whilst the order of training sessions can impair recovery and subsequent training performance (Doma & Deakin, 2013), prior exercise has also been reported to improve subsequent training performance (Cook et al., 2014; Johnston et al., 2017; Mcgowan, Pyne, Thompson, Raglin, & Rattray, 2017; Russell et al., 2016). This has been demonstrated following a range of exercise modalities, including strength (Cook et al., 2014; Johnston et al., 2017), repeated sprint (Russell et al., 2016) and endurance (Mcgowan et al., 2017) exercise. Positive impact upon testosterone concentration (Cook et al., 2014; Russell et al., 2016), core temperature (Mcgowan et al., 2017) and neuromuscular function (Cook et al., 2014; Johnston et al., 2017; Russell et al., 2016) results in improved athletic performance (Cook et al., 2014; Mcgowan et al., 2017; Russell et al., 2016). As the acute endocrine, physiological and neuromuscular responses are specific to the type (Johnston et al., 2017;

Sparkes et al., 2020), volume (Thomas et al., 2014) and intensity (Crewther, Hamilton, Casto, Kilduff, & Cook, 2015) of exercise performed, it is important that these responses are characterised and understood. However, reports evaluating the impact of session order are currently limited in elite athletes with appropriate exercise protocols and recovery durations employed (Johnston et al., 2017; Sparkes et al., 2020), with none following netball training. It is therefore difficult to ascertain whether coaches are prescribing training in such a way as to optimise training performance of both training sessions and the ensuing adaptations.

Of the studies described, few have been performed with female participants, with scarce information in an elite female athlete population. Indeed, of the two highlighted studies reporting the effects of session order in elite team-sport players, both were performed with male participants. Many differences exist between males and females, including basal testosterone concentration (Linnamo et al., 2005), muscle mass and strength levels (Davies, Carson, & Jakeman, 2018), which are important for neuromuscular performance (Bishop, Cureton, & Collins, 1987; Cardinale & Stone, 2006) and may therefore result in altered responses to exercise. Additionally, elite female athletes have higher basal testosterone concentrations than less-trained females (Cook, Crewther, & Smith, 2012; Cook, Kilduff, & Crewther, 2018), with associated positive impact upon neuromuscular performance (Cook et al., 2018). Different endocrine responses have been observed between males and females, with an increase immediately post resistance exercise in testosterone concentration in males, and no change in females (Linnamo et al., 2005), whilst cortisol response (McCaulley et al., 2009; Nunes et al., 2011) and neuromuscular responses (Linnamo et al., 2005) are likely similar. However, more pronounced and longer recovery rates of neuromuscular fatigue have been reported in females compared with males following resistance exercise (Davies et al., 2018). Limited reports are available highlighting the responses to team-sport training in males and females. Of the reports available, it would appear that gender has limited effect upon immediate post-exercise responses (Eliakim et al., 2009), however may influence recovery rates of endocrine function (Mascarin et al., 2018; Sparkes et al., 2018), although this could be due to differences in training status of the participants. Females also undergo cyclical changes in circulating hormones, with biological impact which may influence the neuromuscular system (Cook et al., 2018). Of the few reports available, no effect of menstrual cycle phase on response and recovery of endocrine function has been reported following resistance exercise (Nakamura, Aizawa, Imai, Kono, & Mesaki, 2011), and no effect of hormonal contraceptive use has been reported on endocrine responses in elite hockey players (Crewther et al., 2015). It is therefore clear that a lack of reports are available following netball and strength training exercise in an elite female population.

Therefore, the purpose of this thesis was to examine the responses to netball competition and training, and to understand how best to organise training in elite female players. This was done by:

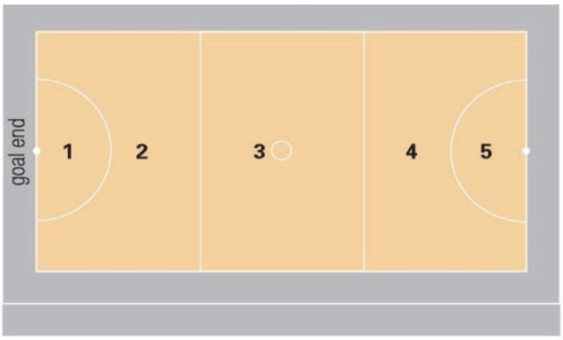
1. Quantifying the internal and external demands of international match-play.
2. Characterising the fatigue responses to both a single and series of international netball matches.
3. Characterising the physiological and fatigue responses to a netball-training session over 24 hours.
4. Investigating the effect of varying strength and netball training session order on performance and fatigue responses over 20 hours.

Chapter 2 Review of Literature

2.1 Netball

Netball is a team-sport played by two teams of seven players on a court with position-specific movement restrictions. Matches are played for 60 minutes, broken in to four 15-minute quarters, interspersed with four- and 12-minute breaks (between quarter and halves respectively). Whilst domestic elite leagues require teams to perform once, or twice, per week over a 16-week season (such as the British Superleague, the highest domestic league in the UK), tournaments can require a greater number of matches in a shorter period of time. For example, at the most recent World Cup (Netball World Cup, 2019) teams performed eight matches over ten days, meaning demands are not that of a single match, rather a high level of performance across a series of matches with limited recovery. However, limited data exists with regards to acute responses to a training session, single match, or competition match-play, making it difficult for the coach or conditioning coach to effectively plan and prescribe training.

A netball-court is divided into thirds with a goal circle at each end. All players have specified areas of the court in which they are able to play (Figure 2.1). For example, the centre position can play across areas two, three and four, requiring the player to cover the full distance of the court, and be active when their team is both defending and attacking. The goal keeper, in contrast, is only able to play in areas four and five, covering a far smaller area, only active when their team is defending and able to recover when the team is in possession of the ball and attacking. These court restrictions contribute to position-specific movement demands (Steele & Chad, 1992), activity profiles (Fox et al., 2013) and Player Load^{TM} performed (Young et al., 2016).



Position	Playing Areas				
Goal Shooter	1	2			
Goal Attack	1	2	3		
Wing Attack		2	3		
Centre		2	3	4	
Wing Defence			3	4	
Goal Defence			3	4	5
Goal Keeper				4	5

Figure 2.1 : Areas of the netball court which positions are permitted to play in. From: Rules of netball 2016, international netball federation. www.netball.sport/game/the-rules-of-netball

2.1.1 Movement demands of match-play

Early studies assessed netball demands via analysis of movement patterns, involving the assignment of each activity as a specific movement, such as standing, walking, jogging or running including the duration and frequency of such events (Davidson & Trewartha, 2008; Steele & Chad, 1992). More recently, these demands have been assessed in elite-level, including locomotor, in addition to game activity such as guarding, passing and shooting (Fox et al., 2013), as well as accelerometry (Bailey et al., 2017; Young et al., 2016). For example, early work by Steele and Chad (1991) analysed four netball matches played between State-level teams (New South Wales, Australia), and characterised activities in to locomotor (e.g. standing, walking, jogging) and non-locomotor (e.g. shooting, passing, rebounding) activities, and determined the relative contribution of match time spent performing each activity. It was found that although players performed activities for a very brief period of time, these movement were repeated a large number of times. For example, on average players stood still for 1.8 to 5.4 seconds, ran for 1.1 to 1.5 seconds and sprinted between 0.0 and 0.7 seconds per activity, dependent upon the position played (

Table 2.1). This work describes a highly intense, intermittent activity profile, where players perform explosive movements interspersed with short recovery periods which may include non-locomotor activities.

Table 2.1: Mean duration (seconds) spent performing each activity for each playing position during match-play (n = 4 per position). Reproduced from Steele and Chad (1991).

Activity	GS	GA	WA	C	WD	GD	GK
Standing	5.4	4.3	3.3	1.8	2.8	3.1	5.4
Walk forward	2.3	3.4	2.8	2.4	3.1	3.3	2.1
Walk backward	2.2	3.0	2.3	1.9	2.1	2.3	1.7
Walk sideways	1.2	1.0	0.9	0.9	1.0	1.1	1.9
Shuffle	1.6	1.7	1.3	1.6	1.7	1.9	1.9
Jog	1.3	1.4	1.5	2.1	1.7	1.7	1.2
Run	1.2	1.2	1.1	1.5	1.1	1.2	1.2
Sprint	0.0	0.4	0.6	0.7	0.5	0.0	0.3
Rebound	1.2	1.3	0.0	0.1	0.0	1.1	1.5
Pass	1.0	0.9	0.9	0.9	1.1	1.0	1.0
Catch	1.2	1.2	1.0	0.9	0.9	0.9	0.8
Jump	1.0	0.8	0.7	0.7	1.0	1.1	1.2
Guard	2.1	2.0	1.6	1.6	1.7	2.4	3.4
Defend	1.4	1.6	1.4	1.3	1.3	1.5	2.0

Abbreviations: GS: goal shooter, GA: goal attack, WA: wing attack, C: centre, WD: wing defence, GD: goal defence, GK: goal keeper.

Positional differences were also found with regards to the number of activities performed, the duration of each activity, and percent of the match spent performing each activity. Therefore, the authors suggest that as the energetic demands differed for positions, the training performed in preparation for competitive match-play should also differ. For example, the mean duration the centre position stood still for was 1.8 s per event, significantly shorter than that of goal-based players (goal keeper, goal shooter, goal attack and goal defence) as well as wing defence, which ranged from 3.1 s to 5.4 s. Additionally, the centre position also spent a higher proportion of the match performing locomotor activities than all other positions, especially that of goal-based positions, suggesting training should be tailored for positions to meet the position-specific demands of competition. More recently, Davidson and Trewartha (2008) analysed three matches performed by English Superleague players (the highest domestic league in the UK) including the centre, goal keeper and goal shooter positions. Results demonstrated that the centre position covered greater distance (mean ± standard deviation; 7984 m ± 767 m,) than goal keeper (4283 m ± 261 m) and goal shooter (4210 m ± 477 m), centre (555 m ± 274 m) and goal shooter (370 m ± 233 m) sprinted similar distances, greater than that of goal keeper (69 m ± 54 m), and centre spent a greater proportion of time performing high intensity activities (running, sprinting and shuffling) resulting in greater work: rest (1.9 ± 0.4) than goal keeper (3.0 ± 0.4) and goal shooter (4.6 ± 0.8). Only one recent study has reported the movement demands of international netball, analysing three matches played by the Australian netball team (Fox et al., 2013). As expected, defensive positions (goal defence, goal keeper, wing defence) performed more activities related to their duties, such as guarding and off-ball guarding, whilst attacking positions performed more sprinting, running, passing and catching (Fox et al., 2013). For all players, the majority of active time was spent shuffling and walking (Table 2.2.2), whilst mid-court positions (goal defence, wing defence, centre, wing attack and goal attack) spent a higher proportion of time jogging than goal-based positions (goal keeper and goal shooter) (Fox et al., 2013). Nearly all activities were performed with a duration between one and three seconds, highlighting the short, explosive, intermittent nature of netball, whilst defensive players were more likely to perform longer duration work periods. Findings confirm the highly specific roles and movement demands of the various court positions, highlighting the individual nature of training required to optimally prepare for international match-play (Fox et al., 2013).

Table 2.2: Mean (± standard deviation) percentage of active time spent performing activities by each court position in international netball. Reproduced from Fox et al., (2013).

Activity	GK	GD	WD	C	WA	GA	GS
Walking	35.2 (±8.9)	40.4 (±9.1)	45.4 (±5.8)	38.9 (±2.1)	46.6 (±3.6)	46.3 (±2.1)	51.7 (±6.5)
Jogging	5.2 (±1.1)	16.2 (±1.9)	10.8 (±1.8)	20.5 (±5.7)	15.6 (±3.5)	15.9 (±3.6)	5.0 (±1.9)
Shuffling	51.7 (±5.1)	20.8 (±5.5)	31.2 (±2.8)	26.1 (±0.4)	21.9 (±3.0)	20.7 (±4.0)	23.6 (±1.7)
Running	1.7 (±0.4)	6.7 (±1.2)	5.0 (±1.6)	5.5 (±2.0)	6.4 (±1.3)	6.7 (±0.9)	5.4 (±2.3)
Sprinting	0.2 (±0.1)	3.1 (±2.1)	3.7 (±2.1)	3.0 (±1.2)	4.8 (±2.0)	3.0 (±1.8)	3.4 (±0.5)
Goal[a]	-	-	-	-	-	3.7 (±0.9)	7.5 (±4.4)
Pass[a]	1.7 (±0.9)	2.4 (±0.2)	3.3 (±1.0)	6.2 (±0.8)	5.1 (±0.6)	3.8 (±0.7)	3.7 (±0.9)
Guard	1.8 (±0.6)	2.4 (±0.3)	4.2 (±0.5)	2.9 (±0.2)	1.4 (±0.1)	1.7 (±1.1)	0.9 (±0.4)
Off-ball guard	34.3 (±4.8)	19.7 (±3.1)	15.7 (±3.3)	10.0 (±1.0)	4.9 (±0.9)	2.1 (±0.4)	0.7 (±0.5)
Defend	5.3 (±1.8)	3.3 (±0.5)	-	-	-	-	-

Abbreviations: GK: goal keeper, GD: goal defence, WD: wing defence, C: centre, WA: wing attack, GA: goal attack, GS: goal shooter. [a] denotes time spent in possession of the ball prior to completing activity.

2.1.2 Internal load of match-play

Internal load metrics have been used in team-sports to quantify training and match-play intensity, and primarily include heart rate, session rating of perceived exertion (Bourdon et al., 2017) and differential rating of perceived exertion (McLaren, Smith, Spears, & Weston, 2017). Measurement of internal load can permit a more detailed understanding of training or match-play demands (McLaren et al., 2017), providing key information for the coach and conditioning coach in optimally preparing players for performance and can also be used to assess fatigue and recovery status (Saw, Main, & Gastin, 2016). The relationship between internal and external load metrics in elite female netball has been reported, identifying strong associations between session rating of perceived exertion and number of changes of direction, number of jumps and total Player Load^{TM} (Simpson et al., 2020). However, to date, no reports exist of heart rate or rating of perceived exertion in elite-standard netball training or match-play, representing a significant gap in the literature.

2.1.3 External load of match-play

As wearable technology has advanced, opportunities for assessing movement demands has also advanced, with accelerometers used to estimate external load of many team sports including handball (Luteberget & Spencer, 2017), hockey (Polgaze, Dawson, Hiscock, & Peeling, 2015) and netball (Bailey et al., 2017; Cormack et al., 2014; Young et al., 2016). Accelerometry derived load provides a more detailed quantification of the demands of training or competition, can identify individual positional differences, and can be used to tailor training to meet these specific demands (Young et al., 2016). Tri-axial accelerometers are housed in small devices, held in place vertically on the upper back, and used to record movement during activity without impairing players. Cormack et al., (2014) investigated differences in Player Load^{TM} across five matches performed by two teams in a state-level championship (Victoria state championships, Australia). Players were grouped in to centre, shooter and defender positions, as denoted by the movement limitations imposed. Centre positions performed greater match load (represented as AU·min^{-1}) than shooters (mean difference ± 90% confidence intervals: 16.4% ± 36.2%), while the difference between centres and defenders (6.7% ± 30.6%) and defenders and shooters (11.6% ± 41.5%) was unclear. Whilst accelerometry has a very strong relationship with distance covered, for example, in elite Australian rules football (Aughey, 2011), the restricted movement imposed in netball, coupled with significant position-specific non-locomotor activities, such as defending, guarding and jumping (Bailey et al., 2017), involving short accelerations and decelerations, may offer greater insight in to movement characteristics than traditional distance measures (Cormack et al., 2014). Only two studies have reported the accelerometry associated with elite competitive netball match-play (Bailey et al., 2017; Young et al., 2016). As differences have been observed between recreational and state-level netball (Cormack et al., 2014), studies in elite, international netball are key to accurately describe the demands of this level of match-play. Across two games played by elite netball players (members of a team playing in the premier netball league in Australia and New Zealand), Bailey et al., (2017) investigated the Player Load^{TM} associated with typically performed activities performed by different positions, providing greater insight than distance covered, or simply the number of activities performed. Off-ball guarding had the highest Player Load^{TM} for a single instance (mean ± SD: 2.8 AU ± 1.1 AU), while passing had the lowest (0.4 AU ± 0.2 AU). However, when compared across an entire match, jogging accounted for the highest Player Load^{TM} (376.8 AU ± 239.1 AU) whilst rebounding contributed the least (9.3 AU ± 6.5 AU). Positional differences were found with regards to the contribution to total Player Load^{TM} from locomotor and non-locomotor activities (Table 2.3). For example, the centre position had a greater contribution of Player Load^{TM} through running, whilst wing defence through off-ball guarding. Indeed, attacking positions (goal shooter, goal attack and wing attack) had the smallest contribution of non-locomotor activities, centre-court positions (centre, goal defence and wing defence) accumulated the greatest overall Player Load^{TM}, with the centre position having the greatest compared with all other positions, while the goal keeper had a greater contribution of non-locomotor activities than locomotor activities, the only position to do so.

Table 2.3: Contribution of locomotor and non-locomotor activities to total match load, represented as (mean ± standard deviation). Effect size represents the magnitude of the difference between contribution of locomotor and non-locomotor activity. Reproduced from Bailey et al., (2017).

	Locomotor (AU)	Non-locomotor (AU)	Effect size[a]
GS	181.9 ± 137.7	32.8 ± 19.1	1.70 ± 0.51
GA	259.2 ± 174.3	45.9 ± 37.2	1.83 ± 0.49
WA	273.4 ± 145.8	76.2 ± 28.0	1.83 ± 0.53
C	303.8 ± 277.5	132.0 ± 134.7	0.80 ± 0.46
WD	227.7 ± 145.3	168.5 ± 222.7	0.32 ± 0.45
GD	116.1 ± 100.7	74.4 ± 120.7	0.40 ± 0.41
GK	84.5 ± 68.5	106.1 ± 191.0	-0.15 ± 0.42
All positions	206.7 ± 172.8	86.0 ± 131.2	0.79 ± 0.17

Abbreviations: AU: arbitrary units; GS: goal shooter, GA: goal attack, WA: wing attack, C: centre, WD: wing defence, GD: goal defence, GK: goal keeper. [a] cohen *d* ± 95% confidence interval.

The performance of a professional netball team, which won the Trans-Tasman Netball league (the premier netball league in Australia and New Zealand), has also been assessed (Young et al., 2016). Centre positions elicited higher Player Load^{TM} than goal-based players, with the centre eliciting the highest Player Load^{TM} compared with all other players (Figure 2.1.2). No differences were found between goal defence, goal keeper and goal shooter positions, unlike reports in Collegiate standard players (Chandler, Pinder, Curran, & Gabb, 2014), and in international standard players (Fox et al., 2013) reporting higher playing intensity for the goal-defence position. This difference may be due to the playing standards, or the unique playing style of this player (Young et al., 2016). Cormack et al. (2014) investigated differences in Player Load^{TM} between different levels of players, including teams playing in the state-level championship (Victorian state league, Australia), and recreational-standard championships across five matches. Higher-standard players accumulated higher Player Load^{TM} than lower-standard players, suggestive of greater distance covered (Aughey, 2011), acceleration, decelerations and jumping movements (Cormack et al., 2014). Although not measured in the study, this could be attributed to greater physical capacity, including metabolic, speed and strength qualities, of higher-standard players.

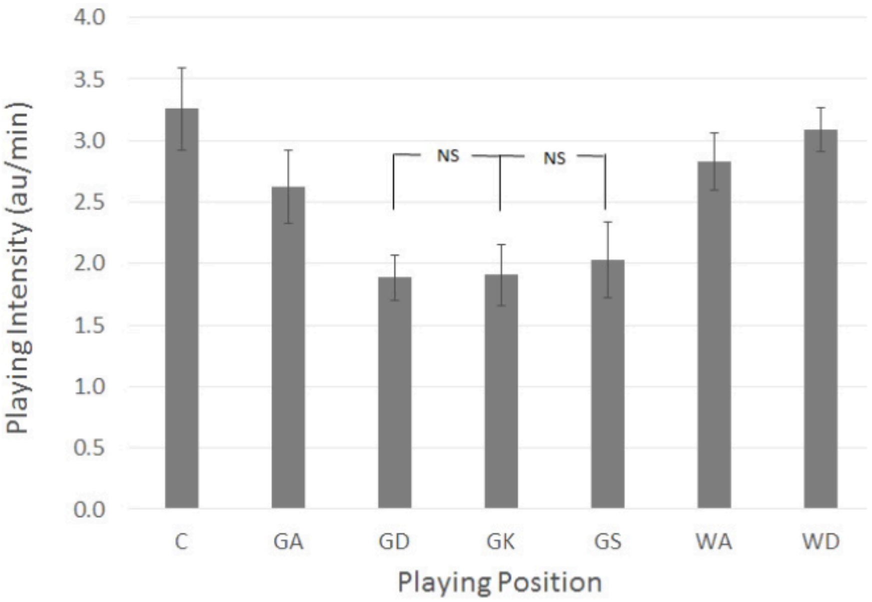


Figure 2.1: Playing intensity during matches assessed via accelerometry for each playing position. The playing intensity for all playing positions was significantly different (P < 0.001) from others apart from those labelled NS. Reproduced from Young et al., (2016). *Abbreviations*: NS: not significantly different, au: arbitrary units, C: centre, GA: goal attack, GD: goal defence, GK: goal attack, GS: goal shooter, WA: wing attack, WD: wing defence.

The variety of metrics used to quantify the demands of match-play provides a well-rounded analysis of positional demands. Whilst the centre position covers greater distance through more locomotor activity (Bailey et al., 2017; Davidson & Trewartha, 2008; Steele & Chad, 1992; Young et al., 2016), differences between other positions may not be seen in total Player Load^{TM}, but rather the type of activity contributing to that load (Bailey et al., 2017; Cormack et al., 2014; Fox et al., 2013). This highlights the individual conditioning required for match-play, and therefore the physiological requirements of training to be optimally conditioned. However, at high-level tournaments, players may be required to play up to eight games in 10 days, meaning the required conditioning is different to that of an individual single match. However, at present there are no studies describing the physical demands of a series of matches or in an international-standard tournament.

2.1.4 Demands of training

Whilst there are a variety of reports describing demands of netball match-play, that of training are more limited, especially in elite-standard players (Young et al., 2016). Chandler et al. (2014) compared the physiological responses to a variety of training sessions to that of a match in collegiate level players. Training sessions consisted of skills (aimed at improving netball skills e.g. passing, catching, movement patterns), game-based (reduced player number and larger playing area to replicate physical demands of match-play), traditional conditioning (interval and maximal aerobic speed training without a ball) and repeated high intensity exercise (repeated sprint, changes of direction and jumping activities). Each type of training session elicited a different physiological response, designed to overload a specific component, including decision making, skills or movement demands under pressure and fatigue. Skills training was found to replicate match-play for rating of perceived exertion and Player Load^{TM}, but had a lower mean heart rate, whilst game-based training, traditional conditioning and repeated high intensity exercise elicited a higher Player Load^{TM} than match-play. Importantly, as rating of perceived exertion was not different between modes of exercise, other parameters should be used by coaches and conditioning coaches, such as heart rate or Player Load^{TM}, to quantify training demands (Chandler et al., 2014). In the only report in elite netball, Young et al. (2016) reported the demands of the main weekly training session compared to match-play over a season. The training session was court based and included components to maintain or improve a mixture of fitness and netball skills in addition to refining match tactics. Total Player

Load^{TM} was greater for the training session than matches (178 AU vs. 155 AU), due to greater duration (116 min ± 24 min vs. 60 min), whilst Player Load^{TM} intensity was greater for matches than training sessions (2.60 AU·min^{-1} vs. 1.52 AU·min^{-1}). Whilst this could suggest that the training session was an inadequate stimulus in relation to the physical demands of match-play, this reduced intensity was due to a considerable amount of extra time spent in the low intensity zone (potentially due to coach interaction, explanation of training etc), as time in other intensity zones was comparable to match-play (Young et al., 2016). It is important therefore to view the demands of training from a variety of sources, including physiological stimulus, Player Load^{TM}, time spent performing different activities and perception of effort in order quantify training and to be optimally conditioned for match-play. A summary of the internal and Player Load^{TM} demands of training and match-play are described in table 2.4. As the demands of netball include both the repetition of short, explosive movements for a single 60 minute match, as well as the performance of a series of daily matches, players often perform multiple training sessions within a day to improve performance and condition for match-play (Simpson et al., 2020). This includes technical on-court training, as well as on and off-court conditioning, in addition to strength training (Chandler et al., 2014; Simpson et al., 2020) in order to condition for all aspects of match-play, as well as develop or maintain technical, tactical and positional aspects of netball.

Table 2.4: Summary of studies reporting internal load and Player Load^{TM} of competitive match-play and training.

Study	Participants	Overview	Internal load	Player Load^{TM}
Cormack et al. (2014)	Two higher (State level) and lower (recreational level) standard teams. n=17 higher standard n=15 lower standard Mean age (±SD): 22.6 years (±4.4 years)	Five matches observed of lower and higher-standard of match-play. Players grouped in to centre, shooter and defender positions based on court-restrictions. Measures: Player Load^{TM} (measured via Minimaxx) from players who played the full 60 min of a match.		Mean (±SD) Player Load^{TM}: Higher standard: 10.0 AU·min^{-1} (± 2.5) Lower standard: 7.0 AU·min^{-1} (± 1.8) Higher standard players accumulated greater Player Load^{TM} than lower standard (mean difference ± 90% CI; 31.3% ± 17.5%). Higher standard: centre positions accumulated greater Player Load^{TM} than shooters (16.4% ± 36.2%). Lower standard: centre positions accumulated greater Player Load^{TM} than shooters (26.6% ± 46.1%) and defenders (14.8% ± 26.8%)
Young et al. (2016)	n=12 Elite professional players 26 years (±4.9 years)	16 competitive matches observed (excluding breaks between quarters) and 17 training sessions Measures: Player Load^{TM} (measured via X8M-3mini)		C, WD and WA had the highest Player Load^{TM}, whilst C had the highest compared with all other positions ($p<0.001$) All positions had different Player Load^{TM} ($p<0.001$) except

		Position specific values represent activity of up to three different players who were routinely substituted		between GD and GK, GK and GS and GD and GS GD, GK and GS had the lowest Player Load$^{\mathrm{TM}}$ ($p \leq 0.05$) C, WD, WA and GA had the highest Player Load$^{\mathrm{TM}}$ and lowest proportion of match spent in the low-intensity zone. Total Player Load$^{\mathrm{TM}}$ was higher for training sessions than matches (178 vs 155 AU, $p<0.001$) due to longer duration (116 ± 24 min vs 60 min) Player Load$^{\mathrm{TM}}$ intensity was higher for matches than training (2.6 vs 1.52 AU·min^{-1}, $p<0.001$)
Chandler et al. (2014)	n=8 Collegiate level players 20.4 years (95% CI; 18.8-22.0 years)	Four matches and 15 training sessions observed. Training sessions categorised as skills, game-based, traditional conditioning and repeated high intensity exercise (RHIE) Measures: Player Load$^{\mathrm{TM}}$ (measured via Minimaxx S4), rating of perceived exertion (RPE), heart rate (HR)	Mean HR of skills training was lower than match-play and all other training ($p<0.01$). Peak HR for game-based (186 ± 8 b·min^{-1}) and RHIE (187 ± 10 b·min^{-1}) training was lower than match-play (193 ± 9 b·min^{-1}). Peak HR for skills training (186 ± 10 b·min^{-1}) and traditional	Match-play (mean AU·min^{-1}: 95%CI; 6.1: 3.0-3.9) had similar Player Load$^{\mathrm{TM}}$ to skills (6.0: 4.0-8.0) but less than game-based (9.0: 8.4-9.6), traditional conditioning (18.5: 16.0-21.0) and RHIE (16.6: 15.6-17.6) training ($p<0.01$) During match-play C had greater Player Load$^{\mathrm{TM}}$ than all other

			conditioning (196 ± 8 b·min^{-1}) was similar to match-play. GA and GS had lower mean HR than C ($p<0.05$). No significant differences between positions for RPE and peak HR during match-play.	positions ($p<0.01$, ES = 0.67-0.91). GK and GS had lower Player Load^{TM} than all other positions ($p<0.05$) GS (mean AU·min^{-1}: 95%CI; 3.4: 3.1-3.6), GK (3.5: 3.0-3.9), WA (5.1: 4.6-5.6), WD (6.5: 6.1-6.9), GA (6.5: 6.1-7.0), GD (6.7: 6.2-7.2), C (9.6: 8.8-10.5).
Bailey et al. (2017)	n=12 Elite players 26 years (±4.9 years)	Two complete matches observed. Playing position was analysed individually (i.e. if a player was substituted data was collected for the replacement player) Measures: Player Load^{TM} (measured via x8m-3mini)		Off-ball guarding accumulated the greatest Player Load^{TM} per instance (2.77 ± 1.05 AU) and passing the lowest (0.40 ± 0.16 AU). Jogging accumulated the greatest player load across the match (377 ± 139 AU) and rebound the lowest (9.3 ± 6.5 AU). Greatest contributions to total Player Load^{TM}: Jogging (23.1%), off-ball guarding (18.6%), walking (15.7%), shuffling (14%), standing (7.6%). C, GD and WD had the greatest Player Load^{TM} overall.

				C had the greatest contribution of locomotor activities. GS, GA and WA had the lowest contribution of non-locomotor activities.

Abbreviations: SD: standard deviation; CI: confidence interval; ES: effect size; AU: arbitrary units; HR: heart rate; C: centre position; GS: goal shooter position; GK: goal keeper position; WA: wing attack position; WD: wing defence position; GA: goal attack position; GD: goal defence position

2.2 Neuromuscular fatigue

One of the most demonstrated and consistent effects, both during and following exercise, is the gradual decline in physiological function and performance experienced by a performer. Whilst this is often termed fatigue, it is difficult to precisely define this. Various mechanisms and systems have been proposed to contribute to this decline in performance, including the cardiovascular system, the neuromuscular system, metabolite accumulation, energy supply, biomechanical factors, thermoregulatory factors and psychological factors (Abbiss & Laursen, 2005). In addition to other definitions, neuromuscular fatigue has been defined as a reduction in the force-generating capacity of the muscle (Gandevia, 2001) and an exercise-induced reduction in maximal voluntary contraction force (Place, Yamada, Bruton, & Westerblad, 2010), and has been demonstrated as a reduction in force (Millet et al., 2002; Paasuke, Ereline, & Gapeyeva, 1999), power production (Tomazin, Morin, & Millet, 2017) or altered muscle co-ordination (O’Bryan, Brown, Billaut, & Rouffet, 2014) as a result of exercise. Indeed, neuromuscular fatigue can result in reduced exercise performance including sprint cycling power production (O’Bryan et al., 2014) and repeated sprint running performance (Elias et al., 2012). As performing training with reduced neuromuscular function can impair training performance (Highton, Twist, & Eston, 2009), can result in greater neuromuscular fatigue for subsequent training (Doma & Deakin, 2013) and can impair subsequent adaptation to training (Jones et al., 2016) it is important to understand in order to optimise training responses and competitive performance. However, it is important to note than a reduction in maximal force capacity is different to task failure (e.g. the inability to maintain a required submaximal contraction), as the underlying mechanisms can differ (Place & Millet, 2020). Additionally, it is possible to observe no decrease in maximal voluntary contraction force whilst fatigue is experienced (Edwards, Hill, Jones, & Merton, 1977). Whilst the contribution to fatigue is clearly multi-faceted, and all definitions are valid, this review will focus on the change in function of the neuromuscular system following exercise.

2.2.1 Mechanisms of neuromuscular fatigue

The decline in neuromuscular fatigue has been categorised broadly in to two categories; central mechanisms for fatigue occurring in the spinal cord and brain (Gandevia, 2001), and peripheral mechanisms for fatigue occurring at or distal to the neuromuscular junction (Allen, Lamb, & Westerblad, 2008).

2.2.1.1 Mechanisms of central fatigue

Central fatigue can be described as a progressive exercise-induced failure of voluntary activation of the muscle (Gandevia, 2001), and can be demonstrated by use of nerve stimulation during a maximal voluntary contraction (MVC) (Merton, 1954). If, during a MVC, the stimulation of an associated motor nerve leads to an increase in force output, then not all motor units were recruited optimally, or were firing at the required rate to produce the required contraction (Herbert & Gandevia, 1999). An increase in this difference as a result of exercise performance signifies that the loss in force output has occurred in processes proximal to the site of motor axon stimulation and therefore implies central fatigue (Taylor & Gandevia, 2008). Central fatigue is defined by Gandevia (2001) as “a progressive reduction in voluntary activation of muscle during exercise” (p1733). Changes in voluntary activation are duration dependent, with greater central fatigue following 20 and 40 km cycling time trials compared with four km (Thomas et al., 2014), and with long duration (four hours) low intensity (55% of maximal aerobic power) cycling exercise (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002). Central fatigue, and hence a decrease in force output, can occur via three identified mechanisms; a decrease output from the motor cortex, an increase in inhibitory input, and a decrease in motoneuron responsiveness through a change in their intrinsic properties (Taylor & Gandevia, 2008).

Decreased output from the motor cortex

Supraspinal fatigue, or fatigue associated proximal to the spinal cord, occurs due to a decline or sub-optimal output from the motor cortex (Gandevia, Allen, Butler, & Taylor, 1996). Transcranial magnetic stimulation of the motor cortex has been used extensively to assess supraspinal fatigue. Briefly, a magnetic coil, positioned over the primary motor cortex, delivers a magnetic stimulus during the performance of a MVC, to evoke a greater output from the stimulated muscle (Thomas et al., 2014). Despite participants maximal effort, transcranial magnetic stimulation of the motor cortex can elicit greater twitches during a MVC (Gandevia et al., 1996). This highlights that at the moment of stimulation, motor cortical output was not maximal, and therefore insufficient to recruit all motor units and to produce maximal force

(Taylor & Gandevia, 2008), with larger differences indicative of greater supraspinal fatigue. For example, voluntary force decreases by around 60% at the end of a two minute maximal elbow flexion, with approximately one quarter of this due to supraspinal fatigue (Gandevia et al., 1996). In the first few seconds of a maximal contraction, it is theorised that motoneurons adapt their firing rates, declining to match the muscle's contractile velocity, a term described as "muscle wisdom", in order to maintain force output (Gandevia, 2001). However, evidence for this theory can be argued, and instead, it is likely that other mechanisms contribute to this decline in neural drive (Taylor & Gandevia, 2008). During sustained or repeated fatiguing contractions, descending drive from the motor cortex becomes suboptimal for force production (Gandevia et al., 1996), with force output decreasing as a consequence as contractions continue. Supraspinal fatigue contributes greater to the drop in voluntary activation during prolonged low-force contractions, than maximal (e.g. one to two minute) efforts (Taylor & Gandevia, 2008), whilst the contribution of central fatigue to more maximal efforts is less (Thomas et al., 2014). Following strong contractions, recovery of voluntary activation can occur within two to three minutes, following weak efforts can take more than 10 minutes, whilst following five hours of running can remain at 30 min post-exercise (Place, Lepers, Deley, & Millet, 2004).

Increase in inhibitory input

As muscles contract, receptors linked with sensory neurons innervating skeletal muscle are activated, modulating the discharge frequency of these nerves and feedback to the central nervous system (Taylor, Amann, Duchateau, Meeusen, & Rice, 2016). This feedback modulates motoneuron excitability (Taylor & Gandevia, 2008), with both increases in excitatory responses (descending drive and muscle spindle afferents) and inhibitory (group Ib, group III and IV and Renshaw cells) afferent feedback (Taylor et al., 2016). Small-diameter muscle afferents (group III and IV) are related to changes in neural activity, group III afferents are mechanically sensitive to muscle contraction and stretch, whilst group IV (including some group III) afferents and receptors are sensitive to intramuscular metabolites and metabolic changes within the muscle in addition to high levels of mechanical strain (Taylor et al., 2016). During exercise, contraction-induced mechanical and chemical stimuli activate these intramuscular receptors, located at the terminal end of these sensory neurons (Kaufman, Hayes, Adreani, & Pickar, 2002; Light et al., 2008), providing inhibitory feedback to the central nervous system resulting in decreases in cortical drive (Gandevia, 2001). Indeed, a study by

Gandevia (1996) demonstrated the inhibitory effect of group III and IV muscle afferents. During a two-minute single-joint maximal isometric contraction, voluntary activation and motoneuron output progressively decreased, then recovered within minutes following cessation of the exercise. However, when blood flow was occluded to limit the removal of metabolites and therefore maintain activation of group III and IV afferents, voluntary activation remained supressed, recovering only when blood flow was initiated (Gandevia et al., 1996). Additionally, Amann (2011) provides evidence for this inhibitory effect in whole body exercise, with evidence of altered performance during a five km cycling time trial. Participants performed a five km cycling time trial with a placebo, or following the administration of fentanyl, an opioid to selectively block sensory feedback from the working muscles, thereby eliminating the inhibitory feedback from increasing inhibitory input. The authors found that blocking these fibres attenuated this inhibitory effect, and central motor drive was significantly higher than voluntarily chosen (i.e. the placebo trial), resulting in greater power output for the first half of the time-trial.

Decrease in motoneuron responsiveness

During fatiguing contractions, the behaviour of motor units reflects the outputs of the excited motoneurons (Taylor et al., 2016). Motoneuron output is influenced by their intrinsic properties, effects of neurotransmitters (such as serotonin and noradrenaline), and synaptic input from sensory feedback and descending drive (Taylor et al., 2016). When repeatedly activated, motoneurons exhibit reduced excitability, or reduced response to excitatory synaptic input, resulting in a decrease in force output (Taylor et al., 2016). During sustained maximal contractions, repetitive activation can decrease motor unit responsiveness to synaptic input, a process termed spike frequency adaptation, or late adaptation (Nordstrom, Gorman, Laouris, Spielmann, & Stuart, 2007; Taylor & Gandevia, 2008). Motor units are activated by excitatory and inhibitory potentials, which act directly on membranes (inotropic), as well as by synaptic or hormonal inputs via receptors in the membrane (metabotropic), including neuromodulators such as serotonin, norepinephrine and thyroid-releasing hormone (Nordstrom et al., 2007). Therefore, motor unit response can vary due to these factors, and indeed motor units may slow their firing rate, or stop firing (Peters & Fuglevand, 1999), in spite of constant, or increased central motor drive (Taylor & Gandevia, 2008). Although recovery has been shown to occur within two minutes (Taylor & Gandevia, 2008) evidence of late adaptation comes predominantly from animal studies, whilst evidence in humans is lacking (Nordstrom et al., 2007). When participants sustain a voluntary sustained contraction over several minutes, additional motor units are recruited, implying that the motoneuron required greater descending drive to maintain the same force output (Johnson, Edwards, Van Tongeren, & Bawa, 2004). Additionally, during voluntary contractions smaller, lower-threshold motoneurons are recruited preferentially over larger motoneurons (the size principle), with changes to activation following sustained submaximal contractions greater for smaller motoneurons compared with larger. This suggests that intrinsic properties of the motoneurons are affected, as repetitively activated motoneurons are reduced in excitability compared to non-active or less active motoneurons, as other influences such as descending drive, would affect motoneurons across the pool (Taylor et al., 2016). Exercise-induced changes in the concentration of neurotransmitters, involved in the transmission of signals between neurons, such as dopamine, noradrenaline and serotonin have also been linked with central fatigue, (Taylor et al., 2016). Serotonin has both an excitatory and inhibitory effect through action via serotonin receptors on motoneurons (Perrier, Rasmussen, Christensen, & Petersen, 2013). Hence, serotonin can reduce motoneuron responsiveness and cause fatigue as a consequence of decreased serotonin release, as can occur with prolonged exercise (Fornal, Martín-Cora, & Jacobs, 2006), or via spill over following strong contractions and a high level of descending serotonergic drive with activation of inhibitory receptors (Cotel, Exley, Cragg, & Perrier, 2013). However, although observations have been made in studies of animals (Cotel et al., 2013; Fornal et al., 2006), there is no direct evidence of the role of serotonin at the motoneuron on fatigue (Taylor et al., 2016).

2.2.1.2 Mechanisms of peripheral fatigue

Whilst central fatigue occurs in the spinal cord and brain (Gandevia, 2001), peripheral fatigue occurs distal to the neuromuscular junction (Allen et al., 2008). This includes disruption to transmission of action potentials, decreased sarcoplasmic reticulum calcium release and reuptake, decreased force output related to accumulation of metabolites, decrease energy status and accumulation of reaction oxygen species (Allen et al., 2008). Peripheral fatigue can occur anywhere along the chain of events involved in the sequence of excitation-contraction coupling (Allen et al., 2008), including initiation of the action potential, transmission along the sarcolemma and transverse tubules, activation of voltage sensors, calcium release and reuptake.

When a muscle is contracted at a high frequency (for example 50-100 Hz) eliciting close to maximal force, force production rapidly declines (Bigland-Ritchie, Jones, & Wood, 1979), termed high frequency fatigue. This rapid decrease in force output has been attributed to a decline in surface action potential (Bigland-Ritchie et al., 1979), likely due to potassium efflux resulting from repeated muscular contractions, resulting in increased extracellular potassium concentration (Juel, Pilegaard, Nielsen, & Bangsbo, 2000), decreasing muscle excitability. However, following this type of excitation, rapid recovery occurs, with a time course of only seconds (Bigland-Ritchie et al., 1979) to two minutes (Balog & Fitts, 1996), as recovery of sodium and potassium concentration gradients can be restored rapidly (Balog & Fitts, 1996). Whilst this type of peripheral fatigue has been demonstrated following maximal voluntary intensity stretch shortening exercise (maximal hopping) lasting 60 s (Tomazin, Sarabon, & Strojnik, 2008) and alpine slalom skiing (high intensity stretch shortening exercise) (Tomazin et al., 2008), it has not been demonstrated following maximal 100 m, 200 m or 400 m sprinting (Tomazin et al., 2012) suggesting it is more apparent following high intensity exercise involving a stretch shortening muscle action.

Low frequency fatigue occurs in response to excitation at relatively low frequencies (for example 10-20 Hz), is a result of impairment in excitation-contraction coupling (Jones, 1996) and is particularly apparent if the exercise (typically high volume of low to moderate intensity contractions) involves mechanical stretch likely to induce muscle damage. For example, Tomazin et al. (2012) found evidence of low frequency fatigue in response to 100, 200 and 400 m sprinting, resulting in a decrease in speed at the end of each trial. Additionally, maximal stretch shortening exercise (maximal hopping) had limited effect on low frequency fatigue, however low frequency torque was reduced following 30s of maximal cycling exercise (Tomazin et al., 2008). The decrease in force production at low frequency stimulation may be due to reduced calcium sensitivity and release from the sarcoplasmic reticulum, due to increased lactate or inorganic phosphate concentration, negatively impacting the excitation-contraction coupling (Allen et al., 2008).

During a sustained, maximal isometric contraction, the decline in force in the first 60 s can be attributed almost wholly to peripheral mechanisms, accounting in total for 89% of the force decline, with central mechanisms adding to this fatigue as the bout progresses (Schillings, Hoefsloot, Stegeman, & Zwarts, 2003). Similarly, during locomotor exercise, peripheral fatigue develops early in the exercise bout, with reductions in voluntary activation when the bout is prolonged (Lepers et al., 2002; Place et al., 2004). Additionally, short duration high intensity cycling exercise (around six minutes at 96% of maximal oxygen uptake) elicits a greater degree of peripheral fatigue than longer, lower intensity (around 30 min at 87% of maximal oxygen uptake) where central mechanisms have greater effect (Thomas et al., 2014).

During or following exercise, mechanisms of both central and peripheral fatigue exist (Thomas et al., 2014; Tomazin et al., 2017), with differences observed between modes of exercise (Tomazin et al., 2017). There have been limited reports of the effect of team-sport match play on neuromuscular fatigue (Brownstein et al., 2017; Rampinini et al., 2011), with more following simulated match-play (Goodall et al., 2017; Marshall, Lovell, Jeppesen, Andersen, & Siegler, 2014; Thomas, Dent, Howatson, & Goodall, 2017), and reports following female team-sport match-play limited to observations of neuromuscular performance only (e.g. Andersson et al., 2008; Clarke, Anson, & Pyne, 2015; Ronglan, Raastad, & Børgesen, 2006). Rampinini et al. (2011) reported the effects of competitive soccer match-play on neuromuscular fatigue in 20 male professional soccer players. Peak torque and voluntary activation during a maximal voluntary contraction of the knee extensors was reduced immediately post-match, and 24 h post, returning to baseline at 48 h post. Additionally, peak torque following electrical stimulation of the femoral nerve at low frequencies (one and 10 Hz) was reduced immediately post and remained depressed for up to 48 h, whilst peak torque at high frequency (100 Hz) was not different following the match (Figure 2.3). Findings suggest that soccer match-play elicits prolonged central and peripheral fatigue, requiring 48 h for full recovery (Rampinini et al., 2011). As metabolic mechanisms of peripheral fatigue, such as inorganic phosphate and pH, recover rapidly (Allen et al., 2008), and peak torque was reduced at low frequencies, the prolonged peripheral fatigue is suggestive of altered excitation-contraction coupling, structural damage at the myofibrillar level and altered calcium handling due to soccer related movements, including sprinting and eccentric muscle contractions (Skurvydas et al., 2016).

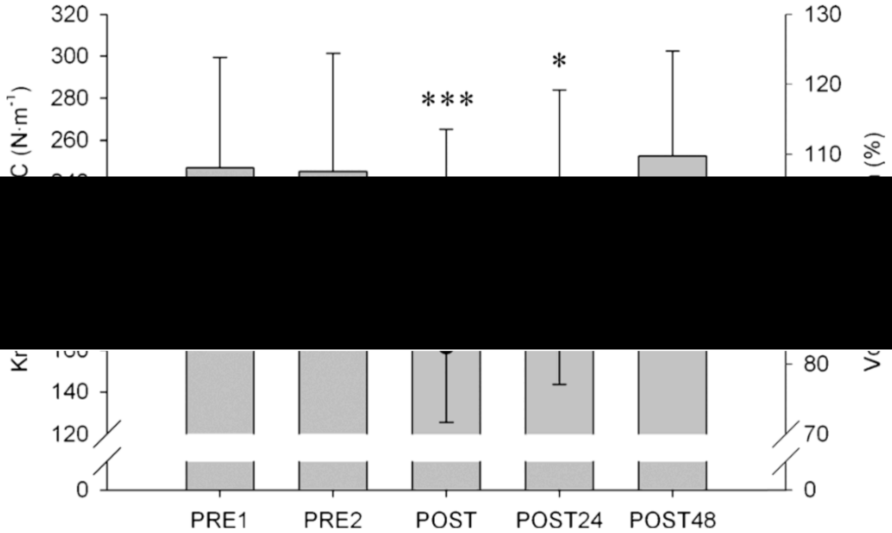


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Figure 2.3: Time course of maximal voluntary contraction (bars) and maximal activation level (line and circles) of the knee extensors. Reproduced from Rampinini et al. (2011).

Abbreviations: Pre1: first baseline; Pre2: second baseline; Post: 40 min post-match; Post24: 24 h post-match; Post48: 48 h post-match; MVC: maximal voluntary contraction. Pre1 and Pre2 were conducted to assess the reliability of measures. * indicates significantly different to Pre1, Pre 2 and Post, $P < 0.05$. *** indicates significantly different to Pre1 and Pre2. $P < 0.001$.

2.2.2 Role of the endocrine system in neuromuscular function

Steroid hormones, released predominantly from the gonads and adrenals, have a wide variety of effects on the body, which can be generally categorised by time course of action. Genomic actions of steroid hormones involves steroid hormones binding to specific receptors, exerting positive or negative influence on the expression of target genes (Beato & Klug, 2000). Whilst the result is slowly emerging changes to protein expression, structure and functioning of target cells (Strelzyk et al., 2012), more rapid effects of steroid hormones occur within seconds to minutes after exposure (Makara, Gabor & Haller, 2001), with impact upon many mechanisms which may affect neuromuscular performance. The combination of both short- and long-term effects may acutely impact neuromuscular performance, adaptation and therefore long-term neuromuscular performance (Crewther et al., 2011).

2.2.2.1 Testosterone

Testosterone is predominantly synthesised in the Leydig cells in the testes, producing around 95% of the testosterone in males (Enea & Boisseau, 2011). Leydig cells are only found in the testes, and as such, is a main contributor to the significantly lower testosterone concentration in females, with concentrations up to 10 times lower than in males (Vingren et al., 2010). A wide range of typical concentrations occur within females, with higher testosterone concentrations found in elite compared with non-elite athletes (Cook et al., 2012; Crewther & Cook, 2018), and the highest concentrations nearing that of the lower end of that of male (Bermon & Garnier, 2017; Bermon et al., 2014). Testosterone is also produced in smaller amounts in the ovaries and adrenal glands (Marouliss & Triantafillidis, 2006), derived from the spill over of the production of other hormones such as cortisol, aldosterone and dehydroepiandrosterone (Conley & Bird, 1997). These hormones share precursors with testosterone and oestradiol and are the primary source of testosterone production in females (Vingren et al., 2010).

2.2.2.1.1 Effects of testosterone on the neuromuscular system

Testosterone has both short- and long-term physiological effects upon the neuromuscular system. Testosterone is considered to be a primary anabolic hormone, increasing protein synthesis, and decreasing protein degradation (Crewther, Cronin, & Keogh, 2006), and therefore impacting positively upon muscle fibre size. As muscle fibre size and cross-sectional area is related to the force generating capacity of a muscle (Bruce, Stuart, Phillips, Suzanne, & WoledgeRoger, 1997), it could be suggested that testosterone is key in modifying neuromuscular performance and sporting performance (Crewther et al., 2011). However, whilst supraphysiological doses of testosterone increases the rate of muscle protein synthesis leading to muscular hypertrophy (Bhasin et al., 1996), exercise-induced increases in anabolic hormones may not enhance muscle protein synthesis (West et al., 2009), hypertrophy or strength development (West et al., 2010). Additionally, testosterone has genomic effects upon the central nervous system. Soma size, dendritic length (Lubischer & Arnold, 1995) and synaptic input (Matsumoto, Micevych, & Arnold, 1988) are all sensitive to testosterone, in addition to the size (Breedlove & Arnold, 1981) and number of motoneurons (Siegford & Ulibarri, 2004). However, it is important to note, that as yet, there is no evidence suggesting that testosterone influences the strength-training associated neural adaptations (Viru & Viru, 2005). Testosterone therefore has long-term effects on both the central and peripheral nervous system, which modulates the neuromuscular system.

Short-term, non-genomic effects of testosterone also impact upon the neuromuscular system. Skeletal muscle contraction is triggered by calcium ions (Berchtold, Brinkmeier, & Müntener, 2000), and indeed, skeletal muscle is sensitive to testosterone, with increased intracellular calcium release in skeletal muscle cells occurring within seconds after testosterone administration (Estrada, Espinosa, Müller, & Jaimovich, 2003). Additionally the force produced by each cross bridge is proposed to be modulated by inorganic phosphate concentration (Guette, Gondin, & Martin, 2005), which has hormone mediated circadian variation across the day (Argov, Renshaw, Boden, Winokur, & Bank, 1988). In addition to physiological effects, testosterone concentration can impact psychological and behavioural aspects linked with performance. Testosterone concentration has been positively associated with aggressiveness (Bateup et al., 2002), dominance (Grant & France, 2001), self-efficacy (Costa, Serrano, & Salvador, 2016) and risk aversion (Sapienza et al., 2009) in females, behaviours which influence the neuromuscular system, both acutely and chronically. For example, in both male (Cook, Crewther, & Kilduff, 2013) and female elite athletes (Cook & Beaven, 2013) testosterone concentration is positively associated with self-selected training load, which, over time could lead to a greater increase in strength development (Figure 2.4).

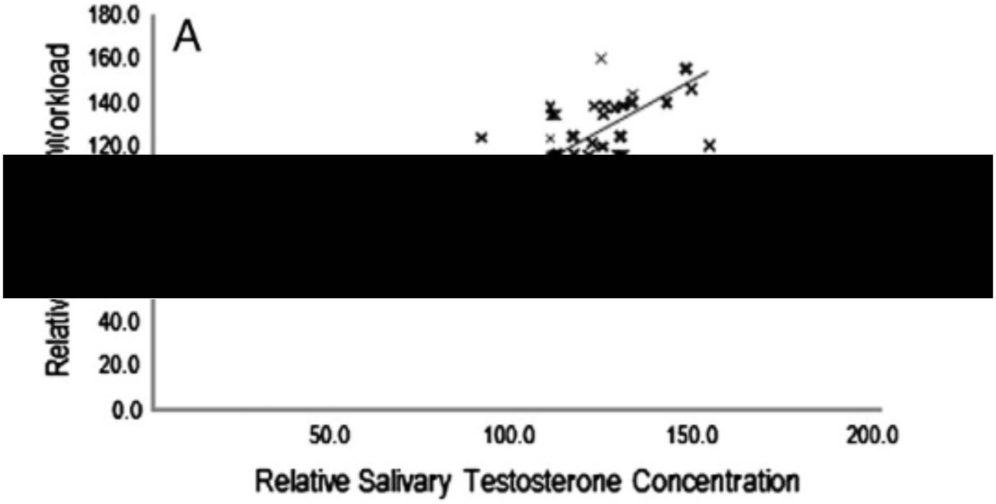

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Figure 2.4: Correlation between salivary testosterone concentration and voluntary workload in elite female athletes. Plot shows relative salivary testosterone concentration against relative voluntary workload in the bench press exercise. Reproduced from Cook and Beaven (2013).

The combination of physiological and psychological effects of testosterone can positively impact upon neuromuscular performance. In a study of elite male and female athletes across a range of sports, Cardinale and Stone (2006) reported the relationship between testosterone concentration and countermovement jump performance. Testosterone concentration was positively associated with countermovement jump performance in both male and female athletes across all sports (Figure 2.5), suggesting that testosterone is important in neuromuscular function, including explosive power (Cardinale & Stone, 2006). A similar observation was reported, with testosterone concentration strongly correlated to back squat and 10 m sprint performance in male participants (Crewther, Cook, Gaviglio, & Kilduff, 2012). However, this correlation was only observed in those with high relative strength (a one rep-maximum of >2 x body weight) highlighting caution in interpreting reports in non-elite or un-trained populations. A similar observation has been made in Olympic weightlifting (Crewther & Cook, 2010). In competitive male athletes, but not female, estimated one-repetition maximum was higher when pre-exercise salivary testosterone concentration was higher. However, this study was limited by sample size (four male and four female), as well as by number of observations. A recent study of female athletes (1332 observations) at the World Athletics Championships reported a greater level of performance for those athletes with higher free testosterone concentrations compared to those with lower concentrations (Bermon & Garnier, 2017). In those competing in the 400 m, 400 m hurdles, 800 m, hammer throw and pole vault, those athletes with higher free testosterone concentrations had a greater performance level than those with a lower concentration (Bermon & Garnier, 2017). However, no effect of testosterone concentration and athletic performance was found for females in other events, or male athletes competing (Bermon & Garnier, 2017), an important finding and consideration when assessing and applying the literature across gender.

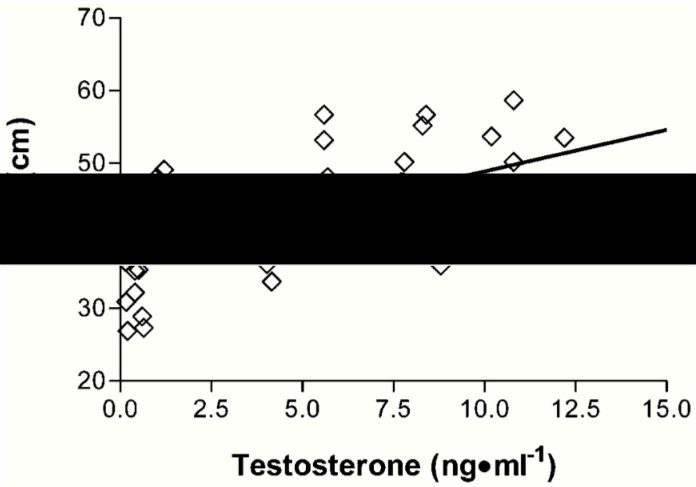

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Figure 2.5: The relationship between countermovement jump height and testosterone concentration (n = 70; r = 0.61; P < 0.001). Reproduced from Cardinale and Stone (2006).

Importantly, in team-based sport, although neuromuscular performance is an important aspect of overall performance, such as in rugby sevens (Ross, Gill, Cronin, & Malcata, 2015), other factors, including tactics, technique and cognition are key to the outcome. It is therefore noteworthy that, in professional rugby union, a game requiring explosive movements underpinned by the neuromuscular system, aggressive behaviours, and tactical and technical aspects, a positive association between pre-match testosterone concentration and performance has been observed in professional male players (Gaviglio, Crewther, Kilduff, Stokes, & Cook, 2014). Conversely, this association was not found when assessing testosterone concentration and performance in University-standard female rugby players (Bateup et al., 2002), or when assessing the pre to post-match change in testosterone concentration and performance in Collegiate-standard soccer players (Edwards, Wetzel, & Wyner, 2006). However, the standard of players was different between studies which may be a factor when interpreting such findings. In elite female athletes varied reports exist. In elite female wrestlers, salivary testosterone concentrations increased from pre to post-competition, with no differences between wins and losses (Hamilton, Van Anders, Cox, & Watson, 2009). However, a positive relationship has been reported between pre-competition testosterone concentration and positive actions in elite female hockey players (Crewther, Hamilton, Kilduff, Drawer, & Cook, 2018).

2.2.2.1.2 Circadian rhythm

Testosterone follows a circadian rhythm, with highest concentrations in the morning, decreasing throughout the day (Teo, McGuigan, et al., 2011) (Figure 2.6), with minimum concentrations around 19:00 to 21:00 (Bremner, Vitiello, & Prinz, 1983). Although neuromuscular and athletic performance displays a circadian rhythm closely linked to body temperature (Hayes, Bickerstaff, & Baker, 2010), with lower values in the morning (when body temperature is also lower) when compared to the evening (Teo, McGuigan, et al., 2011), manipulation of afternoon testosterone concentration has been demonstrated, with positive impact upon performance (Cook et al., 2014; Russell et al., 2016). For example, Cook et al. (2014) reported that the performance of morning resistance training attenuated the decline of testosterone concentration through the day, which did occur following no exercise or sprint exercise. Additionally, afternoon sprint and weight lifting performance was improved following the morning resistance exercise, suggesting the higher relative testosterone concentration as a key mediator in neuromuscular performance (Cook et al., 2014).

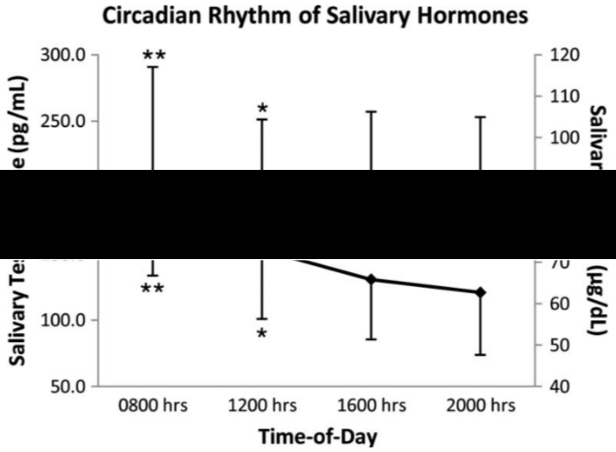

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Figure 2.6 : Within day variation of salivary testosterone and cortisol concentrations (*n* = 20). ** Statistical significance ($P < 0.001$) when compared to 1600 hours. * Statistical significance ($P < 0.05$) when compared to 1600 hours. Reproduced from Teo et al. (2011).

2.2.2.2 Cortisol

Cortisol is an adrenal steroid hormone, released during stress to modulate processes to support responses to challenging situations (Strelzyk et al., 2012). Cortisol has effects on the entire body, through both rapid non-genomic effects, as well as genomic effects, via binding to glucocorticoid and mineralocorticoid receptors (Strelzyk et al., 2012). Genomic effects occur over longer periods of time, inducing slowly emerging changes in gene transcription, altering protein expression of affected cells (Strelzyk et al., 2012), whilst non-genomic effects occur rapidly (within seconds to minutes) after cortisol exposure (Makara, Gabor & Haller, 2001), without changes in protein expression.

2.2.2.2.1 Effects of cortisol on the neuromuscular system

Secreted by the hypothalamic-pituitary-adrenal (HPA) axis, cortisol has a wide spectrum of roles involved mainly in metabolic control and on the neuromuscular system. Cortisol, considered a primary catabolic hormone, in response to a challenging situation increases the pool of available amino acids for adaptation to the stressful situation, providing amino acids for protein resynthesis and repair of damaged proteins (Viru & Viru, 2004). In combination with testosterone, cortisol mediates long term changes in muscle fibre size and hence sporting performance potential (Crewther et al., 2011).

Cortisol also has a range of effects upon metabolic control, including glucose production through gluconeogenesis to provide substrate for energy production, with permissive actions on a range of other hormones (Viru & Viru, 2004). Other non-genomic effects include impact upon the central nervous system (Strelzyk et al., 2012). Cortisol infusion, at physiological levels, affects the functioning and perfusion of the brain under stress (performance of a word discrimination task), within 15 minutes, indicative of a non-genomic action (Strelzyk et al., 2012). This change in central nervous system functioning is proposed to be in order to allow greater attention to specific sensory information to adapt to the stressful situation, by supressing the processing of non-specific background information action (Strelzyk et al., 2012). Cortisol also affects other behaviours which may impact the neuromuscular system, for example, basal cortisol concentration is negatively associated with aggressive behaviour, whilst exogenous cortisol administration increases aggressive behaviours in females but not in males (Böhnke, Bertsch, Kruk, Richter, & Naumann, 2010). However, more recent findings suggest cortisol to act as a moderator of the effect of testosterone on aggressive behaviour (Denson, Mehta, & Ho Tan, 2013; Popma et al., 2007) as well as other behaviours (Mehta & Josephs, 2010; Mehta, Welker, Zilioli, & Carré, 2015) which may impact neuromuscular performance.

Prior to competition, an anticipatory rise in cortisol concentration has been reported in male (Salvador, Suay, González-Bono, & Serrano, 2003; Van Paridon, Timmis, Nevison, & Bristow, 2017), and female athletes (Bateup et al., 2002; Casto & Edwards, 2016; Iellamo et al., 2003), highlighting the response of the HPA axis to the stressful situation or ensuing challenge. This anticipatory rise in cortisol is important to be prepared for both the psychological and physiological demands of sport and is suggested to influence performance through its influence on cognitive processes (Bishop, Duncan, Brett, & Lawrence, 2004) as well as physiological mechanisms (Van Paridon et al., 2017). Higher pre-competition cortisol concentration has been associated with higher level of performance across several sports, including judo (Papacosta, Nassis, & Gleeson, 2015) and triathlon (Balthazar et al., 2012), although not in male rugby union players (Gaviglio et al., 2014). Papacosta et al. (2015) studied the salivary cortisol concentrations before, mid-competition and post-competition in male, National-level judo players. Those players finishing in the top three overall had higher cortisol concentrations prior to commencing warm-up, compared with those finishing fourth place or lower. Similarly, in the endurance sport of triathlon, Balthazar et al. (2012) reported that in male professional triathletes, morning cortisol concentration was positively correlated with performance. However, limited reports exist in female populations, with no relationship between the change in cortisol concentration from pre to post-competition and outcome in female soccer players (Edwards et al., 2006; Oliveira, Gouveia, & Oliveira, 2009). As enhanced cortisol concentrations can increase focus (Strelzyk et al., 2012) and enhance metabolic control (Viru & Viru, 2004), the higher concentration in higher ranked athletes may reflect increased sympathetic nervous system activation and higher levels of physiological and psychological arousal (Papacosta et al., 2015). Similarly, the response to a mid-week exercise stress test has been reported to be related to match outcome (Crewther, Potts, Kilduff, Drawer, & Cook, 2018). In response to an exercise stress test (performed three to four days prior to competition), an increase in cortisol concentration from morning to post-exercise was associated with winning, and a decrease associated with losing in international standard male rugby players (Crewther, Potts, et al., 2018), however no reports are available for female participants.

2.2.2.2.2 Cortisol as a moderator of testosterone activity

Although both testosterone and cortisol concentrations have been reported to be associated with neuromuscular and competitive performance, and behaviour which may underpin this performance, more recent findings suggests that cortisol may be a moderator of testosterone activity (Crewther, Obmiński, & Cook, 2018; Crewther, Thomas, Stewart-Williams, Kilduff, & Cook, 2017; Edwards & Casto, 2013; Ponzi, Zilioli, Mehta, Maslov, & Watson, 2016). For example, when assessed individually, salivary testosterone concentration does not correlate with social status in female collegiate-level athletes (Edwards & Casto, 2013), or hand-grip strength in healthy men (Crewther et al., 2017). However, when individuals with relatively high or low cortisol concentration were considered separately, significant relationships emerged (Crewther et al., 2017; Edwards & Casto, 2013). This finding has been further demonstrated in competitive performance in Olympic weightlifting (Crewther, Obmiński, et al., 2018). In male weightlifters performing in competitions (n = 46) and simulated events (n= 59), testosterone concentration prior to commencing the event, as well as the change in concentration from pre to post event, was unrelated to performance (Crewther, Obmiński, et al., 2018). However, when assessed further, evidence of testosterone and cortisol moderating physiological systems in tandem were found, as the low cortisol group performed better when testosterone concentration was high, and conversely the high cortisol group performed better when testosterone concentration was low prior to competition (Crewther, Obmiński, et al., 2018). Therefore, testosterone and cortisol may not be strictly anabolic and catabolic hormones, but rather hormones which work in tandem to exert complimentary actions that may depend on the task, the situation and environmental needs of the athlete (Crewther, Obmiński, et al., 2018).

2.2.3 The effect of muscle temperature on neuromuscular function

A consequence of exercise is the associated increase in the temperature of exercising muscle (Stewart, Macaluso, & De Vito, 2003), and is well established to be positively associated with neuromuscular function (Sargeant, 1987; West, Cook, Beaven, & Kilduff, 2014). The performance of a warm-up exercise is commonly performed by athletes, with a meta-analysis reporting a positive effect on performance in 79% of studies (Fradkin, Zazryn, & Smoliga, 2010), and muscle temperature as an important component (Sargeant, 1987; West, Cook, Beaven, et al., 2014). An early study showed that passively warming lower-body muscles increases subsequent power output, with the magnitude of effect velocity dependent, by up to 10% per 1℃ increase in muscle temperature (Sargeant, 1987), with more recent findings suggesting similar positive associations between temperature and power output (Cook, Holdcroft, Drawer, & Kilduff, 2013; West, Cook, Beaven, et al., 2014). In elite bob-skeleton athletes, sprint performance following a warm-up was enhanced when the increase in tympanic temperature (from pre warm up to prior to the sprint performance) was greater at the onset of exercise (Cook, Holdcroft, et al., 2013). Similarly, maintaining muscle temperature post warm-up via passive means, without manipulation of the warm-up itself, improved 30 s sprint cycling performance with an associated increase in muscle temperature at the commencement of exercise (Faulkner et al., 2013).

Various mechanisms have been proposed to underpin the effect temperature has upon neuromuscular function. Whilst nerve conduction velocity has been proposed to increase following a warm up (Bishop, 2003), evidence exists to suggest that this does not occur (Pearce, Rowe, & Whyte, 2012). Instead, adenosine triphosphate (ATP) turnover and muscle fibre conduction velocity have been reported to increase following passive warming of the lower limbs compared without warming (Gray, De Vito, Nimmo, Farina, & Ferguson, 2006). The authors propose that the increase in ATP turnover is likely due to an increase in enzymatic processes, as ATPase activity is temperature dependent. Additionally, the increase in muscle fibre conduction velocity is proposed to be due to more rapid action potential delivery to the muscle, increasing calcium release from the sarcoplasmic reticulum, resulting in faster cross-bridge cycling, which in turn requires greater ATP turnover (Gray et al., 2006). The force-velocity characteristics of a muscle also show temperature dependence (De Ruiter & De Haan, 2000) (Figure 2.7). At increased temperatures, the force-velocity curve shifts to the right, meaning for a given force the velocity of contraction increases, and peak force occurs at an increased contraction velocity (De Ruiter & De Haan, 2000).

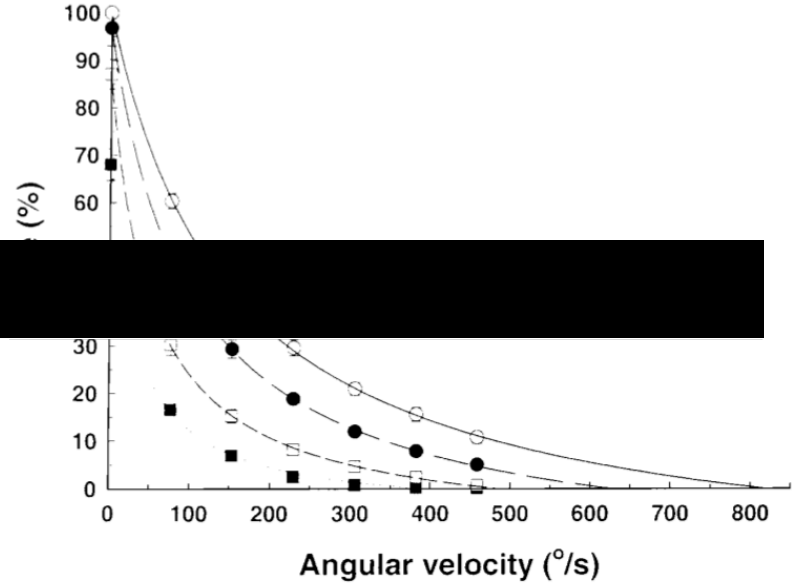

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Figure 2.7: The force/ velocity relationship of adductor pollicis muscle at 37.1°C (open circles), 31.4°C (closed circles), 25.6°C (open squares) and 22.2°C (closed squares). All values were normalised to the maximal isometric force at 37.1°C (100%). Reproduced from De Ruiter and De Haan (2000).

Circadian rhythm changes in neuromuscular function have been reported (Teo, McGuigan, et al., 2011; Teo, Newton, & McGuigan, 2011), and closely associated with fluctuating concentrations of testosterone and cortisol (Teo, McGuigan, et al., 2011). Body temperature however also shows a circadian rhythm, reaching minimum temperatures at around 06:00, and peak at around 18:00 (Reilly, 1990), and has been linked with the circadian rhythm of power output (West, Cook, Beaven, et al., 2014). Indeed, West et al. (2014) reported higher core temperature in elite male rugby-sevens players at 17:00 compared with 10:00, with an associated increase in peak power output in a CMJ by 5.1 % (± 0.7%) highlighting the strong relationship between temperature and neuromuscular function (Figure 2.8).

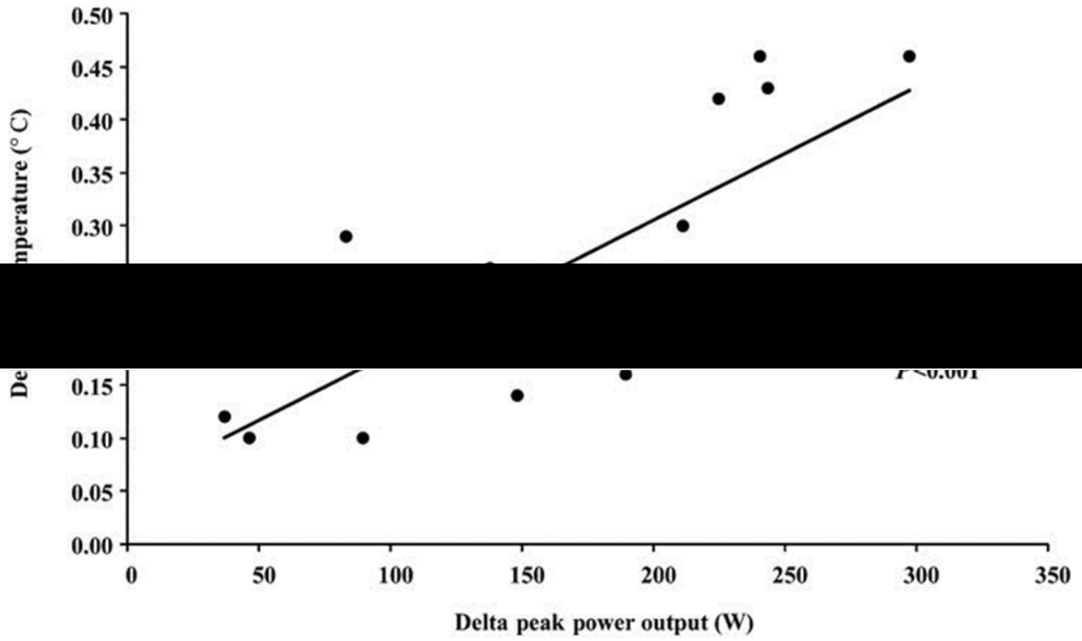

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Figure 2.8: The relationship between change in core temperature and change in lower body power in elite rugby players. Reproduced from West et al. (2014).

2.2.4 The effect of the menstrual cycle and hormonal contraceptive use on neuromuscular performance

2.2.4.1 The effect of menstrual cycle on neuromuscular performance

Females undergo cyclical changes in circulating hormones, regulating the menstrual cycle, which have important biological impacts upon the body, with physiological, physical and emotional consequences. The menstrual cycle typically lasts around 28 days (Figure 2.9), with two distinct phases of 14 days each (Chabbert Buffet, Djakoure, Maitre, & Bouchard, 1998) which can be further defined in to five sub-phases. On day one of the cycle, the follicular phase begins, with menstrual flow (termed the menstrual phase) lasting four to six days (Farage, Neill, & MacLean, 2009). This is followed by the growth of a follicle, secreting increasing amounts of oestradiol through this follicular phase (Chabbert Buffet et al., 1998), culminating in ovulation (the ovulatory phase) (Farage et al., 2009) (Figure 2.9). After ovulation, from day 15 to 28, is the luteal phase, at the end of which hormone concentrations reduce through the pre-menstrual phase, completing the cycle (Buser, 2012; Chabbert Buffet et al., 1998). Core temperature increases around ovulation and remains elevated in the presence of high concentrations of progesterone and oestrogen in the luteal phase, hence reducing in the pre-menstrual phase as concentrations of these hormones reduce (Farage et al., 2009). Testosterone also shows changes throughout the menstrual cycle (Figure 2.10), with an increase from day seven to 14 (42 ± 27%), followed by a reduction to lowest concentrations at day 21, lower than day seven (-26 ± 30%) and day 14 (-48% ± 38%) (Cook et al., 2018). In this study, Cook et al. (2018) reported greater changes in circulation testosterone concentration in elite compared with non-elite female athletes, which may be due to increased basal testosterone concentration for the elite females.

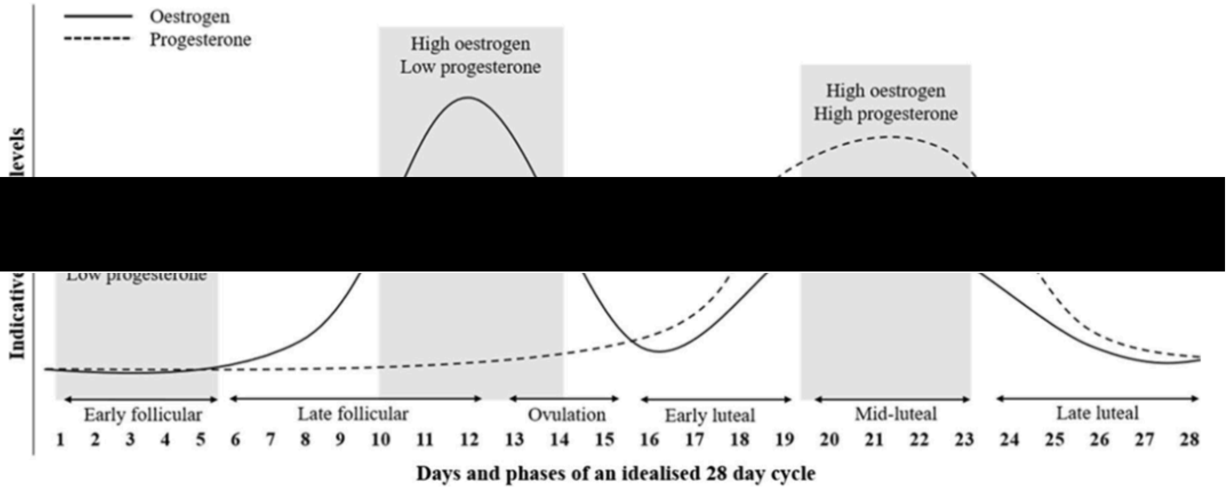

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Figure 2.9: Schematic displaying the hormonal fluctuations across an idealised 28-day menstrual cycle, with ovulation occurring on day 14. Reproduced from McNulty et al. (2020).

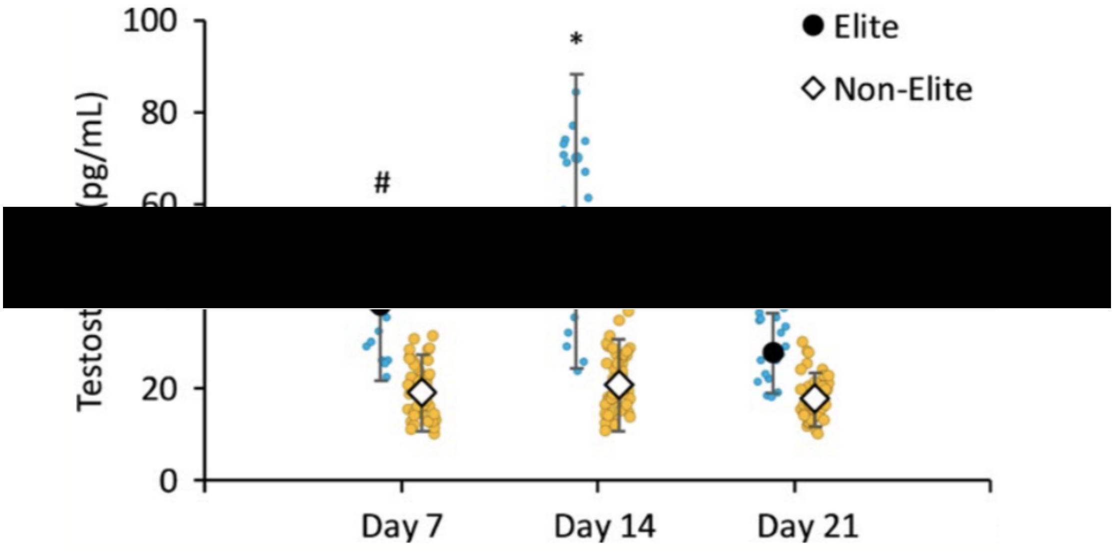

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Figure 2.10: Change in salivary testosterone concentration in elite and non-elite female athletes across the stages of the menstrual cycle (follicular, ovulatory and luteal phases respectively). Values are group mean ± standard deviation, with individual data at each time-point. * Significant from elites on day seven and 21. # Significant from elites on day 21 and non-elites on day seven. † Significant from non-elites on day seven, 14 and 21. α Significant from non-elites on day seven and 21. All $P < 0.05$. Reproduced from Cook et al. (2018).

Although testosterone concentration has been linked with social aspects in females, such as aggressiveness (Bateup et al., 2002), dominance (Grant & France, 2001), self-efficacy (Costa et al., 2016) and risk aversion (Sapienza et al., 2009), as well as neuromuscular performance (Cardinale & Stone, 2006) and athletic performance (Bermon & Garnier, 2017), these observations have been made acutely, rather than longitudinally through the menstrual cycle. Whilst conflicting findings exist, these can be largely explained by methodological shortcomings (McNulty et al., 2020), suggesting the menstrual cycle has no impact on neuromuscular performance (de Jonge, 2003). Although the concentration of testosterone varies between menstrual-phase (day two) and mid-luteal phase (day 21) in healthy females, maximal voluntary isometric strength of the of the first dorsal interosseus muscles does not (Elliott, Cable, Reilly, & Diver, 2003). Maximal cycling power output, squat jump performance, and repeated vertical jump performance is not different between menstrual phase (days one to four), follicular (days seven to nine), or mid-luteal phase (days 19-21) in eumenorrheic females (Giacomoni, Bernard, Gavarry, Altare, & Falgairette, 2000). Similarly, maximal isometric strength, fatiguability and contractile properties of the quadriceps, in addition to hand-grip strength, did not vary across similar phases of the cycle in physically active females (de Jonge, Boot, Thom, Ruell, & Thompson, 2001). In support of this, De Lima Costa et al., (2015) reported no difference between phases in surface electromyography (EMG) of lower-limb muscles during a smith machine squat. A recent meta-analysis found a trivial difference in exercise performance during the early follicular phase, with no other differences between phases of the menstrual cycle, however also noted considerable inter-study differences in design, performance measures and participants, and low quality studies (McNulty et al., 2020). In an elite population, very limited findings exist. Indeed, one report highlights higher motivation to train and peak power during a six second cycling sprint in the ovulatory phase (Figure 2.11) compared to follicular or luteal phase (Cook et al., 2018). However, several limitations exist with this report. Participant groups were not matched, with only six participants termed elite recruited for the study, compared to 16 non-elites and participants came from a range of sports requiring very different training and competitive demands (figure skating, soccer, netball and triathlon). No measurements were involved to determine the menstrual cycle phase, with athletes self-reporting instead. Additionally, the authors state caution to be used, in that complexities of hormonal responses may limit findings to these athletes, environment and testing situations they were obtained (Cook et al., 2018).

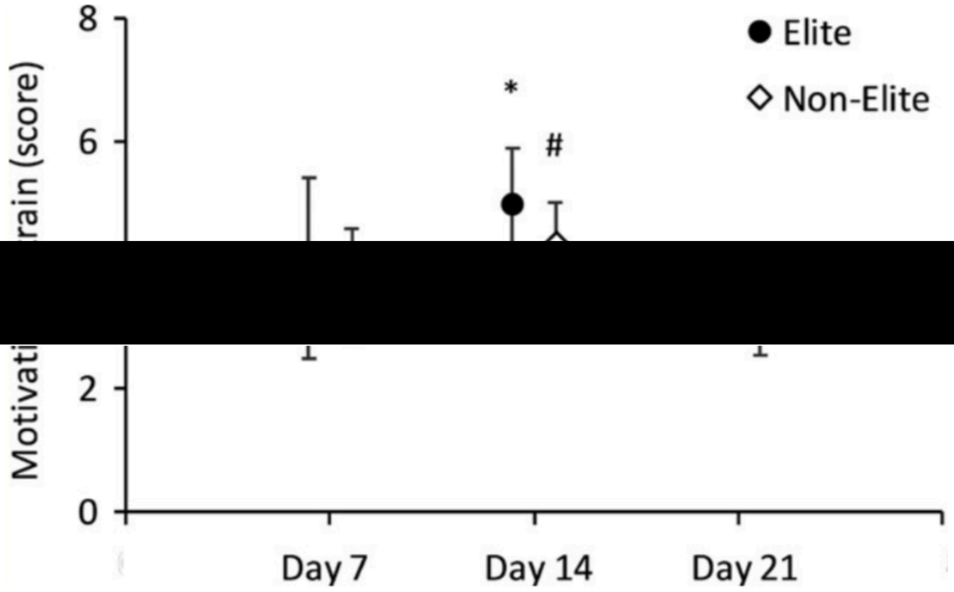

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Figure 2.11: Motivation to train at day seven, 14 and 21 of the menstrual cycle in elite and non-elite female athletes. * Significant from elites on day seven and 21, and non-elites on day seven, 14 and 21. # Significant from elites on day 21 and non-elites on day seven and 21. All $P < 0.05$. Reproduced from Cook et al. (2018).

2.2.4.2 The effect of hormonal contraceptive use on neuromuscular performance

Hormonal contraceptives are exogenous steroid hormones, which inhibit ovulation and result in consistently low-endogenous sex hormone concentrations, and have many different forms including oral contraceptives, injections and implants (Martin, Sale, Cooper, & Elliott-Sale, 2018). Negative side effects of the menstrual cycle can occur, with 77% of elite female athletes not using hormonal contraceptives reporting experiencing stomach cramps, back pain and headaches (Martin et al., 2018). Various forms of hormonal contraceptives are widely used, with almost 50% of 430 elite female athletes reporting to currently use a hormonal contraceptive, and almost 70% reported having used hormonal contraceptives at some point (Martin et al., 2018).

In elite female athletes, non-hormonal contraceptive users have 35% higher salivary testosterone concentrations compared with users (Crewther, Hamilton, et al., 2018), with similar findings in healthy females (Liening, Stanton, Saini, & Schultheiss, 2010; Zimmerman, Eijkemans, Coelingh Bennink, Blankenstein, & Fauser, 2014). Hormonal contraceptives reduce circulating testosterone concentrations by inhibiting ovarian and adrenal androgen synthesis, coupled at the same time by increasing sex hormone-binding globulin, reducing the available free testosterone concentration (Zimmerman et al., 2014). However, in spite of the differences observed in basal testosterone concentration, maximal force of the lower-limbs is not different through the phases of oral contraceptive use (when circulating exogenous hormones are high during consumption, and low during the withdrawal period) in sedentary females, in spite of changes in circulating oestrogen and progesterone, suggesting these hormones have no effect on maximum force production in healthy females (Elliott, Cable, & Reilly, 2005). Similarly, no difference in 200 m swim performance has been observed throughout phases of oral contraceptive use in competitive (state-level or higher) swimmers (Rechichi & Dawson, 2012), or countermovement jump performance, repeated sprint ability or cycling peak power output in state-level or higher-level team sport players (Rechichi & Dawson, 2009). Of significance, was the observation that reactive strength performance was reduced late in the oral contraceptive withdrawal phase, when exogenous oestrogen and progesterone would have been removed from circulation, but endogenous concentrations start to rise, however it is unclear as to how this may be explained (Rechichi & Dawson, 2009). Long-term, training-induced changes in neuromuscular performance are also unaffected by hormonal contraceptive use (Myllyaho et al., 2018; Romance et al., 2019). Neither body composition changes or increases in strength in resistance trained females was different between hormonal contraceptive users and non-users following an eight week strength-training programme (Romance et al., 2019), or in strength or endurance adaptations following concurrent strength and endurance training in physically active females (Myllyaho et al., 2018). Very few studies have been performed in elite female populations, with the aforementioned reports in sedentary, trained or state-level participants. Crewther et al. (2018), studied 23 international-standard female hockey players, including seven players using hormonal contraceptive, and 16 non-users. Across four matches played in nine days, salivary testosterone was measured prior to each match, and playing performance assessed by commonly used statistics as well as coach and player ratings. Although salivary testosterone concentration was higher for non-hormonal contraceptive users, no difference in match performances were observed between groups (Crewther, Hamilton, et al., 2018). Collectively, findings suggest that whilst salivary testosterone is reduced with hormonal contraceptive use, there is no impact upon acute or long-term neuromuscular performance in sub-elite females, and no impact upon team-sport performance in elite female players.

2.3 Measurements of the neuromuscular system

Changes in the neuromuscular system, as previously described in section 2.2, has been observed and quantified by use of many methods, ranging from laboratory-based methods at a single muscle level, to understand central and peripheral contributions (Herbert & Gandevia, 1999; Thomas et al., 2014), to whole body dynamic movements linked to athletic performance (Clarke et al., 2015; Cormack, Newton, McGulgan, & Doyle, 2008).

2.3.1 Laboratory-based measurements of the neuromuscular system

Laboratory-based measurements of the neuromuscular system have been extensively used to quantify central and peripheral contribution to fatigue following exercise (e.g. Herbert & Gandevia, 1999; Merton, 1954; Tomazin et al., 2012). A commonly employed method is the interpolated twitch technique, which allows measurement of voluntary activation and an understanding of motor unit activation (Herbert & Gandevia, 1999). During a maximal voluntary contraction, once force output plateaus, the associated motor nerve is electrically stimulated, which is compared with electrical stimulation to the muscle at rest (a control twitch). An increase in force output during a maximal voluntary contraction suggests that not all motor units were recruited optimally (Herbert & Gandevia, 1999), and if this difference grows following exercise, is evidence of reduced voluntary activation and central fatigue (Taylor & Gandevia, 2008).

Whilst these methods may provide information on the origin of fatigue, it is important to recognise the impact these changes have on fatigue in dynamic movements. Indeed, it has been demonstrated that isometric muscle strength, as measured with maximal voluntary contractions, was not related to sprint or jumping performance (Requena et al., 2009). Magnitude and time course of fatigue can vary following fatiguing exercise (Byrne & Eeston, 2002). Following 100 eccentric squats, performed to induce muscle damage and fatigue, isometric force (measured during an isometric leg extension exercise) decreased by 30%, to a greater degree than the associated decrease in dynamic power (measured during a wingate test on a cycle ergometer) of 13%, one hour following exercise. Additionally, muscular strength recovered linearly over the seven days following exercise, whilst dynamic power decreased further, before subsequent recovery. Furthermore, no relationship has been reported between evoked isometric twitch and countermovement jump performance following potentiating exercise (Mitchell & Sale, 2011; Pearson & Hussain, 2014), proposed to be due to the product of the multi-joint and muscle contribution to a countermovement jump, versus the knee extensors only in the isometric contraction (Mitchell & Sale, 2011). Collectively, whilst these methods can identify the mechanism of fatigue, limitations exist with regards to isometric muscle contractions, single joint, and single muscle exercise, which may not be representative of more global aspects of dynamic exercise and impact upon athletic performance (Byrne & Eeston, 2002; Mitchell & Sale, 2011; Pearson & Hussain, 2014; Requena et al., 2009).

2.3.2 Dynamic measurement of the neuromuscular system

In contrast to laboratory-based measurements of single muscles or joints, dynamic measurement of the neuromuscular system can also be performed. Whilst this includes athletic performance tests such as sprint cycling (Byrne & Eeston, 2002) and sprint running (Andersson et al., 2008), more commonly employed is the performance of countermovement jump tests (Clarke et al., 2015; Cormack, Newton, McGuigan, & Cormie, 2008; Johnston et al., 2015). This involves the participant performing a countermovement jump, with resultant forces measured by use of a force platform (Johnston et al., 2015).

Several variables of jump testing (Table 2.5) have been used to assess changes in neuromuscular performance, with good reliability reported both inter and intraday (Cormack, Newton, McGulgan, et al., 2008). One of the most commonly used variables is jump height (Johnston et al., 2016, 2017; Sparkes et al., 2020, 2018; Thorlund, Michalsik, Madsen, & Aagaard, 2008), defined as the difference between vertical displacement at take-off and maximal vertical displacement (Johnston et al., 2015), with excellent reliability across a range of measurements (Cormack, Newton, McGulgan, et al., 2008; Moir, Garcia, & Dwyer, 2009). Jump height has been related to sprint running performance (Cronin & Hansen, 2005; Requena et al., 2009) and playing standard in rugby players (Gabbett, Kelly, Ralph, & Driscoll, 2009), suggesting changes in jump height important for athletic performance. However, whilst some studies show a decrease in jump height in response to fatiguing exercise (Andersson et al., 2008; Johnston et al., 2016; K. Thomas et al., 2017; Thorlund et al., 2008), other studies have reported no change (Cormack, Newton, McGuigan, et al., 2008; Thorlund, Aagaard, & Madsen, 2009; Wood et al., 2013). Whilst the degree of fatigue experienced following fatiguing exercise may be a factor, it has also been suggested that a change in jump strategy may be used under fatigued conditions. In order to compensate for sub-optimal force generation at the initiation of the jump movement, an altered jump strategy may be used which allows the participant to reach the same height (Cormack, Newton, McGulgan, et al., 2008; Thorlund et al., 2008), hence alternative variables should be used in conjunction.

Table 2.5: Intraday reliability of countermovement jump variables performed by elite male Australian rugby football players. Reproduced from Cormack et al. (2008).

	Mean	TE	Lower 90%CI	Upper 90%CI	SWC	CV%
Height (m)	0.488	0.024	0.018	0.035	0.007	5.2
Flight time (s)	0.586	0.017	0.013	0.025	0.006	2.9
Peak power (W)	5014	166	127	242	112	3.5
Relative peak power (W·kg^{-1})	54	2	1	3	1	3.6
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Relative peak force (N·kg^{-1})	23	0.8	0.6	1.2	0.3	3.4
Mean force (N)	1233	12	10	20	20	1.1
Relative mean force (N·kg^{-1})	13	0.16	0.12	0.24	0.2	1.2
Flight time: contraction time (s)	0.807	0.056	0.043	0.082	0.027	6.1

Abbreviations: TE: typical error; CI: confidence interval; SWC: smallest worthwhile change; CV: coefficient of variation.

Other commonly used variables include peak power output (Johnston et al., 2015, 2017; Kilduff et al., 2008; Russell et al., 2015; Sparkes et al., 2018), the highest value obtained by multiplying vertical ground reaction force by vertical velocity at each time-point (Johnston et al., 2015), peak velocity, (Johnston et al., 2017; Wood et al., 2013), the peak instantaneous velocity value produced during the jump, and rate of force development (Johnston et al., 2017; Kilduff et al., 2008), the change of force during the eccentric deceleration phase divided by duration of the eccentric deceleration phase (Johnston et al., 2015). Peak power output has been reported to be correlated with twitch peak force and rate of force development during an isometric knee extension (Nibali, Chapman, Robergs, & Drinkwater, 2013), and is sensitive to both reductions following fatiguing exercise (Johnston et al., 2016; West, Cunningham, Finn, et al., 2014), and increases following potentiation exercise (Nibali et al., 2013). Additionally, dynamic rate of force development during a countermovement jump has been correlated with that of isometric leg extension exercise ($r = 0.64-0.65$ pre to post, $P \leq 0.05$), with a decrease reported following a simulated handball match (Thorlund et al., 2008), and of particular importance in explosive movements such as change of direction and sprinting (Aagaard, 2003; Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). Collectively, these markers derived from countermovement jump testing have been reported to be valid measurements of neuromuscular function (Nibali et al., 2013; Thorlund et al., 2008), reliable (Cormack, Newton, McGulgan, et al., 2008; Moir et al., 2009) and sensitive to measure changes in neuromuscular performance in elite athletes (Russell et al., 2015; Sparkes et al., 2018; West, Cook, Stokes, et al., 2014).

2.4 Neuromuscular and endocrine system responses to training

In response to exercise, physiological systems are activated and stressed both during and in the ensuing recovery period, with evidence of such responses experienced over a prolonged period of up to 72 h (Anderson, Lane, & Hackney, 2016; Hiscock, Dawson, Clarke, & Peeling, 2018). Responses vary depending on the mode of exercise performed (Jones et al., 2017), the physiological stress that is exerted due to types of movements (Ashton & Twist, 2015), intensity (McCaulley et al., 2009; Seiler, Haugen, & Kuffel, 2007), and volume of exercise (Hiscock et al., 2018) as well as athlete characteristics including training status (Eliakim, Portal, Zadik, Meckel, & Nemet, 2013; Mascarin et al., 2018; Sparkes et al., 2018) and gender (Linnamo et al., 2005). Although a wide variety of responses occur to a stimulus, and with varying time frames post-exercise, this section focuses on responses to the neuromuscular and endocrine systems occurring immediately post-exercise, and the ensuing recovery period over two to 24 h following resistance, technical team-sport training and netball training and competition.

2.4.1 Responses to Resistance Exercise

Whilst there are many studies highlighting the acute neuromuscular and endocrine responses to resistance exercise, there is no consensus due to the wide variety of protocols employed and variation in training status of participants (Ahtiainen, Pakarinen, Kraemer, & Häkkinen, 2004; Johnston et al., 2017; Linnamo et al., 2000), notwithstanding the very limited data in female participants, especially in elite female athletes (Nunes et al., 2011). Of note is that a single definition of types of training does not exist. For example, Linnamo et al. (2005) refer to heavy resistance training as five sets of 10 repetitions performed at approximately 70% of one repetition maximum, whilst McCaulley et al. (2009) refer to this type of protocol as hypertrophy training. Therefore, in this review the following definitions of hypertrophy, strength and power resistance training will be used (Table 2.6) as per that suggested by Kraemer, Duncan, and Volek (1998).

Table 2.6: The definition, including load, number of repetitions and recovery duration, of the various resistance training protocols to be used in this review.

	Hypertrophy	Strength	Power
Load (% of one repetition maximum)	70-75%	≥ 80%	≤ 45%
Repetitions	≥ 8	≤ 6	≤ 10
Recovery period (min)	≤ 2	≥ 3	≥ 3

2.4.1.1 Immediate post-resistance exercise training responses

Several studies have compared the acute responses to various types of resistance exercise protocols, including both matching (McCaulley et al., 2009) and not-matching volume of work performed (Hiscock et al., 2018). McCauley et al. (2009) investigated the acute responses over 48 h in 10 resistance exercise experienced male participants. Participants performed three resistance exercise protocols; hypertrophy, strength and power, in addition to a control protocol including rest only (Table 2.7), with each protocol separated by one week. Serum testosterone and cortisol concentrations were assessed, along with blood lactate concentration, and an isometric squat with EMG of the vastus medialis was used to assess neuromuscular fatigue. Measures were taken immediate pre, immediately post, one h post, 24 h post and 48 h post-resistance exercise.

Table 2.7: Details of the power, strength and hypertrophy resistance exercise protocols employed by McCauley et al. (2009). For hypertrophy and strength protocols the back squat exercise was performed, and for the power protocol unloaded jump squats were performed. Reproduced from McCauley et al. (2009).

	Hypertrophy	Strength	Power
Load (% of one repetition maximum)	70%	90%	0%
Sets	4	11	8
[redacted]	[redacted]	[redacted]	[redacted]
Volume of work (J) x 10^{-3}	84.2 ± 8.5	84.2 ± 19.7	77.0 ± 22.5

The hypertrophy protocol resulted in a significant increase in testosterone and cortisol concentrations compared with the rest protocol from pre to immediately post-exercise, whilst differences were not observed in that following strength or power protocols (Table 2.8). Blood lactate concentration varied between all protocols, suggesting altered metabolic demands based on intensity of exercise and duration of recovery periods between sets. Both the hypertrophy and strength protocols elicited a significantly greater post-exercise blood lactate concentration than power or rest protocols, whilst the hypertrophy protocol elicited a greater concentration than the strength protocol (Figure 2.12). Neuromuscular fatigue was evident following the strength and hypertrophy protocols, with a significant decrease in peak force and rate of force development immediately post-exercise following the strength and hypertrophy protocols compared with rest protocol (Figure 2.13). Additionally, EMG of the vastus medialis was significantly reduced following the strength protocol compared with the hypertrophy protocol (Figure 2.13). Findings show that intra-set recovery duration and intensity of exercise performed has a large effect on the metabolic stress of the exercise, leading to a greater endocrine response. As the metabolic stress is different between protocols, it can be speculated that the mechanism of neuromuscular fatigue may also be different, with greater peripheral fatigue following the hypertrophy protocol than strength or power protocols. It has been well documented that changes in central fatigue occur following heavy strength training exercise (Hakkinen, 1993; Linnamo et al., 2000; Walker, Davis, Avela, & Häkkinen, 2012), and peripheral fatigue is more prominent following hypertrophy based loadings with a greater associated increase in blood lactate concentration than other loading types (Walker et al., 2012).

Table 2.8: Percent changes in testosterone and cortisol concentrations from pre-exercise to immediately post three resistance exercise protocols. Reproduced from McCauley et al. (2009).

	Hypertrophy	Strength	Power	Rest
[redacted]				

* significant ($P < 0.05$) difference to rest protocol

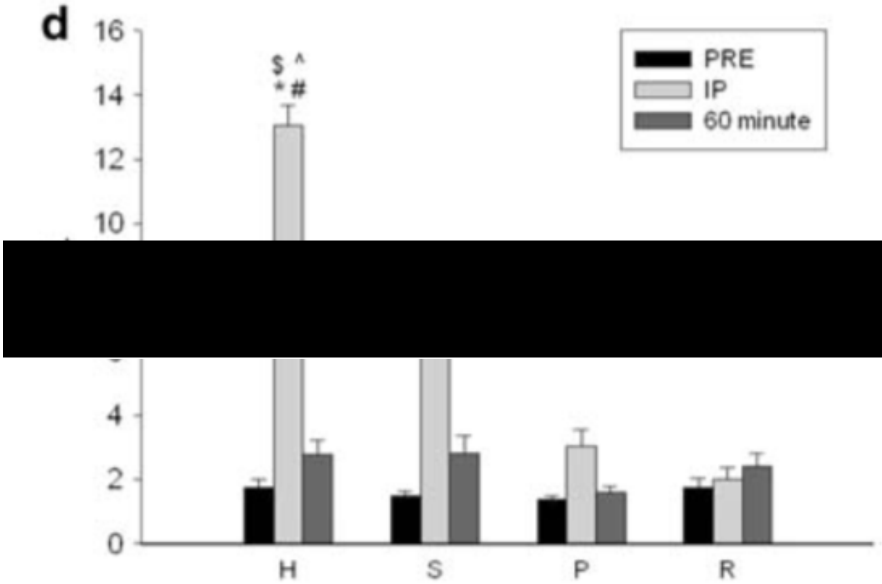

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Figure 2.12 : Blood lactate concentration pre, immediately post and 60 min post-resistance exercise protocols. Reproduced from McCauley et al. (2009). *Abbreviations*: H: hypertrophy protocol; S: strength protocol; P: power protocol; R: rest protocol. $^{\$}$ significant (P < 0.05) difference from power protocol; ^ significant ($p < 0.05$) difference from strength protocol; * significant (P < 0.05) difference from rest protocol; $^{\#}$ Significant (P < 0.001) difference from pre value.

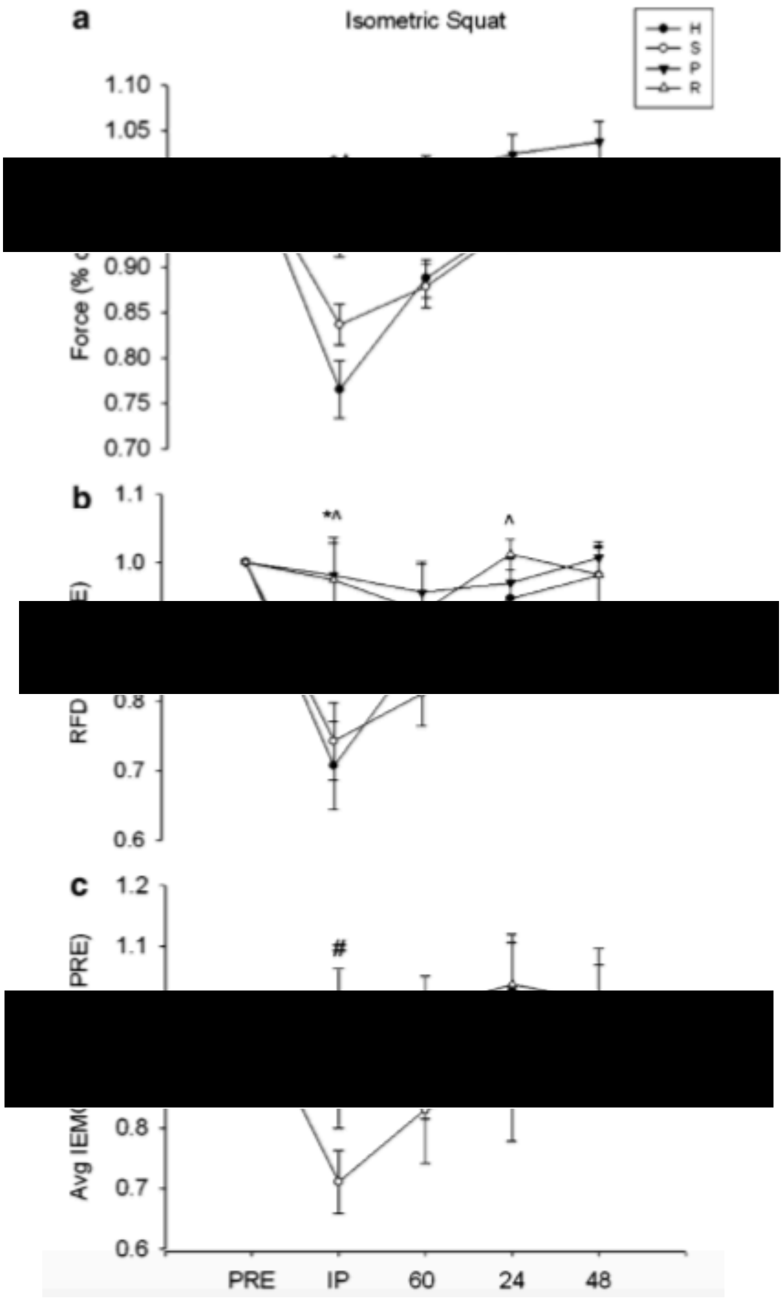

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Figure 2.13: Mean (± standard error): (a) percent of baseline force values; (b) percent of baseline rate of force development; (c) percent of baseline average intergraded electromyography muscle activity from the vastus medialis at immediately post-exercise (IP), 60 min (60), 24 h (24) and 48 h (48) between the hypertrophy (H), strength (S), power (P) and rest (R) conditions during an isometric squat test. * H protocol significantly ($P < 0.05$) decreased in comparison to R condition; ^ S protocol significantly ($P < 0.05$) decreased in comparison to R condition; $^{\#}$ H protocol significantly ($P < 0.05$) increased in comparison to S protocol. Reproduced from McCauley et al. (2009).

Through matching total volume of work performed between protocols, McCauley et al. (2009) clearly demonstrates differences in neuromuscular, endocrine and metabolic responses to resistance exercise, dependent upon intensity of exercise performed and intra-set recovery duration. However, this study is limited due to the performance of only a single exercise (the back squat), resulting in a significantly reduced training volume to what might be typically employed in regular resistance exercise with the performance of multiple exercises (Crewther et al., 2006), whilst matched work protocols would not necessarily reflect typical volumes performed for each type of resistance exercise training (Crewther et al., 2006). To account for these limitations, Hiscock et al. (2018) investigated the acute responses to different types of resistance exercise, however, did not match total work performed between protocols, to better reflect the training which would typically be performed in each type of resistance exercise training. Male team-sport players (n = 12) with at least 12 months resistance-training experience performed three protocols, separated by one week, including the same four exercises of bench press, back squat, deadlift and prone bench pull (Table 2.9). Measures included salivary testosterone and cortisol concentrations to assess endocrine function, and countermovement jump testing to assess neuromuscular performance.

Table 2.9: Details of the power, strength and hypertrophy protocols employed by Hiscock et al. (2018). All protocols included the same four exercises (bench press, back squat, deadlift and prone bench pull). Reproduced from Hiscock et al. (2018).

	Power	Strength	Hypertrophy
Load (% of one repetition maximum)	45%	90%	70%
[redacted]	[redacted]	[redacted]	[redacted]
Recovery period (min)	3	3	1
Volume load (kg)	5630 ± 863	5630 ± 863	11173 ± 1737

Testosterone concentration was reduced immediately following the power protocol compared with pre, not changed following strength, and significantly increased following the hypertrophy protocol, resulting in significantly higher testosterone concentration immediately post-exercise following the hypertrophy protocol compared with strength and power protocols (Table 2.10). Cortisol concentration was reduced immediately following the strength and power protocols compared with pre, whilst no change was reported following the hypertrophy protocol. This resulted in a significantly reduced cortisol concentration immediately post-exercise following strength and power protocols compared with the hypertrophy protocol. All protocols resulted in significantly reduced neuromuscular performance immediately post-exercise compared with pre, whilst this reduction was greater following the hypertrophy protocol when compared with the power protocol (Table 2.11).

Table 2.10: Testosterone and cortisol concentrations (mean ± standard deviation) immediately before and immediately after each of the three resistance-training protocols. Reproduced from Hiscock et al. (2018).

	Power	Strength	Hypertrophy
Testosterone concentration pre (pM)	110 ± 38	110 ± 25	125 ± 37
Testosterone concentration post (pM)	90 ± 22[degj]	103 ± 22[dj]	155 ± 41[e]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
Cortisol concentration post (nM)	1.2 ± 0.6[afgj]	0.9 ± 0.5[afj]	3.6 ± 4.0
Percentage difference from pre (%)	-42.9	-59.1	56.5

[a] significantly differently to pre; [d] significantly different to same time point in hypertrophy; [e] moderate effect compared to pre; [f] large effect compared to pre; [g] moderate effect compared to same time point in strength condition; [j] large effect compared to same time point in hypertrophy condition.

Table 2.11: Peak power and peak velocity (mean ± standard deviation) immediately before and immediately after each of the three resistance-training protocols. Reproduced from Hiscock et al. (2018).

	Power	Strength	Hypertrophy
Mean power pre (W)	3166 ± 396	3228 ± 311	3303 ± 350
Mean power post (W)	3030 ± 422[ai]	2953 ± 345[afh]	2791 ± 358[ah]
Percentage difference from pre (%)	-4.30%	-8.52%	-15.50%
Peak power pre (W)	7902 ± 937	8111 ± 777	8156 ± 835
[redacted]	[redacted]	[redacted]	[redacted]
Peak velocity post (m·s^{-1})	1.53 ± 0.17[i]	1.48 ± 0.15[ag]	1.41 ± 0.16[ah]
Percentage difference from pre (%)	-1.92%	-5.13%	-12.42%
Peak velocity pre (m·s^{-1})	2.85 ± 0.25	2.89 ± 0.24	2.91 ± 0.24
Peak velocity post (m·s^{-1})	2.76 ± 0.27[ai]	2.70 ± 0.26[ag]	2.58 ± 0.29[ag]
Percentage difference from pre (%)	-3.16	-6.57	-11.34

[a] significantly different to pre ($P \leq 0.05$); [f] significantly different to same time point in hypertrophy protocol ($P \leq 0.05$) [g] moderate effect compared to pre; [h] large effect compared to pre; [i] moderate effect compared to same time point in hypertrophy condition.

Whilst neuromuscular responses immediately post-exercise are similar between these two studies, differences in protocols must be acknowledged. The loading in the hypertrophy protocols was similar between studies (Table 2.7 and Table 2.9), meaning that the inclusion of extra exercises in the study by Hiscock et al. (2018) resulted in a greater overall volume of training performed. However, by matching volume of work performed between protocols in the study by McCauley et al. (2009), 11 sets of three repetitions of the back squat were performed, which is significantly greater than that in the study by Hiscock et al. (2018). Indeed, even though Hiscock et al. (2018) involved four exercises, two were upper-body, meaning a far greater degree of overload and stress was achieved in the former study in the squat exercise. Regardless, neuromuscular responses were indeed similar between studies, providing evidence for an immediate post-exercise reduction in neuromuscular function following a wide range of resistance exercise protocols. Additionally, the testosterone and cortisol responses were similar between studies, with an increase in testosterone and cortisol concentrations following hypertrophy exercise.

2.4.1.1.1 Influence of training status upon immediate post-resistance training responses

These responses described have been in response to resistance exercise performed by resistance trained males only. As training status influences maximal strength (Ahtiainen et al., 2004), responses to training may be different between these populations. Ahtiainen et al. (2004) investigated the differences in endocrine and neuromuscular responses to resistance exercise involving four sets of eight to 12 repetitions of the back squat exercise in physically active (but un-trained in resistance exercise) and strength-trained athletes. Testosterone concentrations increased post-exercise compared to pre-exercise to a greater degree in the strength-trained than physically active groups, whilst changes in cortisol concentration and neuromuscular fatigue were not different between groups. However, this study included resistance-trained individuals, none of which were competitive, and also employed only a single exercise in the resistance exercise protocols. In contrast, the responses of male elite academy rugby union players has been reported following the performance of strength based resistance exercise (Johnston et al., 2017). Players performed five sets of four repetitions of the back squat and the Romanian dead lift exercises at 85% of one repetition maximum, with four minutes recovery between sets. Salivary testosterone concentrations were not different immediate post-exercise, whilst blood lactate and salivary cortisol concentrations were significantly increased compared with pre-exercise. Additionally, countermovement jump peak power output, jump height, peak velocity and average rate of force development were reduced. These findings are similar to that of the aforementioned study by McCauley et al. (2009) and Hiscock et al. (2018), collectively suggesting training status does not significantly affect the acute neuromuscular and endocrine responses to resistance exercise. In summary, neuromuscular fatigue is evident following a wide range of resistance exercise protocols (Hiscock et al., 2018; Johnston et al., 2017; McCaulley et al., 2009), with greater fatigue potentially experienced following the higher volume of training associated with hypertrophy training (Hiscock et al., 2018). Testosterone concentration is likely to increase following hypertrophy based exercise (Ahtiainen et al., 2004; Hiscock et al., 2018; McCaulley et al., 2009), yet remain unchanged following strength or power based protocols (Hiscock et al., 2018; Johnston et al., 2017; McCaulley et al., 2009), whilst cortisol concentration may increase following hypertrophy and strength based exercise (Hiscock et al., 2018; Johnston et al., 2017; McCaulley et al., 2009), and is likely linked with metabolic stress, as indicated by an increase in blood lactate concentration.

2.4.1.1.2 Influence of gender upon immediate post-resistance training responses

Many differences exist between males and females, including basal testosterone (Linnamo et al., 2005), muscle mass and strength levels (Davies et al., 2018), which have been reported to be important for neuromuscular performance (Bishop et al., 1987; Cardinale & Stone, 2006), and may therefore interact to bring about altered responses to resistance exercise. Linnamo et al. (2005) observed an increase in testosterone concentration in physically active male participants following the performance of five sets of 10 repetitions (of sit ups, bench press and leg extension exercises) with two-minutes rest, performed at the maximal load which could be lifted. However, no such increase was observed in physically active females performing the same protocol, with no change in testosterone concentration from pre to post-exercise. Additionally, neuromuscular fatigue responses were found to be similar between genders, with a significant reduction post-exercise. A similar finding of no change in testosterone concentration has been reported in recreationally active females (Nakamura et al., 2011). Participants performed hypertrophy based resistance exercise including three sets of 10 repetitions at 75-80% of one repetition maximum, with 60 s recovery, of lateral pull-down, leg curl, bench press, leg extension and back squat exercises. No significant change in testosterone concentration was observed immediately following the resistance exercise, whilst cortisol concentration was significantly reduced. One study has reported the endocrine responses to different resistance-exercise protocols in elite female athletes (Nunes et al., 2011). Elite

(National standard) female basketball players (*n* = 14) performed three resistance-exercise protocols and one control session consisting of no exercise (Table 2.12). Testosterone concentration was not different post-exercise compared with pre-exercise, or compared to a control day for all protocols, whilst cortisol concentration increased from pre to post-exercise following the strength hypertrophy protocol only, and was higher post-exercise following all protocols than the control day (Figure 2.14). Collectively, findings suggest, that whilst an increase in testosterone concentration is observed in males following hypertrophy based resistance exercise (Hiscock et al., 2018; McCaulley et al., 2009), no change is likely in females (Linnamo et al., 2005; Nakamura et al., 2011; Nunes et al., 2011). Neuromuscular responses are likely similar in males and females (Linnamo et al., 2005), as is the cortisol response (McCaulley et al., 2009; Nunes et al., 2011).

Table 2.12: Details of the resistance-exercise protocols employed in the study by Nunes et al. (2011). All protocols included the performance of bench press, squat and bicep curl. Strength hypertrophy involved the performance of eight maximal sets; five, four, three, two and one repetition with three-minute rest periods, followed by three sets of 10 repetitions with two minutes recovery. Reproduced from Nunes et al. (2011).

	Endurance	Strength hypertrophy	Power
Load (% of one repetition maximum)	60%	100%	50%
Sets	4	8	3
[redacted]	[redacted]	[redacted]	[redacted]
Recovery period (min)	1	2-3	3

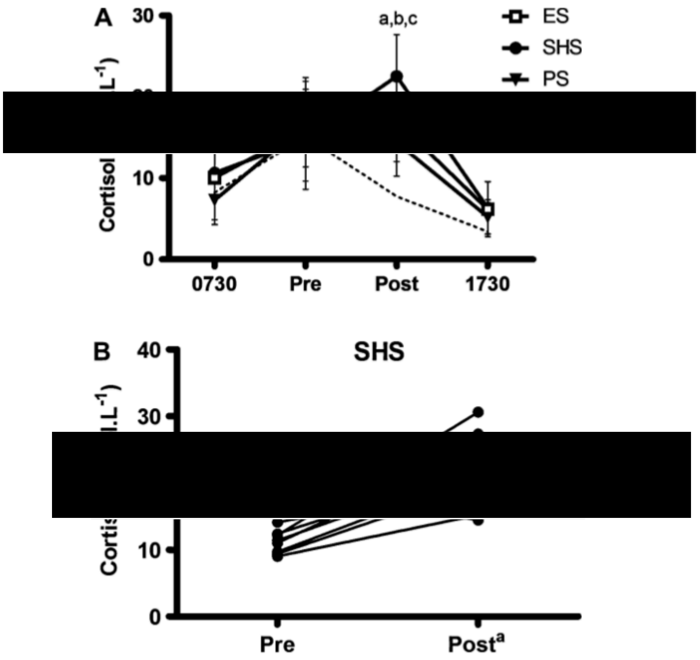

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Figure 2.14: A: Cortisol concentrations across the endurance scheme (ES), strength-hypertrophy scheme (SHS), power scheme (PS) and non-exercising day (NE) (mean ± standard deviation). [a] SHS difference from pre-exercise ($P < 0.05$), [b] all schemes different from non-exercising day. B: Individual cortisol concentrations in the strength-hypertrophy scheme. [a] Different from pre-exercise ($P < 0.05$). Reproduced from Nunes et al. (2011).

2.4.1.1.3 Influence of menstrual cycle and oral contraceptive use upon immediate post-resistance training responses

To date, only one study has reported the effect of menstrual cycle phase on responses to resistance-exercise protocols (Nakamura et al., 2011), with no study assessing the impact of hormonal contraceptive use. Eight recreationally active eumenorrheic females performed two resistance-exercise protocols; one during the early follicular phase (days four to seven of the menstrual cycle), and one during midluteal phase (seven to 10 days after ovulation). Resistance exercise is as described in the previous section, whilst measures including blood lactate concentration, serum testosterone and cortisol concentrations immediately prior to, following and for 60 min post-exercise. Resting testosterone and cortisol concentrations were not different between the phases of the menstrual cycle, and immediate post-exercise blood lactate, testosterone and cortisol concentrations were not different either. Based on this one study it would suggest that immediate hormonal responses to resistance exercise are not influenced by phases of the menstrual cycle in physically active females.

2.4.1.2 Recovery post-resistance training

Recovery of testosterone and cortisol concentrations is not different following strength, power or hypertrophy protocols in resistance-trained males (McCaulley et al., 2009). The hypertrophy protocol resulted in an immediate post-exercise increase in testosterone and cortisol concentrations when compared with other protocols, however this had returned to baseline within 60 minutes of recovery, and was not different to that following strength, power or rest protocols at this time point. Similarly, at this time point neuromuscular performance had recovered to baseline. Linnamo et al. (2005) also reported recovery of testosterone and cortisol concentrations and neuromuscular performance within one hour post-exercise. However, a different time-course of recovery was reported by Hiscock et al. (2018), potentially due to the multi exercise protocol, resulting in a greater volume of exercise performed compared with McCauley et al. (2009). Neuromuscular performance was initially reduced immediately post-exercise following all protocols, to a greater extent following hypertrophy compared with the power protocol and returned to baseline at 12 h post the power protocol, 24 h post the strength protocol, and 72 h post the hypertrophy protocol. The authors propose that the greater volume of training performed in the hypertrophy protocol may have resulted in greater micro trauma and damage to muscle fibres, therefore requiring longer to recover. No difference in testosterone concentration was observed between protocols at 24 h post, with no difference in values when compared with pre. In contrast, cortisol concentration followed a different recovery profile. In the hypertrophy protocol, an increase immediately post-exercise was found in comparison to other protocols, however at 24 h post, this was significantly reduced compared with other protocols, returning to similar values at 48 h post. In elite athletes, Johnston et al. (2017) reported an initial post-exercise increase in cortisol concentration, which reduced compared with pre-exercise at two hours post, whilst testosterone concentration remained at an unchanged concentration compared with pre and post-exercise. In contrast, neuromuscular performance had returned to baseline at this time period following an immediate post-exercise reduction. However, it should be noted that the lack of a control group or other protocols in the study by Johnston et al. (2017) makes it difficult to determine the relevance of such changes in endocrine markers with regards to, for example, expected circadian rhythm decreases (Kokalas, Tsalis, Tsigilis, & Mougios, 2004). Collectively, findings suggest that recovery of neuromuscular function can occur within one to two hours, depending on the protocol performed (Johnston et al., 2017; Linnamo et al., 2005; McCaulley et al., 2009), whilst neuromuscular fatigue can occur for up to 72 h post-exercise (Hiscock et al., 2018). Testosterone concentration is likely to recover within one to two hours (Linnamo et al., 2005; McCaulley et al., 2009), whilst cortisol concentration can be affected for up to 48 h post-exercise (Hiscock et al., 2018).

2.4.1.2.1 Influence of gender upon recovery post-resistance training

Linnamo et al. (2005) reported no differences in the recovery rates of neuromuscular and endocrine function between physically active male and females over a two-hour period, with all variables returning to baseline within two hours. However, more pronounced neuromuscular fatigue and longer recovery rates in females has been reported (Davies et al., 2018). Resistance trained males and females performed resistance exercise including the performance of five sets of five repetitions of the back squat exercise, with 90 s rest between sets at 80% of one repetition maximum. This was followed by an additional set at the same load, performed until volitional exhaustion in an attempt to induce similar neuromuscular fatigue across all participants. Measures included countermovement jump height and knee extensor strength during a maximal voluntary concentric, isometric and eccentric contraction. Neuromuscular performance was reduced four hours post-exercise in both groups, with a greater reduction in countermovement jump height in females at this time point. At 24 h post, all variables remained reduced, with a greater reduction in countermovement jump height and concentric strength in the female group, which remained reduced at 72 h post in females only. In a similar study, it has been demonstrated that females have a greater loss of force during a maximal voluntary contraction than males following eccentric dorsiflexor exercise, with a longer time for full recovery (Power, Dalton, Rice, & Vandervoort, 2013). However, this type of exercise is specifically designed to create muscle damage and is not applicable to regularly performed resistance exercise. Similarly, the study by Davies et al. (2018) employed a resistance-exercise protocol which is not similar to those previously reported. Recovery duration was very short at 90s, less than that would be regularly employed for strength-based protocols, yet the number of repetitions was low. Additionally, the exercise culminated in a set performed to volitional failure, which is not commonly employed in other studies, and likely led to a high level of neuromuscular fatigue. Hence, whilst differences in recovery rates may be observed between gender when highly fatiguing, or muscle damage inducing exercise is performed (Davies et al., 2018; Power et al., 2013), no differences are likely to be observed following more typical resistance-exercise schemes (Linnamo et al., 2005).

2.4.1.2.2 Influence of menstrual cycle phase upon recovery post-resistance training

In the only report to date, Nakamura et al. (2011) reported no effect of menstrual cycle phase on recovery of endocrine function over the 60 min following a resistance-exercise protocol. A summary of the key studies reporting the neuromuscular and endocrine responses to resistance training is presented in table 2.13.

Table 2.13: Summary of studies reporting the neuromuscular and endocrine responses to resistance training

Study	Participants	Design	Exercise scheme	Neuromuscular response		Testosterone response	Cortisol response
McCauley et al. (2009)	n=10 Resistance experienced Male Mean (±SD): 21.8 years (±1.9 years)	3 x RE protocols separated by one week. Time-points: pre, post, 60 min (60P), 24 h (24P), 48 h post. Measures: peak force, rate of force development (RFD) and muscle activity measured during an isometric squat. Serum testosterone and cortisol concentrations.	Hypertrophy (H): 4 x 10 @ 75%1RM/ 1.5 min rest Strength (S): 11 x 3 @ 90%1RM/ 5 min rest Power (P): 8 x 6 @ body mass/ 3 min rest. Control: No exercise Exercise: back squat	Peak power: Post: significant decrease following S and H protocols. 60P: all protocols recovered to baseline RFD: Post: significant decrease following S and H protocols. 60P: all protocols recovered to baseline 24P: significant decrease following S compared to control Muscle activity: Post: significant decrease following S protocol in comparison to H protocol. All other differences at all time-points were not significant. All significant differences ($p<0.05$)		Pre to post: H: 32.3%* S: 19.6% P: 10.7% C: 3.4% *significant difference to control ($p<0.05$)	Pre to post: H: 12.4%* S: -18.2% P: -23.0% C: -35.9% *significant difference to control ($p<0.05$)
Hiscock et al. (2018)	n=12 Multisport players, > 12	3 x RE protocols separated by one week.	Hypertrophy (H): 3 x 10 @ 70%1RM/ 1 min rest	Peak power: H: Post: -11.9%[a] 12h: -8.7%[ab]	Peak velocity: H: Post:-11.3%[a] 12h: -6.5%[ab]	H: Post: 24.0%[a] 24 h: -12.8%	H: Post: 56.5% 24 h: -52.2%[a]

	months resistance exercise experience Male 25.0 years (±3.3 years)	Time-points: post, 12 h, 24 h, 48 h, 72 h post. Measures: salivary testosterone and cortisol concentrations, countermovement jump performance	Strength (S): 3 x 3 @ 90%1RM/ 3 min rest Power (P): 3 x 6 @ 45%1RM/ 3 min rest Exercises: bench press, back squat, deadlift and bench pull	24 h: -6.1%^{abc} 48 h: -4.8%^{abc} 72 h: 0.2%^{bcde} S: Post: -10.7%^{a} 12h: -5.8%^{ab} 24 h: -0.2%^{bc} 48 h: 1.7%^{bcf} 72 h: 2.8%^{bc} P: Post: -5.0%^{a} 12h: -1.2%^{b} 24 h: 2.1%^{b} 48 h: 4.2%^{abf} 72 h: 5.2%^{abc}	24 h: -5.5%^{ab} 48 h: -3.8%^{abc} 72 h: 0.7%^{bcde} S: Post: -6.6%^{a} 12h: -3.1%^{ab} 24h: 0.4%^{bcf} 48h: 2.1%^{abcdf} 72h: 2.1%^{abcd} P: Post: -3.2%^{af} 12h: -0.7%^{b} 24h: 1.1%^{bc} 48h: 1.8%^{bc} 72h: 3.5%^{abc}	48 h: 6.4% 72 h: 2.4% S: Post: -6.4%^{f} 24 h: 1.8% 48 h: 10.9% 72 h: -10.0%^{f} P: Post: -18.2%^{afg} 24 h: -6.4% 48 h: 4.5%^{d} 72 h: -12.7%^{af}	48 h: 8.7% 72 h: -34.8%^{ac} S: Post: -59.1%^{af} 24 h: -19.1%^{f} 48 h: 0.0%^{b} 72 h: -31.8%^{a} P: Post: -42.9%^{afg} 24 h: -19.1%^{f} 48 h: 66.7%^{abg} 72 h: 14.3%^{fg}
				Mean difference compared to pre. ^{a} significant difference to pre ($p<0.05$) ^{b} significant difference to post ($p<0.05$) ^{c} significant difference to 12h ($p<0.05$) ^{d} significant difference to 24h ($p<0.05$) ^{e} significant difference to 48h ($p<0.05$) ^{f} significant difference to H ($p<0.05$) ^{g} significant difference to S ($p<0.05$)			
Johnston et al. (2017)	n=15 Academy level rugby players Male	Strength training session performed. Time-points: pre, post, 2h post.	5 x 4 @ 85%1RM/ 4 min rest. Exercises: back squat and Romanian dead lift	Peak power (W) Pre: 5368 (±446) Post: 5073* (±532) 2h: 5363 (±397)	Jump height (m) Pre: 0.39 (±0.06) Post: 0.37* (±0.05)	Pre: 17.1 (±5.0) Post: 18.2 (± 5.0) 2h: 15.6 (±6.1) Units: nmol·L^{-1}	Pre: 516 (±99) Post: 373* (±136) 2h: 290* (±103) Units: nmol·L^{-1}

	21 years (±1 years)	Measures: plasma testosterone and cortisol concentrations, countermovement jump performance		Peak velocity (m.s^{-1}) Pre: 2.91 (±0.20) IP: 2.83* (±0.16) 2h: 2.90 (±0.19)	2h: 0.39 (±0.06)		
				*significant difference to pre ($p \leq 0.05$)		*significant difference to pre ($p \leq 0.05$)	
Linnamo et al. (2005)	n=8 Female 23.3 years (±0.5 years) n=8 Male 27.1 years (±0.7 years) Physically active, no background in regular strength training or competitive sports	Three resistance exercise protocols performed separated by at least two weeks. Time-points: neuromuscular; pre, after each set, 1 h and 2 h post. Endocrine: 0800, pre, during, after, 1 h and 2 h post. Measures: peak force during a maximal voluntary isometric leg extension, serum testosterone concentration	Heavy resistance exercise (HRE): 5 x 10 @ 100%10RM/ 2 min rest Submaximal heavy resistance exercise (SHRE): 5 x 10 @ 70%10RM/ 2 min rest Maximal explosive resistance exercise (EE): 5 x 10 @ 40%10RM/ 2 min rest Exercises: sit-ups, bench press, leg press	Male change post-exercise vs pre: mean (± SD) SME: -16.9% (±4.8%) HRE: -23.7% (±16.3%) EE: -11.0% (±8.2%) Female change post-exercise vs pre: SME: -16.2% (±7.1%) HRE: 18.8% (±7.7%) EE: 12.2% (±6.8%) No differences in fatigue or recovery rates were observed between gender		HRE: Male increased ($p < 0.05$) post-exercise (27.1 ± 8.5 vs 29.4 ± 9.9 nmol·L^{-1}) Returned to baseline within 1 h No change for female following any protocol No other significant differences were observed	

Nakamura et al. (2011)	n=8 Recreationally active, no regular exercise or training Eumenorrheic females 25.4 years (± 1.2 years)	RE during early follicular phase (EF; days 4-7) and during midluteal phase (ML; 7-10 days after ovulation) Time-points: post, 30 min and 60 min post Measures: serum testosterone and cortisol concentrations	3 x 10 @ 100%10RM/ 1 min rest Participants lifted in each set to failure, then spotters assisted to complete the 10 reps. Exercises: lat pull-down, leg curl, bench press, leg extension and squat		No significant difference immediately post-exercise for EF or ML phase Decrease 60 min post exercise following both EF and ML phase ($p<0.05$) No significant difference between EF and ML phase at any time-point	Significant decrease immediately post-exercise, 30 and 60 min post compared to pre ($p<0.05$) No significant difference between EF and ML phase at any time-point
Nunes et al. (2011)	n=14 Elite basketball players Female 26.2 years (±3.9 years)	Non-exercise control and 3 x RE protocols separated by 14 days. Time-points: 0730, pre, post, 1730	Endurance (E): 4 x 12 @ 60%1RM/ 1 min rest. Strength-hypertrophy (SH): 5,4,3,2,1 / 3 min rest, then 3 x 10/ 2 min rest @ 100%1RM.		No significant changes across E, SH, and P protocols compared to pre-exercise and control day	Post-exercise increase following E, SH and P compared to control ($p<0.05$). SH post-exercise increase above

		Measures: salivary testosterone and cortisol concentrations	Power (P): 3 x 10 @ 50%1RM/ 3 min rest. Control: no exercise Exercises: bench press, squat, biceps curl.			pre-exercise ($p<0.05$) No other significant differences observed

Abbreviations: SD: standard deviation; RE: resistance exercise; 1RM: one repetition maximum; 10RM: 10 repetition maximum. Exercise scheme is described as repetitions x sets throughout.

2.4.2 Responses to technical sport-specific training

Several studies exist reporting hormonal and neuromuscular responses following team-sport specific training sessions, namely soccer (Mascarin et al., 2018; Sparkes et al., 2018), hockey (Crewther et al., 2015) Australian rules football (Elias et al., 2012) and volleyball (Eliakim et al., 2013, 2009), however none at present following netball-specific training. Sport-specific training regularly aims to develop several qualities related to performance simultaneously (Sparkes et al., 2018), often due to proximity of competitive fixtures and the multifaceted nature of team sports. Therefore, this review will focus on the neuromuscular and endocrine responses to team-sport training where the aim is to replicate or overload the physical demands of match-play, whilst developing technical, tactical and decision-making qualities under pressure concurrently.

2.4.2.1 Immediate post-technical sport-specific training responses

In a comprehensive study, Sparkes et al. (2018) examined the responses to a regularly performed soccer training session in 16 elite, professional male football players. Training consisted of seven small sided games, performed by five players on each side for six minutes, interspersed with two minutes passive recovery (42 minutes total playing time) which players rated as “very hard” (rating of perceived exertion from one to 10; mean ± SD = 7.1 ± 1.3 AU). Measures were taken before, immediately after, two hours post and 24 hours post, and included salivary testosterone and cortisol concentrations and countermovement jump testing. When compared with measures taken before the training session, there was a small increase in testosterone concentration, small decrease in cortisol concentration and a small to moderate decrease in neuromuscular performance immediately post-training (Table 2.14).

Table 2.14: Mean (± standard deviation) fatigue marker responses across each time point, along with mean differences and qualitative inferences of the effect magnitude for differences from baseline values. Reproduced from Sparkes et al. (2020).

	Baseline	0 h	Mean difference from baseline	QI
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Testosterone ($pg \cdot ml^{-1}$)	181 ± 64	201 ± 79	+20 ± 29	S*
Cortisol ($\mu g \cdot dl^{-1}$)	0.54 ± 0.28	0.45 ± 0.29	-0.09 ± 0.16	S*

Abbreviations: PPO: peak power output; JH: jump height; QI: qualitative inference. Magnitude and likelihood of differences; S: small; M: moderate; * 75-95%, likely.

Findings have also been reported in professional female soccer players (Mascarin et al., 2018). Thirteen players performed a training session consisting of four blocks of four minutes of training, interspersed with three minutes of recovery (16 minutes total playing time). Measures were taken before, 10 minutes after, 24, 48- and 72 hours after, and included serum testosterone and cortisol concentrations. No changes to endocrine function were observed 10 minutes post exercise. As post-exercise blood lactate concentration has been reported to be related to post resistance exercise endocrine responses (Hiscock et al., 2018; McCaulley et al., 2009), it is therefore noteworthy that in spite of a significantly greater post-exercise blood lactate concentration in the study by Mascarin et al. (2018) compared with Sparkes et al. (2018) (6.4 ± 2.2 mM compared with 2.6 ± 1.1 mM respectively) no change in cortisol concentration was observed. However, whilst the decrease in cortisol concentration in the study by Sparkes et al. (2018) may reflect the expected circadian rhythm decline (Kokalas et al., 2004), the lack of change in the study by Mascarin et al. (2018) may be considered an increase in comparison to the associated circadian rhythm decline. This may reflect the higher intensity of exercise performed, due to increased energy provision and associated increase in cortisol concentration (Viru & Viru, 2004), however the significantly different volume of training must also be considered. Training session duration was over twice as long in the study by Sparkes et al. (2018) (42 minutes compared with 16 minutes), therefore making comparisons difficult between these studies.

Elias et al. (2012) investigated the neuromuscular responses to an Australian rules football training session in professional male players (*n* = 14). Players performed the main weekly training session (non-contact) including the performance of a 10-minute warm up, 30 minutes of skill development (e.g. kicking, passing, positional training) and four blocks of small-sided games; lasting 2.5 minutes with 2.5 minutes recovery between blocks. Countermovement and squat jump testing (ratio of flight time to contact time), along with repeated sprint ability testing (six x 20 m sprints departing every 30 seconds) was performed immediately pre, post, one, 24- and 48 hours post-training. Immediately post-training repeated sprint ability decreased (18.97 ± 0.41 seconds) compared to pre (18.53 ± 0.38 seconds) whilst countermovement and squat jump performance remained unchanged. The study assessed the ratio of flight time to contact time, which has previously been found to be sensitive to assess changes in neuromuscular fatigue in Australian rules football players (Cormack, Newton, & McGuigan, 2008), however appears to lack the sensitivity following training in this population. It should also be noted, whereas the aforementioned studies performed solely a warm-up followed by small sided games, the study by Elias et al. (2012) included drills to develop skills without replicating match movements, as well as small sided games to overload these components under pressure. Therefore, whilst only 10 minutes of small sided games were performed, considerably less than that of Sparkes et al. (2018) and Mascarin et al. (2018), other elements of training were included.

Crewther et al. (2015) investigated the hormonal responses to technical hockey training in elite, female players (*n* = 29). Players performed regular training over a 15-day period, including resistance exercise, cardiovascular training and technical team-sport training. Training sessions were classified as "light" and "heavy" training, and players perceived differences in this intensity. Measures included salivary cortisol and testosterone concentrations, which were assessed before and after light and heavy technical-training sessions. Cortisol concentration deceased (-52%) following light training, which could reflect normal circadian rhythm, especially as training was performed between 0900 and 1100, whilst testosterone concentration did not change. Following heavy training, testosterone (45%) and cortisol (46%) concentrations increased, which the authors state could be explained by greater physical exertion, as evidenced by greater rating of perceived exertion scores. Additionally, some heavy training sessions also aimed to replicate match-play intensity which may have influenced competitive and dominant behaviours, and affected testosterone availability (Edwards & Kurlander, 2010).

2.4.2.1.1 Influence of training status upon immediate post technical sport-specific training responses

Training status has been reported to affect the cortisol response following team-sport training (Eliakim et al., 2013). Female players (*n* = 13) performed a 60-minute volleyball training session at the beginning of, and at the end of a seven-week training phase. Whilst the blood lactate response was not different following training sessions, suggesting the relative intensity was similar between sessions, post-exercise cortisol concentration was significantly reduced following training at the end of the training phase compared with at the beginning. However, whilst this observation suggests a reduced catabolic response following training when performing more accustomed exercise, it should be noted that this study was performed with adolescent players (mean age = 16.0 ± 1.4 years), and in a fasted state, which may limit applicability to the findings of the aforementioned studies. Players in the study by Sparkes et al. (2018) had just finished the competitive season, and hence were conditioned to training and match-play intensity, while in the study by Mascarin et al. (2018), the competitive season ended two months prior, without any detail of previous consistent training prior to testing. This difference in training status may have influenced the post-exercise blood lactate concentration, and hence cortisol concentration via metabolic disturbances (Viru & Viru, 2004), or may have resulted in a greater catabolic state in the study by Mascarin et al. (2018) due to the performance of unaccustomed exercise.

2.4.2.1.2 Influence of gender upon immediate post-technical sport-specific training responses

The influence of gender on responses to team-sport training has been reported, however whilst this was in elite, National-standard male and female volleyball players, these were adolescent players aged 13 to 18 (Eliakim et al., 2009). Participants (14 male, 13 female) performed a typical 60 minute training session including the performance of a 20 minute dynamic warm up, 20 minutes of technical drills, followed by seven sets of conditioning exercises, each lasting approximately 90 seconds, with 60 seconds rest in between sets. The conditioning exercise involved seven consecutive sprints from the back of the court to the net, followed by a maximal jump and hit of the ball. Serum testosterone and cortisol concentrations were measured immediately before and after the training session. Following training, testosterone concentration increased, and cortisol concentration remained unchanged in both genders, with no difference between groups. Findings suggest that gender does not influence the endocrine responses following this type of training, however this study may be limited by the age of participants and the performance of training in a fasted state.

2.4.2.1.3 Influence of menstrual cycle and oral contraceptive use upon immediate post-technical sport-specific training responses

To date, only one study has investigated the effects of hormonal contraceptive use on responses to technical team-sport training (Crewther et al., 2015). Elite, international-standard female hockey players (*n* = 29) performed light or heavy intensity technical training sessions, with players grouped into non-hormonal contraceptive users (*n* = 19) and users (*n* = 10). Hormonal contraceptive users had lower absolute testosterone concentration, a lower testosterone response to training compared with non-hormonal contraceptive users, whilst the cortisol response was comparable across groups (Figure 2.15).

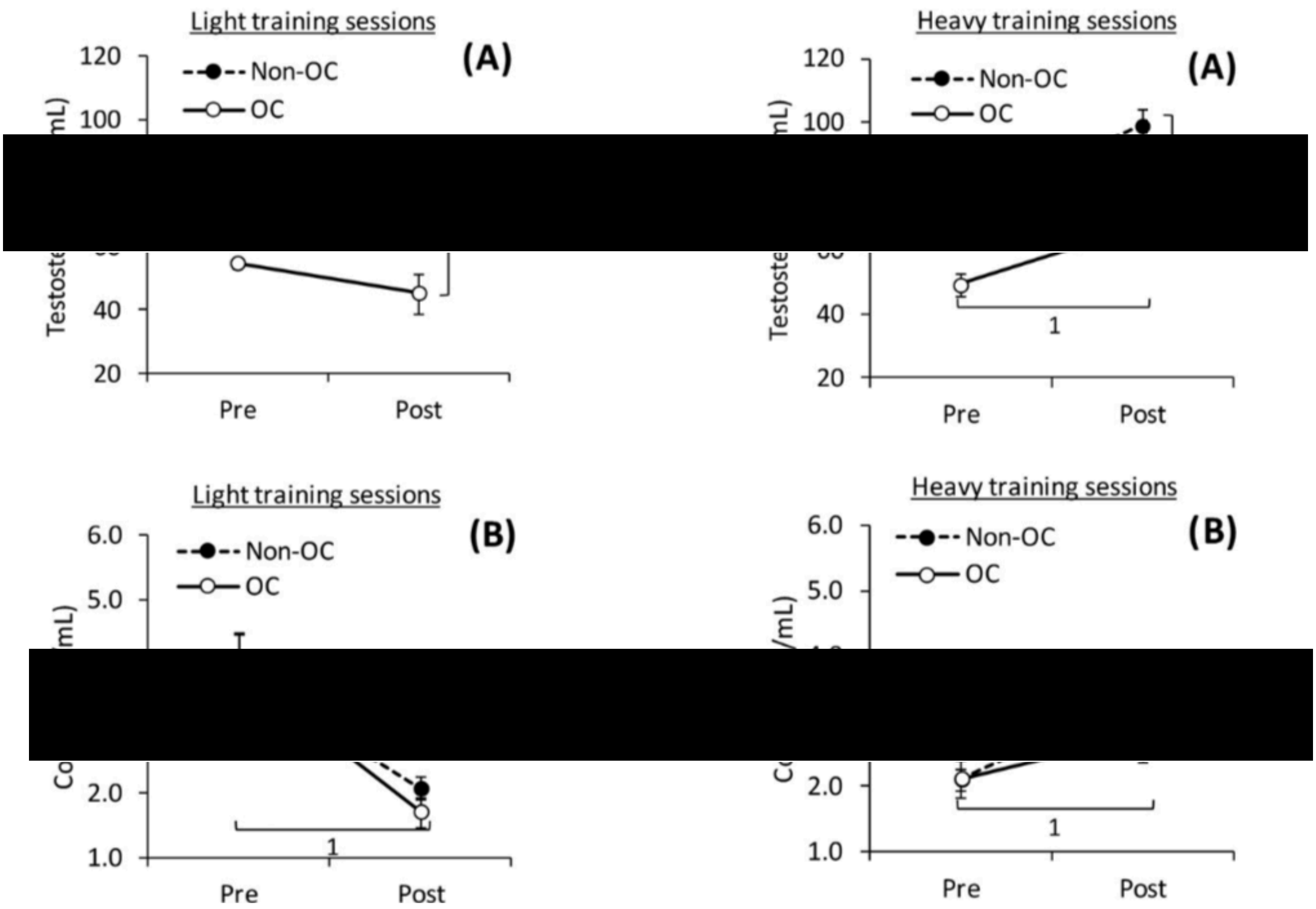

Figure 2.15: Estimated marginal means (± standard error) for salivary testosterone (A) and cortisol (B) concentrations before and after the light and heavy training sessions for the hormonal contraceptive and non-hormonal contraceptive groups. Reproduced from Crewther et al. (2015). *Abbreviations*: non-OC: non-hormonal contraceptive group; OC: hormonal contraceptive group. 1 indicates significant sample effect (P <0.001), 2 indicates significant group effect (P < 0.001).

Collectively, it appears that training intensity has a large effect on the immediate post-training hormonal responses to sport-specific training sessions (Crewther et al., 2015), in addition to the aims of the session (e.g. replicating match-play intensity and focus) which may influence behaviour and hormonal responses (Crewther et al., 2015; Edwards & Kurlander, 2010). Training status may influence the catabolic response to training, with a greater response following more unaccustomed exercise (Eliakim et al., 2013; Mascarin et al., 2018; Sparkes et al., 2018), testosterone response may be reduced with hormonal contraceptive use (Crewther et al., 2015), whilst gender (Eliakim et al., 2009) has no effect. Neuromuscular performance likely reduces post-exercise (Sparkes et al., 2018), however it should be noted that reports in females are very limited, as are reports of the neuromuscular responses to this type of exercise.

2.4.2.2 Recovery post-technical sport-specific training responses

Few reports have detailed the recovery of endocrine and neuromuscular responses to this type of exercise. Sparkes et al. (2018) reported a bi-modal recovery pattern of neuromuscular performance, with recovery to baseline two hours post (following an immediate post-training decrease), and a further reduction 24 h post, whilst Elias et al. (2012) reported a greater decrease in repeated sprint ability 24 h post compared to immediately post-training, returning to baseline 48 h post. It could be suggested that recovery of neuromuscular performance two hours post is due to removal of exercise associated accumulation of metabolites, which may have impaired excitation-contraction coupling via peripheral mechanisms immediately post-exercise (Allen et al., 2008), whilst a further impairment 24 hours post may be due to impaired excitation-contraction coupling resulting from low frequency fatigue (McLellan & Lovell, 2012) with exercise-induced muscle damage of type two muscle fibres (Byrne, Twist, & Eston, 2004). Both Sparkes et al. (2018) and Mascarin et al. (2018) found testosterone and cortisol concentrations to decrease two hours post soccer training, in spite of different immediate post-training responses, which likely reflects the circadian rhythm decline seen throughout the day (Kokalas et al., 2004; Kraemer et al., 2001). At 24 h post-training, Sparkes et al. (2018) reported testosterone concentrations to return to near baseline, with cortisol concentrations reduced, whilst Mascarin et al. (2018) reported testosterone and cortisol concentrations to be reduced at 24 h post-training, returning to baseline 72 h post.

There are no reports to date investigating the effects of gender, menstrual cycle phase or hormonal contraceptive use following team-sport training. Collectively, findings suggest that neuromuscular performance may be impaired for up to 48 h (Elias et al., 2012; Sparkes et al., 2018), whilst endocrine responses may be evident for up to 72 h post-training (Mascarin et al., 2018). A summary of the studies reporting the endocrine and neuromuscular responses to team-sport training is provided in table 2.15.

Table 2.15: Summary of studies reporting the neuromuscular and endocrine responses to team-sport training

Study	Participants	Design	Training session	Neuromuscular response	Testosterone response	Cortisol response
Sparkes et al. (2018)	n=16 Professional soccer players Male Aged 18-23 years	Players performed small sided games Time-points: pre, post (+0h), 2 (+2h) and 24 (+24h) h post Measures: salivary testosterone and cortisol concentrations, countermovement jump	5 min warm up 7 x 6 min blocks = 42 min of work/ 2 min rest between blocks 5 players v 5 players. Pitch: 24 x 29 m Aim: to score as many goals as possible	PPO +0h: -2.1% (possible small) +2h: -1.3% (trivial) +24h: -1.7% (possibly small) JH +0h: -8.6% (possibly moderate) +2h: +0.2% (trivial) +24h: -6.8% (likely small) Mean difference (qualitative inference)	+0h: +11.1% (possibly small) +2h: -33.9% (possibly moderate) +24h: +1.2% (trivial) Mean difference (qualitative inference)	+0h: -16.5% (possible small) +2h: -71.8% (likely large) +24h: -21.3% (likely small) Mean difference (qualitative inference)
Mascarin et al. (2018)	n=13 Professional soccer players Female Mean age (±SD): 18.8 years (±0.8 years)	Players performed small sided games Time-points: 0700, pre, post, 24, 48 and 72 h post. Measures: serum free testosterone and cortisol concentrations	8 min warm up 4 x 4 min blocks = 16 min of work/ 3 min rest between blocks 120 m^2 per player Aim: to pass the end lines with the ball.		Pre: 32.4 (±9.9) +0h: 32.5 (±12.4; most likely trival) +24h: 19.1 (±8.3; very likely) +48h: 29.5 (±8.4; likely) +72h: 32.4 (±10.6; most likely trivial)	Pre: 16.3 (±3.7) Post: 16.4 (+3.4; most likely trivial) +24h: 11.0 (±3.9; very likely) +48h: 14.9 (±3.7; likely) +72h: 16.9 (±3.7; likely trivial)

					Mean (±SD; qualitative inference)	Mean (±SD; qualitative inference)
					Units: ng·dl^{-1}	
Elias et al. (2012)	n=14 Professional Australian rules football players Male 20.9 years (±3.3 years)	Players performed a regularly undertaken training session Time-point: 45 min pre, post, 24 and 48 h post Measures: countermovement jump, repeated sprint activity (6 x 20m sprints departing every 30 s)	Main weekly training session 10 min warm up 30 min skill development (kicking, handball and positioning drills) 4 x 2.5 min non-contact small sided games/ 2.5 min rest Pitch: 25 x 15 m Aim: to score more goals than the other team	Ratio of flight time to contraction time: Pre: 0.67 (±0.19) Post: 0.66 (±0.11) +24h: 0.66 (±0.13) +48h: 0.64 (±0.18) No significant differences Repeated sprint activity (s): Pre: 18.53 (±0.38) Post: 18.97 (±0.41)^{a} +24h: 19.28 (±0.55)^{b} +48h: 18.62 (±0.70) Mean (±SD) ^{a}moderate change (ES = 0.6-1.2) ^{b}large change (ES = 1.2-2.0)		
Crewther et al. (2015)	n=10 Elite female hockey players using hormonal	Players monitored over 15-day training block Four light training sessions	Lasted approximately two hours, involved combination of skill (e.g. hockey team training) and/		Heavy training: +45% Light training: no change	Heavy training: +46% Light training: -52%

	contraceptives (HC) n=19 Elite female hockey players not using hormonal contraceptives (Non-HC) 25.3 years (±2.1 years)	Three heavy training sessions Time-points: pre and post session Measures: salivary testosterone and cortisol concentrations	or physical (e.g. weight training, cardiovascular) conditioning. In total, 50% of total training focused on skill development and 50% on conditioning.		A greater increase was observed for heavy vs light training (p<0.01) A greater change was observed for Non-HC vs HC (p<0.05)	Response to heavy training was significantly different to light training (p<0.01) No difference between groups was observed

Abbreviations: SD: standard deviation; ES: effect size; PPO: peak power output, JH: jump height; HC: hormonal contraceptive users; Non-HC: non hormonal contraceptive users.

2.4.3 Neuromuscular and endocrine responses to training session order

The majority of sports require athletes to undertake multiple training sessions in a given day, comprising various modalities of training (Cormack, Newton, & McGuigan, 2008; García-Pallarés et al., 2009; Sandbakk & Holmberg, 2017). Whilst some studies have shown positive adaptations to concurrent training programmes comprising various modes of exercise, such as strength and endurance training (García-Pallarés et al., 2009; Häkkinen et al., 2003), reports also exist of a reduced training effect (Jones, Howatson, Russell, & French, 2016; Sabag et al., 2018). As previously discussed in section 2.4, endocrine and neuromuscular responses are specific to the type of exercise performed. Therefore the order of training within a concurrent training paradigm can be important in determining subsequent training performance (Sparkes et al., 2020) and the ensuing adaptations (Jones et al., 2016; Sabag et al., 2018) due to either potentiation (Cook et al., 2014) or interference (Fyfe et al., 2014). Whilst the immediate post-exercises responses and short-term recovery to a variety of training modes have been described previously in section 2.4, this section will focus on the impact of training session order at key time-points when athletes perform subsequent training; within the same training day and 24 hours post-training on the following training day.

2.4.3.1 Positive impact of training-session order on subsequent performance

There are many reports describing the effect of training-session order of various modes of exercise (for example combined resistance exercise and endurance running exercise) upon neuromuscular and endocrine responses (Cadore et al., 2012; Jones et al., 2017; Schumann et al., 2013, 2014). However, as athletes would typically perform training sessions with recovery periods lasting several hours, rather than as one single session incorporating various forms of exercise, this section focuses on studies involving the performance of multiple training sessions within a training day, of which there are limited reports. In one such study, Johnston et al. (2017) reported the effects of training session order in Academy-level rugby players when performing speed (six repetitions of 50 m sprint with five minutes recovery between trials) followed by strength (five sets of four repetitions of the back squat and Romanian dead lift exercises at 85% of one repetition maximum, with four minutes recovery between sets) training, with a two-hour recovery period, and in the opposite order with seven days separating protocols. In spite of the significantly different metabolic responses between the training sessions, no differences in responses were observed for neuromuscular performance or endocrine function between protocols prior to commencing the second training session or 24 h post. Whilst weight lifted and internal load of the resistance-training session was not different between protocols, that is whether or not preceded by sprint training, sprint performance was enhanced when preceded by resistance training. However, as the training session was performed approximately two hours later in the day in this protocol, this difference could be attributed to circadian rhythm responses of muscle temperature (Teo, McGuigan, et al., 2011), as well as the impact of training session order. Regardless, sprint-training performance was enhanced when preceded by strength training, without impact on the strength-training session or fatigue the following day, suggesting a favourable order for this combination of training modalities.

There have been several reports highlighting the positive priming effects of prior training on subsequent neuromuscular performance (Cook et al., 2014; Russell et al., 2016). Following a morning (09:00) strength-training session (three sets of three repetitions of the bench press and back-squat exercises at 50, 80, 90 and 100% of one repetition maximum with one minute recovery between sets), afternoon (15:00) testosterone concentration was elevated (Figure 2.16) compared with concentrations following speed (five repetitions of 40 m with one minute recovery between repetitions) or control (no exercise), whilst countermovement jump peak power output, 40 m sprint performance and three repetition maximum in the back squat were enhanced (Cook et al., 2014) (Table 2.16).

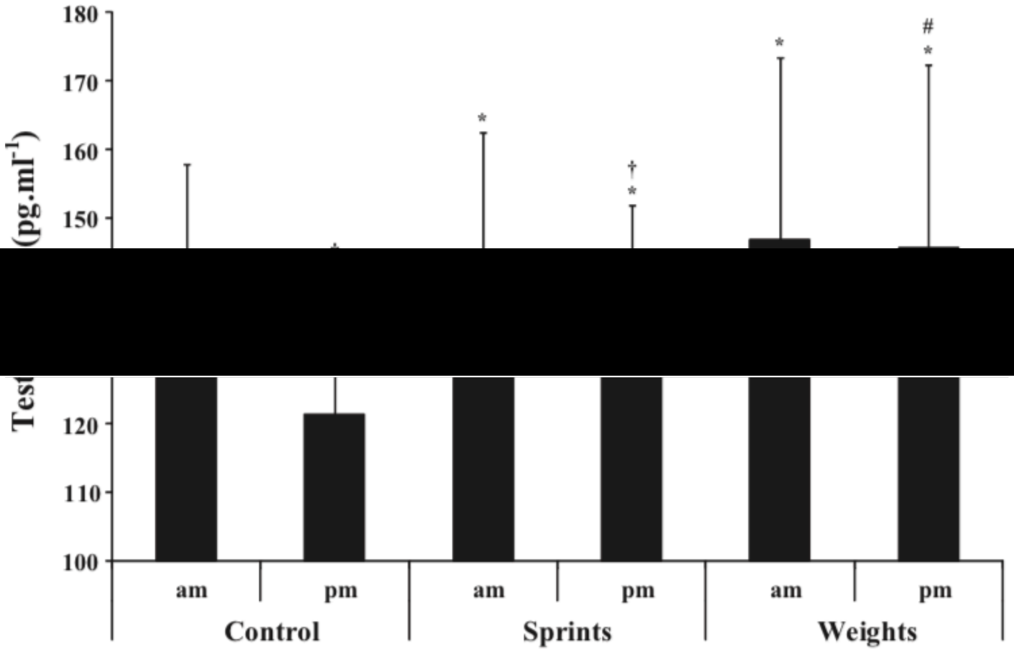

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Figure 2.16: Salivary testosterone concentration responses to the three priming protocols. † indicates significant decline from am ($P < 0.05$). * indicates significantly different to control at the respective time point ($P < 0.05$). # indicates different to sprint at the respective time point ($P < 0.05$). Reproduced from Cook et al. (2014).

Table 2.16: Player performance responses to the three priming protocols employed by Cook et al. (2014). Reproduced from Cook et al. (2014).

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

Abbreviations: RM: repetition maximum; BBP: barbell bench press; CMJ: countermovement jump; PPO: peak power output. [a] indicates different to Control protocol. [b] indicates different to all other conditions.

Furthermore, Russell et al. (2016) investigated the priming effects of various morning exercise protocols (performed at 08:00) on afternoon (after a five-hour recovery period) hormone responses, countermovement jump and sprint running performance. Morning speed training (six repetitions of 40 m sprint with 20 s recovery between repetitions) had the greatest effect on afternoon hormonal responses (Figure 2.17), and improved countermovement jump and sprint performance. Upper-body resistance training (five sets of 10 repetitions of the bench press exercise at 75% of predicted one repetition-maximum, with 90s rest between sets) positively influenced testosterone concentration and sprint performance, whilst sprint cycling (six repetitions of six second sprints with 54 seconds passive rest between sprints, performed at a load of 7.5% body mass) improved countermovement jump performance only.

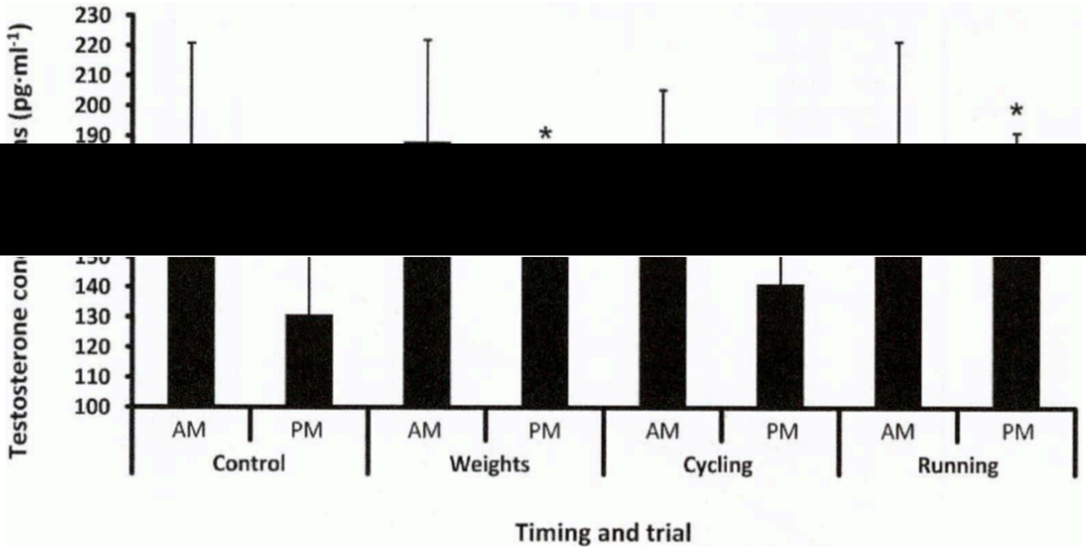
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Figure 2.17: Testosterone concentrations throughout the four morning priming protocols. Mean ± standard deviation. * indicates significant difference ($P < 0.05$) compared with corresponding time point in control. Reproduced from Russell et al. (2016).

Morning exercise has also been reported to positively impact subsequent performance through positive influences upon core temperature (Mcgowan et al., 2017). National standard swimmers performed three trials consisting of either morning exercise (07:30) involving swimming (1200 m of various intensity), swimming and resistance exercise (1200 m of various intensity, followed by a 10-minute circuit-based resistance exercise protocol) or no exercise (control). This was then followed by a six-hour recovery period prior to performing a 100m swimming time trial. Prior to commencing the afternoon warm up, core temperature was elevated above that of no exercise (mean ± 90% CI: 0.2°C ± 0.1°C) and swim only exercise (0.1°C ± 0.2°C) following the swimming and resistance-exercise protocol, and further elevated immediately before the time trial (0.6°C ± 0.3°C) when compared with no exercise. Swimming time-trial performance was improved following the swimming only (1.6% ± 0.6%) and swimming and resistance-exercise protocol (1.7% ± 0.7%) compared with the no-exercise protocol. As performance was improved following both morning exercise protocols, it can be suggested that whilst the prior exercise had a positive effect on performance through an increase in core temperature, and likely increase in muscle temperature (Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004) and neuromuscular function (West, Cook, Beaven, et al., 2014), secondary mechanisms may have positively influenced performance such as hormonal responses.

A recent study reported the acute neuromuscular and endocrine responses to training-session order in male semi-professional soccer players (Sparkes et al., 2020). Players performed a familiar resistance-training session (four sets of four repetitions of the back-squat, Romanian dead-lift and barbell hip thrust at 85% of one repetition maximum) as well as an on-field soccer-training session (six games of seven minutes with two minutes recovery between each game performed by five players on each team). Separated by one week, players performed resistance training followed by soccer training, and soccer training followed by resistance training, with a two hour recovery period between sessions. Immediately following the initial training session, countermovement jump peak power output was reduced and testosterone concentrations increased following resistance compared with small-sided games, whilst cortisol concentrations reduced following small sided games two hours post (Figure 2.18). However, in spite of these differences between training sessions, similar to that of Johnston et al. (2017), there was no impact of session order upon hormonal responses prior to commencing the subsequent training session, or hormonal and neuromuscular responses the following day. Additionally, there were no differences in the internal and external demands of the small sided games training session, suggesting no negative impact of prior training session performance on subsequent soccer training performance. However, as no markers of neuromuscular performance were obtained immediately before training session two, or indications of internal or external load performed during the resistance-training session, the impact of prior exercise on resistance-training performance cannot be determined.

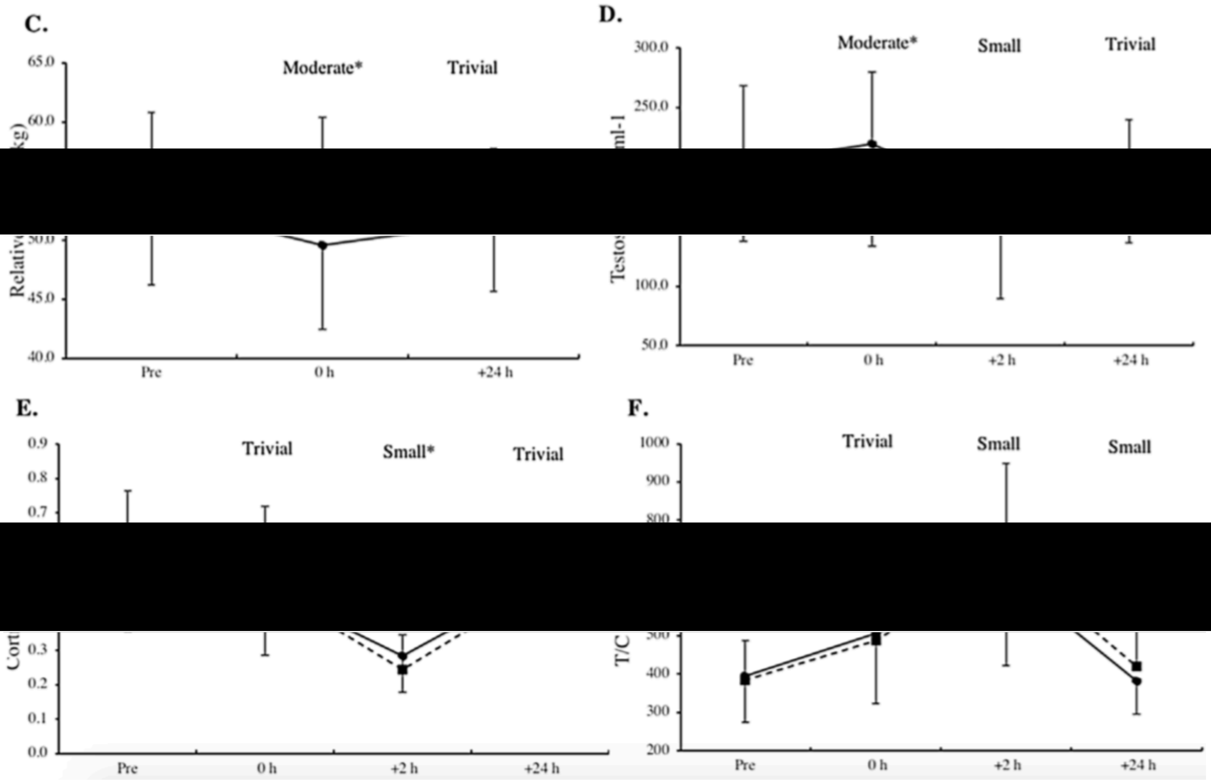

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Figure 2.18: Mean (± standard deviation) relative peak power output (C), testosterone concentration (D), cortisol concentration (E) and testosterone to cortisol ratio (F) to each protocol (small-sided games + resistance; dashed lines: resistance + small-sided games; solid lines). Effect sizes are shown for the between protocol differences between each time point and pre-values. * indicates a significant difference between protocols. Reproduced from Sparkes et al. (2020).

It therefore appears that prior exercise can positively influence subsequent training performance, through impact upon testosterone concentration (Cook et al., 2014; Russell et al., 2016), core temperature (Mcgowan et al., 2017) and neuromuscular function (Cook et al., 2014; Johnston et al., 2017; Russell et al., 2016) resulting in improved athletic performance (Cook et al., 2014; Mcgowan et al., 2017; Russell et al., 2016), however is dependent upon the type of exercise performed (Russell et al., 2016).

2.4.3.2 Negative impact of training session order on subsequent performance

Evidence of impaired performance also exists when endurance running exercise is performed the same day as resistance exercise (Doma & Deakin, 2013). Fourteen trained and moderately trained runners performed resistance exercise (six sets of six repetitions of the leg press exercise, and four sets of six repetitions of the leg extension and leg curl exercises, with three minutes recovery between each set) and endurance running (progressive warm up followed by 10 minutes at 70% of ventilatory threshold, 10 minutes at 90% of ventilatory threshold and four intervals at 110% of ventilatory threshold performed for 1.5 to two minutes with 1.5 to two minutes recovery between intervals) separated by six hours. This was performed as both endurance exercise followed by resistance exercise, and resistance exercise followed by endurance exercise, with seven days separating protocols. The following day, 18 h post the second training session of the day, participants performed a treadmill test to examine running economy and time to exhaustion at 110% of ventilatory threshold. Additionally, neuromuscular testing, involving the performance of a maximal isometric contraction of the knee extensors, was performed pre and post each training session and at the same time point as running economy, 18 h post training. Immediately prior to the second training session, neuromuscular function had returned to baseline following an initial post-exercise decrease in the endurance-strength protocol, however remained reduced in the strength-endurance protocol (Figure 2.19). Running economy 18 h following the second training session was impaired following the strength-endurance protocol compared to both baseline (without prior exercise) and the endurance-strength protocol, whilst time to exhaustion was reduced in both protocols. As neuromuscular function was impaired at the onset of the endurance running session when preceded by strength training, the endurance-training session may have been performed in a fatigued state, resulting in greater disturbances the following day. Indeed, in the studies of both Johnston et al. (2017) and Sparkes et al. (2020) neuromuscular performance had returned to baseline when participants commenced the second training session of the day. It should also be noted that participants were of significantly different training status between these studies. Those of Johnston et al. (2017) and Sparkes et al. (2020) were accustomed to both forms of training performed, and well-trained, being academy-standard or semi-professional respectively. However, in the study by Doma and Deakin (2013), participants were of a lower standard, and had not performed any lower-body resistance exercise for the previous two months. This difference in training status, and subsequent lack of recovery at the onset of the second training session appears therefore significant in determining the residual fatigue experienced when performing multiple training sessions within the day.

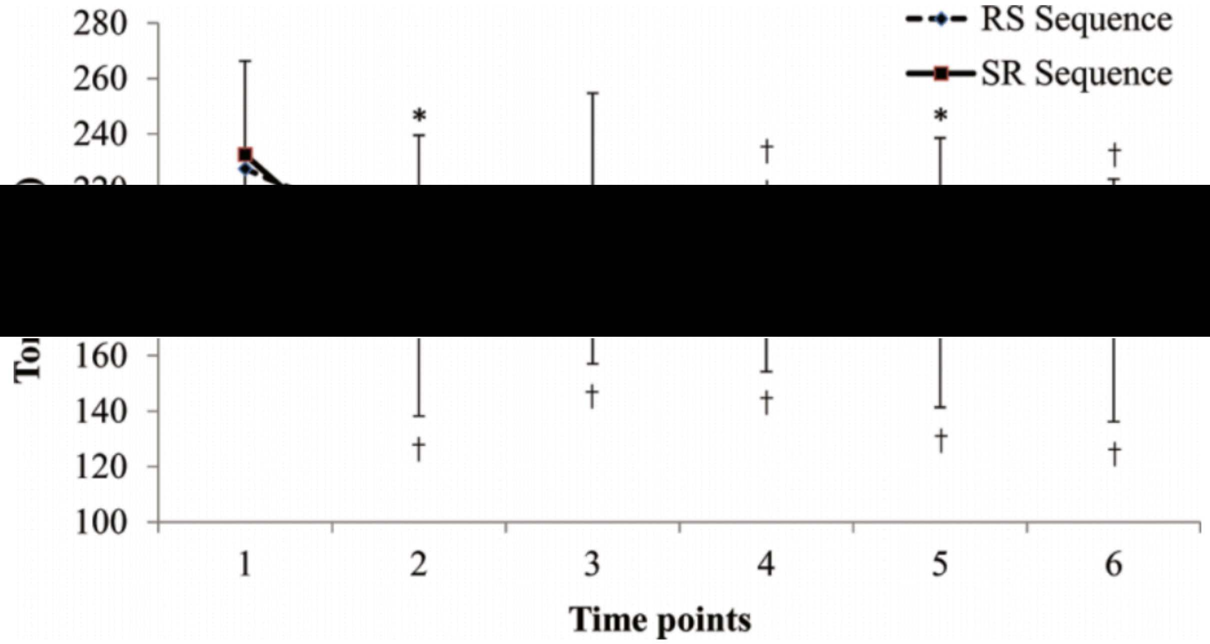

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Figure 2.19: Torque from a maximal voluntary isometric knee extension contraction prior to (1) and immediately post (2) training session one, prior to (3) and immediately post (4) training session two, and prior to (5) and immediately post (6) testing performed the following day. Mean ± standard deviation shown for both protocols involving running followed by strength training (RS sequence) and strength training followed by running (SR sequence). * indicates significantly less than time point 1 ($P < 0.05$), † indicates significantly less than time point 1 ($P < 0.01$), ‡ indicates significantly less than time point 3 ($P < 0.01$). Reproduced from Doma and Deakin (2013).

The order of training sessions performed during concurrent training paradigms can be important in determining the ensuing adaptations (Jones et al., 2016; Sabag et al., 2018), with multifactorial mechanisms interfering with the quality of training performance (Leveritt et al., 1999) or compromises to the molecular responses (Baar, 2006; Hawley, 2009). Several studies demonstrate concurrent strength and endurance exercise, relative to resistance exercise alone, results in impaired strength (Bell et al., 2000; Jones et al., 2017; Kraemer et al., 1995), hypertrophy (Kraemer et al., 1995) and power development (Häkkinen et al., 2003; Kraemer et al., 1995; Lee et al., 2020), termed the interference effect, whilst resistance exercise has limited or no effect on aerobic endurance improvements (Figure 2.20). However, more recent findings question the purported negative impact of the interference effect, with the potential for concurrent training to augment rather than attenuate hypertrophy responses (Kazior et al., 2016; Lundberg, Fernandez-Gonzalo, Gustafsson, & Tesch, 2013). Whilst methodological considerations must be taken in to consideration, including training status of participants and length of training programme (Fyfe & Loenneke, 2018), findings suggest training-programme design, including recovery duration between training sessions (Lundberg et al., 2013; Wojtaszewski, Nielsen, Hansen, Richter, & Kiens, 2000), nutritional interventions (Areta et al., 2013; McBride et al., 2009) as well as order (Doma & Deakin, 2013; Johnston et al., 2017) may be critical in determining this response.

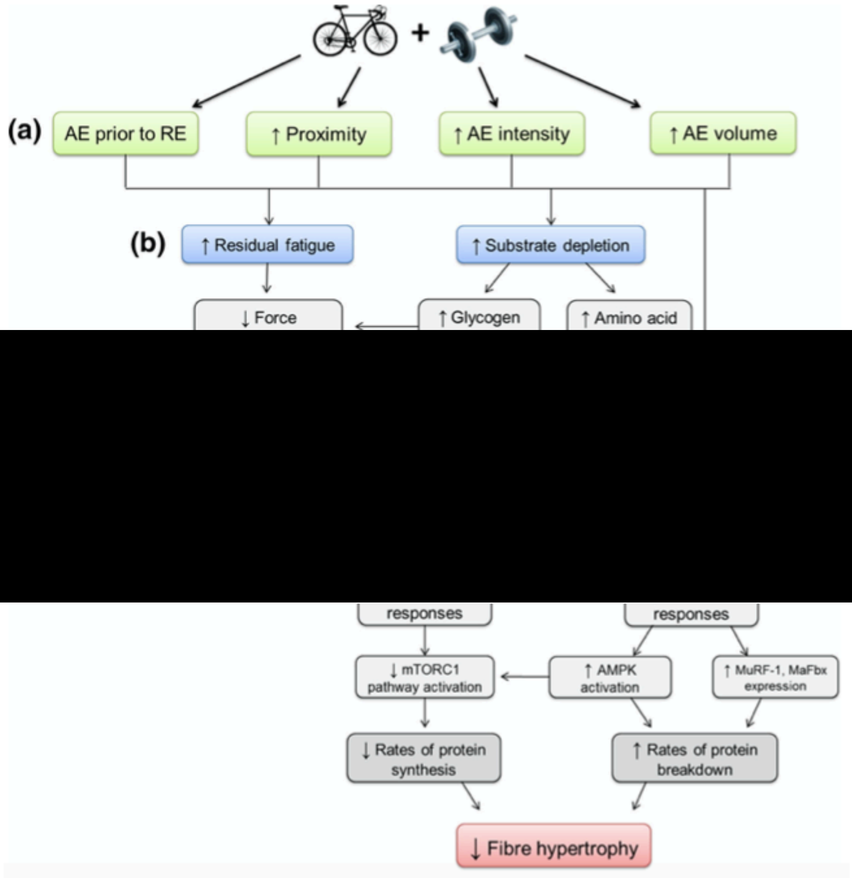

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Figure 2.20 : Conceptual framework for the potential role of individual concurrent training variables (a) in exacerbating the interference effect, either by (b) compromising the resistance exercise itself via increased residual fatigue and/ or substrate depletion, or (c) by attenuating the anabolic response to resistance exercise. Reproduced from Fyfe et al. (2014). *Abbreviations*: AE: aerobic exercise; AMPK: adenosine monophosphate-activated protein kinase; MaFbx: muscle-atrophy f-box (atrogin 1); mTORC1: mammalian (mechanistic) target of rapamycin complex 1; MuRF-1; muscle ring-finger 1; RE: resistance exercise, ↑ indicates increase or greater, ↓ indicates decrease or reduction.

Collectively, as there are limited observations in this area in well-trained individuals, including applicable recovery periods between training sessions, and combinations of types of training, in addition to no reports in females, conclusions are difficult to ascertain. Findings suggest that in well-trained team-sport male players, training-session order does not influence the hormonal or neuromuscular responses over a 24 hour period (Johnston et al., 2017; Sparkes et al., 2020), whilst recovery of neuromuscular performance may be important in determining this response (Doma & Deakin, 2013; Johnston et al., 2017; Sparkes et al., 2020). Furthermore, sprint-training performance can be enhanced when preceded by strength training (Johnston et al., 2017), however it is unclear if a similar observation would be found in a female population, and in response to combinations of other modes of exercise. A summary of the key studies reporting the endocrine and neuromuscular responses to training session order is provided in table 2.17.

Table 2.17: Summary of studies reporting the neuromuscular and endocrine responses to training-session order.

Study	Participants	Design	Training session	Neuromuscular response	Testosterone response	Cortisol response
Johnston et al. (2017)	n=15 Academy level rugby players Male Mean age (±SD): 21 years (±1 years)	Randomised crossover design of two orders of training Speed training followed 2 h later by weight training (SW) Weight training followed 2 h later by speed training (WS) Time-points: pre, post, 2, 22 h post Measures: plasma testosterone and cortisol concentrations, countermovement jump	Speed: warm up followed by 6 x 50 m maximal sprints/ 5 min rest between sprints Weights: 5 x 4 @ 85%1RM/ 4 min recovery Exercise: Romanian dead lift	No significant differences in 50 m sprint time or countermovement jump performance between session orders Peak 10 m time was faster following WS compared with SW	No significant differences between session orders	No significant differences between session orders
Sparkes et al. (2020	n=14 Semi-professional	Crossover design of two orders of training separated by one week	Small sided games: 5 min warm up, 6 x 7 min blocks (42 min total)/ 2 min	No significant difference in countermovement jump height between session orders	Greater elevation at +0h following RE+SSG	No significant difference between session orders

	soccer players Male 22.1 years (±3.1 years)	Small sided games followed 2 h later by resistance training (SSG+RE) Resistance exercise followed 2 h later by small sided games (RE+SSG) Time-points: pre, post (+0h), 2h (+2h) and 24h (+24h) post Measures: salivary testosterone and cortisol concentrations, countermovement jump	recovery between blocks. Pitch size: 24 x 29 m Aim: to score more goals than the opposition Resistance exercise: 4 x 4 @ 85%1RM/ 4 min recovery. Exercises: parallel back squat, Romanian dead lift and barbell hip thrust	Countermovement peak power output reduced at +0h following RE+SSG compared with SSG+RE Mean difference at +0h compared to pre (±SD): SSG+RE: -0.84 $\mathrm{W\cdot kg^{-1}}$ (±2.75), ES = 0.12 RE+SSG: -3.53 $\mathrm{W\cdot kg^{-1}}$ (±2.48), ES = 0.50 Difference between protocols: -2.69 $\mathrm{W\cdot kg^{-1}}$ (±3.30), ES = 1.03	compared with SSG+RE Mean difference at +0h compared to pre (±SD): SSG+RE: -4.4 $\mathrm{pg\cdot ml^{-1}}$ (±32.5) RE+SSG: 17.0 $\mathrm{pg\cdot ml^{-1}}$ (±25.3) Difference between protocols: 21.4 $\mathrm{pg\cdot ml^{-1}}$ (±26.7)	
Doma and Deakin (2013)	n=14 Trained and moderately trained runners (no resistance	Crossover design of two orders of training Running followed 6 h later by	Running: progressive warm up, 10 min @ 70% of ventilatory threshold (VT), 2 min rest, 10 min @ 90% of VT, 2 min	No significant difference in peak torque between session orders		

	training experience for >2 months) Male 23.3 years (±6.1 years)	strength training (RS) Strength training followed 6 h later by running training (SR) Time-points: pre and post each training session Measures: maximal voluntary contraction of knee extensors	rest, 4 x 1.5-2 min @ 110% of VT with 1:1 rest Strength: 6 x 6 of incline leg press, 4 x 6 of leg extension and leg curls/ 3 min rest between sets			

Abbreviations: 1RM: one repetition maximum; ES: effect size; SD: standard deviation

2.5 Chapter conclusions

Demands of netball have been reported in elite-standard players, using a range of methods, including notational analysis, movement analysis and more recently using accelerometry and an indoor positioning system. Unique playing demands, including types and frequency of non-locomotor activity (e.g. passing, re-bounding, off-ball guarding) as well as patterns of locomotor activity, are experienced by players due to role of individual positions, as well as court playing restrictions. However, the physiological and perceptual responses to netball match-play have yet to be profiled, with no reports highlighting the internal load of match-play. Additionally, no reports exist highlighting the internal and external demands of consecutive matches, as is the case during competitions when as many as eight matches are played in 10 days. As competitions require the performance of multiple matches played daily, the fatiguing responses to, and recovery from match-play is important to understand. However, at present no data exists reporting the physiological or perceptual responses to an individual training session, match or series of matches.

Exercise induces a wide range of physiological responses which affects the neuromuscular system at both central and peripheral levels. These responses can both inhibit and enhance the neuromuscular system. For example, exercise is associated with an increase in muscle temperature which exerts a positive influence on the neuromuscular system (West, Cook, Beaven, et al., 2014), whilst an associated increase in metabolite concentration can inhibit the neuromuscular system (Allen et al., 2008). Both mechanisms of fatigue and potentiation can co-exist, exerting positive and negative influences on the neuromuscular system at the same time with varied time-frames during which effects are observed. It is therefore challenging to measure both the mechanism of fatigue, as well as degree of fatigue, as various mechanisms are positively and negatively impacting upon the neuromuscular system at the same time. It can therefore be suggested that measuring the change in neuromuscular performance is a more suitable method of understanding the balance of these factors, as this accounts for all inputs to the neuromuscular system.

There are various methods to measure neuromuscular performance. Laboratory-based protocols have been extensively used and provide information on the origin of fatigue, that is the contribution to fatigue from central and peripheral mechanisms. However, limitations exist, with regards to the movements, including single-joint exercises, that can be employed, whilst the responses do not necessarily reflect changes in dynamic exercise performance, questioning applicability. Dynamic exercise protocols have also been used to measure neuromuscular performance, with the countermovement jump being extensively used. Variables of countermovement jump testing show good levels of reliability, and are related to athletic performance, including sprint running performance, and are sensitive to fatigue experienced in elite athletes. Collectively, the literature suggests countermovement jump testing to be suitable to measure changes in neuromuscular performance and impact upon dynamic movements.

A wide variety of responses are evident following a variety of exercise stimuli. For example, mechanisms and contributions to a decrement in neuromuscular performance differ according to intensity, duration and type of exercise. However, there are limited accounts following typical team-sport activity in female athletes and none following netball training. Many factors influence the post-exercise responses to training, including training status, training intensity and session aims, in addition to mode of exercise. Additionally, the time-frame of recovery of neuromuscular performance varies dependent upon these factors and mechanism of fatigue. Therefore, there is a lack of information in this area currently available to assist coaches and conditioning coaches in planning netball training.

Many athletes, including netball players, perform multiple training sessions in a day in an attempt to improve conditioning for competition. Whilst responses to the second training session of the day could be assumed to be the same as if performed individually, this may not be the case, and subsequent training performance may be impaired due to prolonged fatigue of the neuromuscular system (Doma & Deakin, 2013). Indeed, there is currently little evidence with appropriate training session and recovery time-frames available, especially applicable to elite female netball players, making it difficult to ascertain expected responses to the performance of multiple training sessions.

Whilst many reports highlight the impact of training-session order of various modes of exercise, few exist in an appropriate population and employing appropriate training sessions and recovery time-frames. Training-session order can enhance subsequent training performance (Cook et al., 2014; Johnston et al., 2017), however it can also negatively influence recovery and subsequent training performance (Doma & Deakin, 2013). This can lead to altered recovery, training performance and long-term adaptive response. It is therefore important to understand the responses to training-session order to sport-specific training modalities in order to optimise the training response. However, this is currently challenging for coaches and conditioning coaches, as no reports exists including the performance of netball training.

Much of the research discussed previously is limited due to training status of the participants (i.e. not elite) and is performed in male rather than female populations. Females undergo cyclical changes in circulating hormones, with important biological effects on the body throughout the menstrual cycle. Additionally, elite female athletes demonstrate higher testosterone concentrations than lower standard and un-trained females, affecting the magnitude of hormonal and neuromuscular responses to stimuli (Cook et al., 2018). Conflicting evidence exists with regards to the effects the menstrual cycle and hormonal contraceptive use has on responses to exercise; however, evidence does exist suggesting varied responses compared to males. Available evidence suggests trivial or no impact of menstrual cycle phase or hormonal contraceptive use on neuromuscular performance.

2.6 Research aims

Figure 2.21 summarises existing knowledge, gaps in the literature and areas that this thesis will investigate. This includes demands of and responses to International or elite-standard match-play, to netball-specific training and to the effect of training session order including netball and strength training sessions. After reviewing the available literature, the following research aims have been identified for this thesis:

- To describe the internal and external demands of international netball match-play. Specifically, the thesis will aim to answer the following questions:
    - What are the internal and external demands of international netball for different positional groups?
- To describe the neuromuscular responses to an individual and series of international netball matches. Specifically, the thesis will aim to answer the following questions:
    - What are the neuromuscular, endocrine and perceptual responses to a single international netball match?

  - What are the neuromuscular, endocrine and perceptual responses to a series of international netball matches?
  - What is the recovery profile of these markers over three days following an international netball tournament?
- To describe the neuromuscular responses to a regularly performed on-court netball-training session over 24 hours. Specifically, the thesis will aim to answer the following questions:
  - What are the immediate post-exercise neuromuscular, endocrine and perceptual responses to this session?
  - What is the pattern of these responses over a 24 h period?
- To describe the neuromuscular responses to performing two training sessions within the same training day. Specifically, the thesis will aim to answer the following questions:
  - What are the immediate post-exercise neuromuscular, endocrine and perceptual responses to strength training and netball training?
  - What is the impact of prior exercise (netball followed by strength training versus strength followed by netball training) on netball-training performance?
  - What is the impact of training-session order (netball followed by strength training versus strength followed by netball training) on neuromuscular, endocrine and perceptual responses within the training day?
  - What is the impact of training-session order (netball followed by strength training versus strength followed by netball training) on neuromuscular, endocrine and perceptual responses over 20 hours?

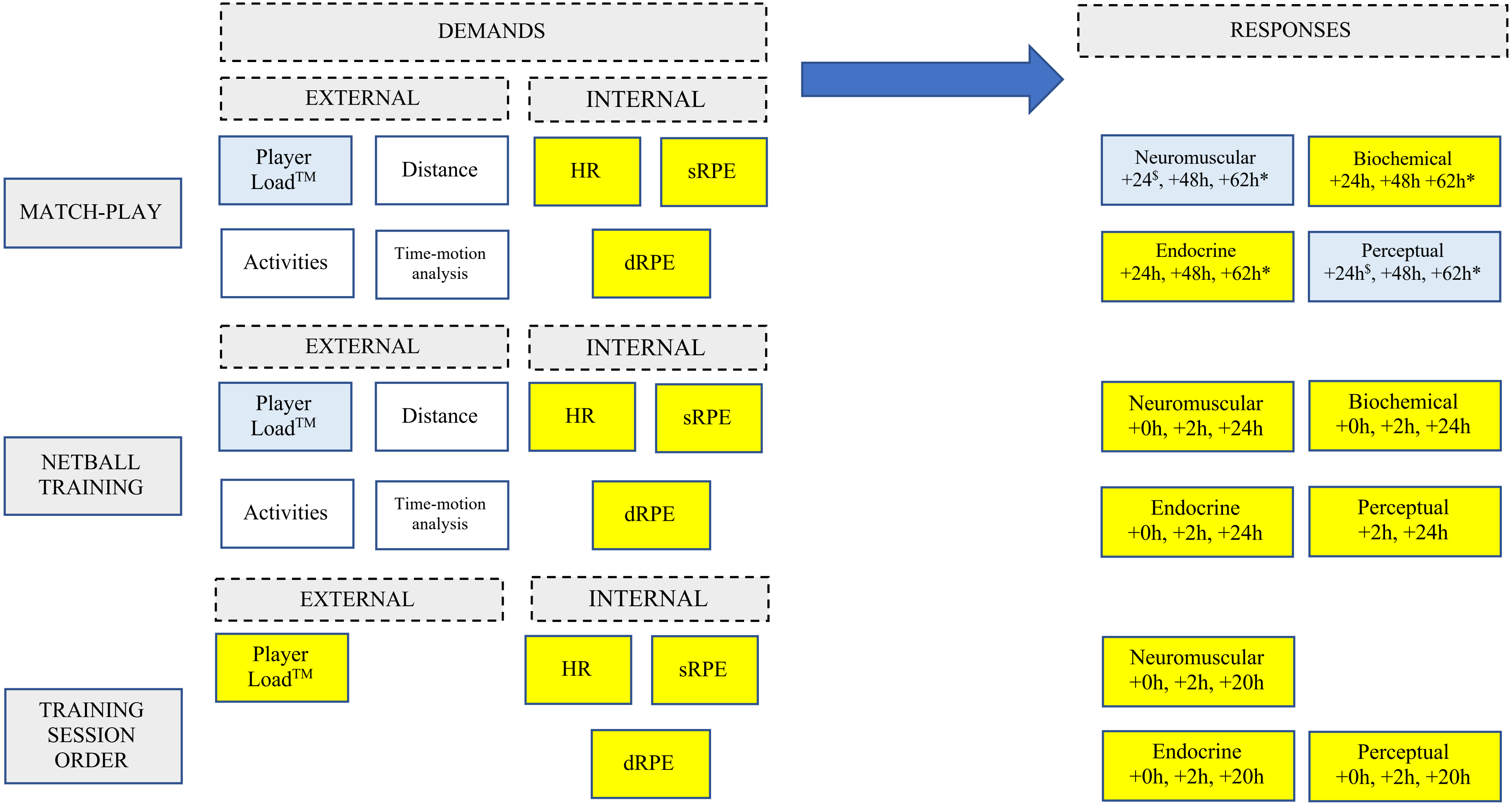

Figure 2.21: Summary of existing knowledge and gaps in the literature of the demands of, and responses to, International or elite-standard netball, including areas of investigation for this thesis. White boxes indicate knowledge that currently exists, yellow indicates gaps in the literature which this thesis will investigate, and blue indicates knowledge that currently exists and that this thesis will expand upon. *Abbreviations:* HR: heart rate; sRPE: ratings of perceived exertion; dRPE: differential ratings of perceived exertion. *denotes 62 h following the final match of the tournament. $denotes that previous knowledge exists at that time-point. +0h, +2h, +20h, +24h, +62h denotes time-point of measurements taken.

Chapter 3 General Methods

3.1 Introduction

This thesis includes a variety of studies to investigate the physiological, neuromuscular, biochemical and perceptual responses to competition, netball and resistance exercise. While the methods employed were specific to the aims of each experimental study, there was considerable overlap across studies. As such, this section aims to provide a description of these methods.

3.2 Neuromuscular performance

Neuromuscular performance was assessed in each chapter, calculated from the vertical component of the ground reaction force.

Protocol

A portable force platform with built-in charge amplifier (type 92866AA, Kistler Instruments Ltd., Farnborough, UK) was used to measure the ground reaction force of the countermovement jump. The ground reaction force was sampled at 1000 Hz through a 16-bit analogue to digital converter (Kistler Instruments Ltd., Farnborough, United Kingdom) using the manufacturer's software (Bioware, version 3.2.7.0), with vertical force range set at 20 kN as per previously established studies (Owen, Watkins, Kilduff, Bevan, & Bennett, 2014). The force platform was factory calibrated and confirmed before each testing session.

Players stood stationary on the force platform, with the instruction to stand as still as possible, for determination of mass, referred to as the stance phase. After a three second countdown, the player performed a countermovement jump, with a self-selected depth. Prior to each jump, players were verbally instructed to jump as high and as fast as possible, and to keep hands on hips at all times to isolate the lower limbs (Owen et al., 2014). Two jumps were performed consecutively with a rest period of 45-60 s between each jump.

Calculation of body weight and determination of initiation of jump

Countermovement jump data was exported from the manufacturer's software to a custom-built excel spreadsheet for analysis. Body weight was calculated as the mean value of the ground reaction force, measured for one second prior to the instruction to jump in the stance phase. The initiation of the jump was calculated as per a previously established method (Owen et al., 2014). This was defined as the instant, after the instruction to jump was given, that the ground reaction force exceeded the mean body weight plus or minus 5 standard deviations as measured during the stance phase, minus 30 ms (Owen et al., 2014). This method aimed to ensure that the whole of the jump phase was retained, but none of the stance phase. Take-off was defined as the first intersection of force with the take-off threshold force (Street, McMillan, Board, Rasmussen, & Heneghan, 2001). This threshold was defined as the offset force plus the peak residual during the 0.4 s offset period (Street et al., 2001). The offset was determined by finding the 0.4 s moving average during the flight phase with the smallest standard deviation (Street et al., 2001).

Calculation of impulse and velocity

Power was determined from the force-time trace at the start of the countermovement jump using the impulse momentum principle (Owen et al., 2014). Impulse was calculated by multiplying the vertical ground reaction force minus body mass by 0.005 s (the sampling frequency). The impulse was divided by body weight (in kg) for each time point to calculate instantaneous velocity. Summing the instantaneous velocities over time then produced a velocity-time profile.

Countermovement jump variables

Three key variables were calculated in each experimental chapter from the force and velocity data. Jump height (CV=4-5%; Cormack, Newton, McGulgan, et al., 2008) was calculated by multiplying the velocity at each sampling point by the time (0.005 s) to determine maximal vertical displacement. Jump height was then defined as the difference between vertical displacement at take-off and maximal vertical displacement. Peak power (CV=3.5%; Cormack, Newton, McGulgan, et al., 2008) was calculated by multiplying force with the corresponding velocity at each time point and identifying the highest value. Relative peak power (CV=3.6%;

Cormack, Newton, McGulgan, et al., 2008) was calculated by dividing peak power by body weight in kg.

One further variable was also calculated in chapter six. Peak velocity (CV=2.5%; Kennedy & Drake, 2021), defined as the peak velocity value produced during the jump.

3.3 Hormonal analysis

In each chapter, saliva samples were collected for subsequent hormone analyses. Players were instructed to avoid eating or drinking fluids other than water for 60 minutes prior to sampling in order to avoid contamination of samples, and to avoid water intake within 10 minutes of sample collection. A two millilitre saliva sample was collected via passive drool (Crewther et al., 2013) in to sterile containers, and subsequently stored at -70°C until assay. After thawing and centrifugation (2000 revolutions$\cdot$min^{-1} for 10 minutes), the saliva samples were analysed in duplicate for testosterone and cortisol concentrations using commercially available kits (Salimetrics, LLC, State College, PA, USA). The minimum detection limit for the testosterone assay was 6.1 pg$\cdot$ml^{-1}, with interassay coefficient of variation of < 10%. The cortisol assay had a detection limit of 0.12 ng$\cdot$ml^{-1} with interassay coefficient of variation of < 7%. Samples for each participant were assayed in the same plate to eliminate inter-assay variability.

3.4 Indirect marker of muscle damage

Creatine kinase is thought to transfer from skeletal muscle fibres, damaged from repeated intense contractions, into the plasma, and as such increases in serum concentration are observed in response to prolonged activity, such as ultramarathons (Skenderi, Kavouras, Anastasiou, Yiannakouris, & Matalas, 2006) as well as repeated high intensity exercise (Howatson & Milak, 2009). Although validity is questioned (including variance across protocols and individuals), creatine kinase activity has been widely considered and used an indirect marker of muscle damage (Clarkson, Kearns, Rouzier, Rubin, & Thompson, 2006; Skenderi et al., 2006). In chapters four and five creatine kinase concentrations were assessed. Whole blood samples (120 µl) were collected from the fingertip of the player's non-dominant hand and immediately stored on ice in EDTA prepared collection tubes (Microvette 500, Sarstedt, Numbrecht, Germany) before being centrifuged at 3000 revolutions$\cdot$min^{-1} for 10 min

(Labofuge 400R; Kendro Laboratories, Langenselbold, Germany). Plasma samples were then drawn, and subsequently stored at −70°C before being analysed for creatine kinase activity using commercially available kits (CK-NAC, ABX Diagnostics, Northampton, United Kingdom) on a spectrophotometer (Cobas Mira; ABX Diagnostics, Northampton, United Kingdom). Samples were measured in duplicate (coefficient of variation; CV=3%) and recorded as a mean.

3.5 Mood

Following exercise mechanisms of fatigue exist both physiologically and psychologically, including, for example disruption or changes to perceived stress, perceived fatigue, sleep and mood (Main & Grove, 2009). Changes in overall mood is correlated to work performed and is sensitive to physiological responses to exercise, such as increases in creatine kinase activity and decreases in countermovement jump performance (Shearer et al., 2017). Decreases in mood have been observed acutely following a single training session (Sparkes et al., 2018) as well as a series of competitive matches (Shearer et al., 2017). Additionally, mood and aspects relating to mood are negatively affected following intensified training with insufficient recovery (Halson et al., 2002). In response to a two week intensified period of cycling training, perceptual responses (including overall mood, tension, fatigue, vigour and confusion, measured using the profile of mood states) (McNair, Lorr, & Droppleman, 1971) and physiological responses (including maximal heart rate and time trial performance) were adversely affected, returning towards baseline following a two week recovery period (Halson et al., 2002). It is therefore important to assess mood responses alongside physiological responses to fully understand fatigue and recovery from exercise (Halson et al., 2002; Shearer et al., 2017).

Mood responses were recorded in each chapter. Players recorded perceived mood using a modified version of the brief assessment of mood (BAM+) (Shearer et al., 2017) (Appendix 1). This was recorded each morning in chapter four, immediately pre-exercise in chapter five, and immediately pre and post-exercise in chapter six. Using a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc), a series of 10 questions were answered one at a time with a 100 mm visual analogue scale anchored with "not at all" and "extremely" to record how players felt at that moment in time. The questions assessed:

alertness, sleep quality, confidence, motivation, anger, confusion, tension, depression, fatigue and muscle soreness. Questions were worded, such as “How angry do you feel?” and “How motivated to train do you feel?”. An overall mood score was generated by subtracting the mean score of negative related items from the mean score of the positive related items using the equation below (Shearer et al., 2017):

Mood score = (Alertness + sleep quality + confidence + motivation) / 4 - (Anger + confusion + tension + depression + fatigue + muscle soreness) / 6

This method of calculating an overall mood score using the BAM+ has been reported to have acceptable internal consistency (Cronbach alpha score of 0.65 to 0.82; Shearer et al., 2017), to be moderately correlated to high intensity match activity (measured by global positioning system) and is sensitive to physiological responses to competition in elite team-sport athletes (Shearer et al., 2017). Individual scores were also used, such as perceived level of muscle soreness, sleep quality and perceived fatigue level.

3.6 Rating of perceived effort

Rating of perceived effort was recorded in each chapter. Within 15 minutes post-exercise players recorded session rating of perceived exertion (sRPE) (Foster et al., 2001) along with differential rating of perceived exertion (dRPE) for breathlessness (RPE-B), leg-muscle exertion (RPE-L), upper-body muscle exertion (RPE-U) and cognitive/ technical demands (RPE-T) (Weston, Siegler, Bahnert, McBrien, & Lovell, 2015). Questions were asked one at a time with ratings provided using a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer Inc.) using a numerically blinded CR100® scale with verbal anchors. Differential rating of perceived exertion has been demonstrated to be reliable (CV<3%; Field et al., 2020) provide a detailed quantification of internal load during team-sport activities (McLaren et al., 2017), is a sensitive marker of match exertion (Weston et al., 2015) and distinguishes between different areas of effort (McLaren et al., 2017; Weston et al., 2015). Players provided ratings on their own in order to reduce the likelihood of the researcher, or peers, influencing an individual’s decision.

3.7 Intensity of netball

In each chapter, the intensity of netball performance was measured by the same methods. Activity during netball was recorded using commercially available microtechnology units (Catapult S5, Catapult Innovations, Leeds, UK) housing a tri-axial accelerometer sampling at a rate of 100 Hz. In order to minimise movement artefacts, players wore a custom-made vest in which the units were held in place vertically in the centre of the upper back, slightly superior to the shoulder blades (Barrett, Midgley, & Lovell, 2014). Players used the same unit for all netball sessions in each study, in order to avoid inter-device variability. Data were downloaded using the manufacturer's software (Catapult sprint 5.1, Catapult Innovations, Leeds, UK) and analysed for external load (represented as Player Load^{TM}: AU) with detailed calculations described previously (Boyd, Ball, & Aughey, 2011). This marker of intensity has been widely used in team sports (Luteberget & Spencer, 2017; Polgaze et al., 2015) including netball (Bailey et al., 2017; Chandler et al., 2014; Young et al., 2016) and has been reported to be a valid and reliable method of measuring activity in team-sport movements (Barrett et al., 2014, 2016; Boyd et al., 2011; Luteberget, Holme, & Spencer, 2018). Luteberget et al. (2018) reported the reliability of Playerload in elite handball players across 12 training sessions. Players wore two units, taped together and held vertically on the upper-back throughout all training sessions. Reliability between units was high (CV=0.9%), suggesting Player Load^{TM} was reliable across devices. Other studies have also reported high reliability of tri-axial accelerometers, including in treadmill running (CV=5.9%; Barrett et al., 2014), simulated football matches (CV=3.6-3.8%; Barrett et al., 2016) and Australian football matches (CV=1.9%; Boyd et al., 2011). Internal exertion during netball was measured by heart rate telemetry. Players wore a heart rate monitor (Polar Team System 2, Polar Electro, Warwick, UK), which recorded at beat-to-beat intervals. Data was subsequently downloaded and analysed using the manufacturer's software (Polar Team 2, Polar Electro, Warwick, UK).

Chapter 4 Neuromuscular, physiological and perceptual responses to an elite netball tournament

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4.1 Introduction

Whilst several studies have reported the movement demands of elite netball in recent years (Bailey et al., 2017; Fox et al., 2013; Young et al., 2016), to date no studies have profiled the physiological responses to elite level tournament match-play. Several reports of the movement of elite netball exist, including by use of notational analysis (Fox et al., 2013), accelerometry (Bailey et al., 2017; Young et al., 2016) and an indoor positioning system (Brooks et al., 2020). Goal defence, goalkeeper and goal shooter positions have been reported to perform at the lowest playing intensities and highest proportions of match time spent in the low-intensity zones when compared to players occupying wing attack, wing defence, centre, and goal attack positions (Young et al., 2016). Additionally, Bailey et al. (2017) reported the accelerometer-based loads associated with typical activities, reporting off-ball guarding to elicit the highest load per instance, whilst jogging accumulated the greatest load across a match.

At present, a single study has reported the responses to an isolated match reporting a reduction in perception of fatigue and neuromuscular performance immediately and 24 h after an 80 min elite level match, returning to baseline 36 h later (Wood et al., 2013). Many tournaments require teams to play up to eight matches in 10 days, therefore, the demands are not limited to that of a single match, rather the ability to perform and recover over a series of days. Findings of previous studies reporting the neuromuscular and perceptual recovery profiles (Wood et al., 2013) may be limited by match duration (80 min compared to 60 min for international matches), small sample size (*n*=6) and single match design as opposed to that of a tournament, leading to an underestimation of the responses to tournament match-play. Recent reports of match demands have differed (Fox et al., 2013) to previous reports in elite players (Otago, 1983), as such recent rule changes (January 2016), intended to reduce stoppages and increase the speed and intensity of match-play, may have compromised the application of previous literature regarding the demands and responses to netball match-play. Limited information exists regarding the Player Load^{TM} of professional netball (Bailey et al., 2017; Brooks et al., 2020; Young et al., 2016), and no studies have examined the physiological demands and responses to either a single or multiple instances of international-standard netball match-play. A deeper understanding of the movement patterns, coupled with physiological demands, can allow effective training to be prescribed to optimise adaptation and performance, however this information is currently limited (Bailey et al., 2017).

Therefore, the purpose of this study was to examine the physiological, neuromuscular, endocrine and perceptual responses to an international netball tournament as well as the physiological demands of international-standard netball.

4.2 Methods

4.2.1 Design

This observational study examined the response to a netball tournament performed over three consecutive days. Matches commenced at 19:00, 15:00 and 15:00 h on days one, two and three, respectively. Match one and two were performed against lower ranked opponents and match three against higher (World rankings as defined by the international Netball Federation at the time of the tournament). On the morning of each match (~07:30 h), and three-days (approximately 62 h) after the final match (~07:30 h), scores for perceived mood (adapted brief assessment of mood+; BAM+), and samples of whole blood (Creatine Kinase concentration; CK) and saliva (cortisol; C and testosterone: T concentrations) were collected, and countermovement jump testing performed. Players followed nutritional advice provided by the team nutritionist throughout the entire study, including high carbohydrate and protein intake to prepare for and recover optimally from competition. Match intensity was quantified using both internal (heart rate telemetry) and external (accelerometry) load metrics. Following the match, players individually recorded session (sRPE; Foster et al., 2001) and differential ratings of perceived exertion (dRPE; Weston et al., 2015) using a numerically blinded CR100® scale via an Android tablet. These values were recorded during the cool down period, ~15 min after match-play.

4.2.2 Participants

Eleven female players (age: 25 ± 4 years; mass: 71.8 ± 7.8 kg; height: 1.8 ± 0.1 m) from an international netball team were recruited. Players were assigned according to positions to goal-based (*n=2*, goal shooter and goal keeper) and mid-court (*n*=9, goal defence, wing defence, wing attack, centre and goal attack) groups based on court movement restrictions. This study included an international tournament played at the end of the 2016 domestic season. As such, all players had competed weekly in the British Super League (the highest netball league in Britain) and were engaged in full-time training (strength, speed, endurance and netball-specific training sessions four to six times per week) as part of their club's performance preparation programme. Five players used no form of hormonal contraceptive and players were requested to self-monitor menstrual cycles and days of contraceptive consumption; however menstrual cycle information was not used in subsequent analyses. This study was approved by the Swansea University ethics committee (Appendix 2), players were informed of the benefits and risks of the investigation before signing informed consent forms and completing health screening and were made aware that all material would be anonymised. All mandatory health and safety procedures were complied with in completing this research study.

4.2.3 Procedures

Mood

Perceived mood was collected using the BAM+ each morning. As well as an overall mood score, individual values were assessed for perceived muscle soreness, perceived fatigue, perceived sleep quality and perceived motivation to compete. For more detail, please refer to chapter 3.5.

Endocrine response

Salivary hormone responses were assessed each morning, with players instructed to avoid eating food or drinking fluids other than water. For more detail, please refer to chapter 3.3.

Creatine kinase response

Creatine kinase responses were assessed from capillary blood, sampled from the fingertip of the non-dominant hand. For more detail, please refer to chapter 3.4.

Neuromuscular response

Players performed a standardised warm-up before performing countermovement jump testing to assess neuromuscular responses. This warm-up was performed following mood and hormonal measurements, so as not to influence these markers. Peak power output and jump height measures were calculated to assess responses of neuromuscular performance. For more detail, please refer to chapter 3.2.

Netball intensity

External load was quantified by use of accelerometry, with players using the same unit for each match. Data was analysed for Player Load™ for each quarter, excluding breaks between quarters, with data represented as Player Load™ intensity ($AU{\cdot}min^{-1}$). Data was pooled and reported for each position rather than individual players, such that for every match each position would have a single Player Load™ intensity for each quarter. Players wore heart rate monitors throughout matches, with heart rate recorded at beat-to-beat intervals. Data was downloaded and analysed for each quarter, excluding breaks between quarters, and only whilst the player was on-court, using the Polar team system software. Heart rate data was reported for each player and associated to the position which had been played. For more detail, please refer to chapter 3.7.

Ratings of perceived exertion

Following each match, players recorded sRPE and indices of dRPE to assess perceived exertion of match-play. Players must have performed a minimum of one quarter for sRPE and dRPE to be included in subsequent analyses. For more detail, please refer to chapter 3.6.

4.2.4 Statistical analyses

Data are reported as mean difference ± 90% confidence limits unless otherwise stated. Visual inspection of the residual plots revealed evidence of heteroscedasticity; therefore, except for sRPE, dRPE, mood and heart rate, analyses were performed on log-transformed data. Separate mixed linear mixed models (SPSS v.24, Armonk, NY: IBM Corp) were used to examine the effect of tournament match-play on measures of physical exertion (Player Load™, heart rate, sRPE, dRPE) and, thereafter, the effect of playing position on match physical exertion, and, the effects of tournament match-play on the players' neuromuscular, physiological and perceptual responses (peak power output, jump height, creatine kinase concentration, testosterone concentrations, cortisol concentrations). In these models, match (match one, match two, match three), playing position (mid-court, goal-based) and time (day one, day two, day three, three days post), respectively were entered as the fixed effects. In all models, players were included as a random effect with random intercept to account for the dependency that arises from a hierarchical data structure such as ours (i.e., repeated measurements from the same players). From here, a custom-made spreadsheet (Hopkins, 2007) was used to determine magnitude based inferences (Batterham & Hopkins, 2006) for all differences, with inferences based on standardised thresholds for small, moderate, large and very large differences of 0.2, 0.6, 1.2 and 2.0 of the pooled between-subject standard deviations (SD) (Hopkins, Marshall, Batterham, & Hanin, 2009). The chance of the difference being substantial or trivial was interpreted using the following scale: 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely (Batterham & Hopkins, 2006). Uncertainty in all estimates is expressed via 90% confidence limits and the magnitude of effects assessed mechanistically, whereby if the confidence limits overlapped the thresholds for the smallest worthwhile positive and negative effects, effects were deemed unclear (Hopkins et al., 2009).

4.3 Results

4.3.1 Responses to the tournament

Analyses revealed no bias in hormonal markers as a function of contraceptive use, therefore players were assessed regardless of hormonal contraceptive use or non-use. In response to a single netball match, from day one to day two, creatine kinase activity (likely very large; 72.6% ± 26.4%) and fatigue (likely small; 56.2% ± 46.0%) increased, whilst motivation (likely moderate; -19.5% ± 14.3%), overall mood (likely moderate; -27.9% ± 17.6%), sleep quality (possibly moderate: -16.3% ± 15.6%), cortisol concentrations (likely small; -27.4% ± 23.7%), testosterone concentrations (possibly small; -10.8% ± 10.8%) and jump height (possibly small; -4.0% ± 2.5%) decreased, with a possible trivial difference for peak power output and unclear difference for soreness (Table 4.1). Following two netball matches, from day one to day three, creatine kinase activity (most likely very large; 120.8% ± 33.7%), fatigue (possibly large; 146.9% ± 46.0%) and soreness (possibly moderate; 57.7% ± 37.9%) increased, whilst overall mood (likely large; -42.8 ± 17.6%), motivation (likely moderate; -20.6% ± 14.3%), sleep quality (possibly moderate; -30.8% ± 15.6%), testosterone concentrations (possibly small; -8.7% ± 11.0%) and peak power output (possibly small; -3.3% ± 1.7%) decreased, with a possible trivial difference for jump height and most likely trivial difference for cortisol concentrations. Following the performance of two consecutive matches, from day two to three, creatine kinase activity (likely moderate; 27.9% ± 19.5%), fatigue (likely moderate; 58.1% ± 29.5%), soreness (possibly moderate; 49.6% ± 36.0%) and cortisol concentrations (possibly moderate; 43.3% ± 46.8%) increased whilst overall mood (possibly moderate; -20.6% ± 24.4%) and sleep quality (possibly moderate; -17.3% ± 18.6%) decreased, with an unclear difference for testosterone concentrations and motivation, and likely trivial difference for jump height and peak power output. Three days post-tournament overall mood (likely very large; -57.5% ± 20.5%), sleep quality (likely large; -38.7% ± 18.1%), motivation (likely moderate; -24.3% ± 16.6%), peak power output (likely small; -4.2% ± 1.9%), jump height (possibly small; -3.9% ± 2.8%) and testosterone concentrations (possibly small; -10.0% ± 12.7%) decreased, whilst fatigue increased (very likely moderate; 127.2% ± 53.6%) compared to day one, with unclear differences for cortisol concentrations, creatine kinase activity and soreness.

Table 4.1: Mean ± SD cortisol, testosterone and creatine kinase concentrations, jump height, peak power output and perceived well-being across the three days of the tournament and three days post. Magnitude and uncertainty of the difference shown compared to day one.

	Day 1	Day 2	Day 3	3 days post
Cortisol	0.61 (±0.25)	0.47 (±0.23)	0.65 (±0.29)	0.58 (±0.34)
(µg·dl^{-1})		S**	T****	U
Testosterone	116.2 (±33.5)	102.9 (±25.9)	105.4 (±25.3)	95.7 (±27.0)
(pg·ml^{-1})		S*	S*	S*
CK	123.3 (±30.9)	217.2 (±67.4)	283.0 (±121.3)	141.9 (±113.0)
(U·L^{-1})		VL**	VL****	U
PPO	3311 (±440)	3235 (±389)	3194 (±369)	3120 (±294)
(W)		T*	S*	S**
Jump height	0.30 (±0.05)	0.29 (±0.04)	0.29 (±0.04)	0.30 (±0.16)
(m)		S*	T*	S*
BAM+	51.5 (±15.2)	37.2 (±21.7)	29.6 (±20.2)	23.6 (±30.6)
(AU)		M**	L**	VL**
Soreness	31.8 (±23.6)	33.5 (±21.4)	50.2 (±20.5)	41.6 (±25.6)
(AU)		U	M*	U
Fatigue	17.6 (±19.0)	27.5 (±9.1)	43.5 (±15.8)	42.3 (±20.1)
(AU)		L*	L*	M***
Sleep quality	76.5 (±18.0)	64.1 (±24.8)	53.0 (±24.6)	48.1 (±24.9)
(AU)		M*	M*	L**
Motivation	75.5 (±15.5)	60.7 (±25.7)	59.9 (±18.2)	60.0 (±16.5)
(AU)		M**	M**	M**

Magnitude of the difference: U: unclear T: trivial; S: small; M: moderate; L: large; VL: very large. *Uncertainty of the difference*: *: possibly (25-75% (likelihood of the difference being…); **: likely (75-95%); ***: very likely (95-99.5%); ****: most likely (>99.5%). *Abbreviations*: AU: arbitrary unit; SD: standard deviation; CK: creatine kinase concentration; PPO: peak power output; BAM+: adapted brief assessment of mood.

4.3.2 Match demands

Match data are presented in Table 4.2. Mean playing time for players across the three matches was 119.8 min (± 48.5 min; ± SD) and outcomes included two wins and a loss for matches one to three respectively. Greater mean heart rate for match one occurred relative to match two (possibly small; 1.2% ± 0.02%). Likely trivial differences were observed for Player Load^{TM} and unclear differences for sRPE and dRPE variables. For match three versus one for RPE-B (likely small; 20.1% ± 25.4%), RPE-L (possibly small; 18.2% ± 24.5%), RPE-U (possibly small; 18.1% ± 22.4%) and RPE-T (possibly moderate; 23.2% ± 19.8%), greater values were observed. A possible trivial difference existed for Player Load^{TM} and unclear differences for sRPE and mean heart rate. Match three produced greater sRPE (likely small; 21.7% ± 27.4%), RPE-B (possibly moderate; 32.0% ± 26.7%), RPE-L (possibly moderate; 30.8% ± 25.9%), RPE-U (likely small; 30.6% ± 23.7%), RPE-T (possibly moderate; 27.1% ± 20.2%) and mean heart rate (possibly small; 1.1% ± 2.0%) versus match two. There was a possible trivial difference for Player Load^{TM}.

Table 4.2: Mean ± SD heart rate (absolute and percent of age predicted maximum), sRPE, indices of dRPE and Player Load™ intensity for each match averaged across all players (*n=31)*. Magnitude of difference and uncertainty shown between each match.

	Match 1	1 v 2	Match 2	2 v 3	Match 3	3 v 1	Overall
Mean HR (b·min^{-1})	170 (±8.0)	S*	169 (±9.4)	S*	171 (±9.2)	U	170 (±8.7)
Mean HR (% of max)	87.7 (±3.6)	S*	86.7 (±4.4)	S*	88.0 (±4.8)	U	87.5 (±4.2)
sRPE (AU)	63.4 (±20.3)	U	58.6 (±30.2)	S**	73.0 (±29.3)	U	65.3 (±26.9)
RPE-B (AU)	56.2 (±27.1)	U	51.5 (±28.1)	M*	71.5 (±34.7)	S**	60.1 (±30.6)
RPE-L (AU)	57.1 (±21.2)	U	52.1 (±28.4)	M*	70.7 (±30.6)	S*	60.3 (±27.5)
RPE-U (AU)	38.1 (±22.2)	U	35.9 (±25.7)	S**	50.3 (±25.3)	S*	41.7 (±24.5)
RPE-T (AU)	53.3 (±19.5)	U	51.5 (±19.1)	M*	67.7 (±25.9)	M*	57.8 (±22.4)
Player Load™ (AU·min^{-1})	7.9 (±1.9)	T**	8.2 (±2.3)	T*	8.7 (±2.6)	T*	8.2 (±2.2)
Player Load™ (AU)	501 (±124)	T**	527 (±146)	T*	531 (±159)	T*	520 (±137)

Magnitude of the difference: U: unclear; T: trivial; S: small; M: moderate; L: large; VL: very large. *Uncertainty of the difference*: *: possibly (25-75% (likelihood of the difference being…); **: likely (75-95%); ***: very likely (95-99.5%); ****: most likely (>99.5%). *Abbreviations*: AU: arbitrary unit; SD: standard deviation; sRPE: session rating of perceived exertion; dRPE: differential rating of perceived exertion; RPE-B: rating of perceived breathlessness; RPE-L: rating of perceived leg muscle exertion; RPE-U: rating of perceived upper body muscle exertion; RPE-T: rating of perceived cognitive/ technical demand.

4.3.3 Positional demands

Overall, mid-court positions performed at a greater Player Load^{TM} intensity (possibly very large; 85.7% ± 49.6%), mean heart rate (possibly moderate; 3.7% ± 3.8%) (Table 4.3), and reported higher sRPE (possibly moderate; 40.7% ± 40.0%), RPE-B (likely moderate; 55.9% ± 51.9%), RPE-L (possibly large; 79.3% ± 48.1%), RPE-U (possibly moderate; 47.2% ± 54.9%) and RPE-T (possibly moderate; 36.9% ± 36.7%) compared to goal-based positions (Table 4.4).

Table 4.3**:** Mean ± SD heart rate (absolute and percent of age predicted maximum) and Player Load^{TM} for each match and averaged across all matches for mid-court and goal-based positional groups. Magnitude of difference and uncertainty shown between positional groups.

		Match 1	Match 2	Match 3	Mean	Difference between positional groups
Mid-court (n=24)	Mean HR (b·min^{-1})	170 (± 8.9)	172 (± 8.7)	173 (± 7.2)	172 (± 7.9)	M*
	Mean HR (% of max)	88.1 (± 4.0)	88.6 (± 3.4)	89.1 (± 3.1)	88.6 (± 3.4)	M*
Mid-court (n=15)	Player Load^{TM} (AU·min^{-1})	8.9 (± 0.8)	9.4 (± 0.8)	10.0 (± 0.6)	9.4 (± 0.8)	VL*
Goal-based (n=7)	Mean HR (b·min^{-1})	168 (± 4.0)	160 (± 4.5)	162 (± 14.6)	162 (± 7.6)	
	Mean HR (% of max)	86.1 (± 0.5)	82.5 (± 3.8)	83.1 (± 9.9)	83.7 (± 4.9)	
Goal-based (n=6)	Player Load^{TM} (AU·min^{-1})	5.2 (± 0.5)	5.2 (± 1.8)	5.3 (± 2.6)	5.2 (± 1.4)	

Magnitude of the difference: U: unclear T: trivial; S: small; M: moderate; L: large; VL: very large. *Uncertainty of the difference*: *: possibly (25-75% (likelihood of the difference being…); **: likely (75-95%); ***: very likely (95-99.5%); ****: most likely (>99.5%). *Abbreviations*: SD: standard deviation; HR: heart rate; AU: arbitrary unit.

Table 4.4**:** Mean ± SD sRPE and dRPE for each match and averaged across all matches for mid-court and goal-based positional groups. Magnitude of difference and uncertainty shown between positional groups.

		Match 1	Match 2	Match 3	Mean	Difference between positional groups
Mid-court (n=24)	sRPE (AU)	64.9 (± 20.7)	66.3 (± 33.6)	76.0 (± 28.6)	69.5 (± 27.1)	M*
	RPE-B (AU)	60.4 (± 28.8)	57.3 (± 32.3)	74.4 (± 35.2)	64.8 (± 31.9)	M**
	RPE-L (AU)	60.8 (± 22.2)	59.4 (± 30.7)	76.3 (± 28.9)	66.2 (± 27.4)	L*
	RPE-U (AU)	42.0 (± 23.3)	42.1 (± 28.9)	53.9 (± 25.7)	46.5 (± 25.5)	M*
	RPE-T (AU)	59.8 (± 15.8)	56.4 (± 17.2)	68.2 (± 27.2)	62.0 (± 20.9)	M*
Goal-based (n=7)	sRPE (AU)	57.5 (± 24.7)	40.7 (± 6.5)	59.5 (± 40.3)	50.9 (± 21.9)	
	RPE-B (AU)	39.5 (± 10.6)	38.0 (± 5.3)	58.0 (± 41.0)	44.1 (± 20.0)	
	RPE-L (AU)	42.5 (± 9.2)	35.0 (± 13.7)	45.5 (± 33.2)	40.1 (± 16.9)	
	RPE-U (AU)	22.5 (± 3.5)	21.3 (± 4.7)	34.0 (± 21.2)	25.3 (± 11.0)	
	RPE-T (AU)	27.5 (± 0.7)	39.3 (± 21.0)	65.5 (± 27.6)	43.3 (± 23.0)	

Magnitude of the difference: U: unclear T: trivial; S: small; M: moderate; L: large; VL: very large. *Uncertainty of the difference*: *: possibly (25-75% (likelihood of the difference being…); **: likely (75-95%); ***: very likely (95-99.5%); ****: most likely (>99.5%). *Abbreviations*: AU: arbitrary unit; SD: standard deviation; sRPE: session rating of perceived exertion; dRPE: differential rating of perceived exertion; RPE-B: rating of perceived breathlessness; RPE-L: rating of perceived leg-muscle exertion; RPE-U: rating of perceived upper-body muscle exertion; RPE-T: rating of perceived cognitive/ technical demand.

4.4 Discussion

The aims of this study were to characterise the physiological, neuromuscular, endocrine and perceptual responses to an international tournament and to identify the position-specific demands of international netball. The primary findings were that the performance of both a single, and multiple matches resulted in a varied recovery profile, with greater perturbations in perceived well-being and physiological function following consecutive matches, and fatigue evident up to three days post-tournament. Additionally, mid-court positions performed at greater internal intensity and accumulated greater Player Load^{TM} compared to goal-based positions.

4.4.1 Creatine kinase response

Across the tournament, creatine kinase concentration, reported to be indicative of skeletal muscle damage (Cunniffe et al., 2010), accumulated before returning to baseline thereafter. Whilst there are no reports in netball, investigations in other team sports have reported peak values occurring 24 h post-match, remaining elevated for females for up to 69 h (Andersson et al., 2008). Three days post-tournament, creatine kinase concentration and perceived soreness had returned to baseline, however neuromuscular performance and testosterone concentrations remained suppressed. This may suggest that neuromuscular performance is impacted by testosterone concentration rather than muscle damage, that creatine kinase concentration is not sensitive to detect changes in muscle damage, or that various markers of fatigue collectively interact.

4.4.2 Responses to a single match

Following the performance of a single match, testosterone concentrations were reduced, and remained reduced until three days post-tournament, whilst cortisol concentrations decreased following the first match, then returned and remained at baseline following the second match. Testosterone concentration is associated with enhanced neuromuscular performance (Cook et al., 2014), decision making, behaviour, contractile signalling (Crewther et al., 2011), motivation (Cook et al., 2018) and performance (Crewther et al., 2013). A reduction, as seen in the present study, may have negatively affected one or more of these reported associations, with a resultant impact upon performance. The recovery of cortisol concentrations following two matches may suggest a varied anticipatory response with a greater anticipatory rise prior to the first and final match (higher ranked opponent for the final match). However, alternatively the late commencement (19:00 h compared to 15:00 h) of match one may have negatively affected post-match processes and recovery. Menstrual phase and hormonal contraceptive use were not controlled for in the present study, however no difference was found in basal testosterone concentrations between hormonal contraceptive users and non-users. Additionally, recent reports highlight only a difference in magnitude of testosterone concentration response to a stimulus, rather than the response itself, and no impact upon performance with hormonal contraceptive use (Cook et al., 2018).

4.4.3 Playing demands

This is the first study to characterise playing demands during an international tournament reporting Player Load^{TM}, perceived effort and heart rate. Internal load and Player Load^{TM} was greater for mid-court compared to goal-based positions (Table 4.3 & 18). Greater Player Load^{TM} for mid-court positions has been reported in professional netball (Fox et al., 2013; Young et al., 2016), and is likely due to court movement restrictions resulting in a higher active time (Fox et al., 2013), time spent in high-intensity zones (Young et al., 2016) and type of on and off-ball locomotor and non-locomotor activity (Bailey et al., 2017). Collectively, this suggests that players should not only be conditioned for the position specific movement demands, but also the different physiological and type of effort (as indicated by dRPE) experienced during international match-play. Both sRPE and dRPE can be used by conditioning staff to guide the individualisation of the training stimulus to the positional demands.

4.4.4 Responses to consecutive matches

As markers of fatigue were further reduced following a greater number of consecutive matches, training should aim to replicate these demands to minimise this disturbance, especially when considering that some international tournaments are over twice as long as in the present study. Unlike perceptual and endocrine responses, neuromuscular performance was not further reduced following consecutive matches. Perceptual markers could therefore be considered as a simple monitoring tool to identify sufficient training load to replicate the fatiguing consequences associated with international netball. It should be noted however that players performed different proportions of each match. For example, some played a high proportion of the first match, followed by a small proportion of the second, whilst others performed the opposite, which may influence findings over a longer tournament. Sleep quality was negatively affected following a single, and to a greater extent following consecutive matches, a consideration for coaching and support staff, as sleep has been reported to be vital for recovery (Halson, 2008). Three days post-tournament, when players commenced training, perceived well-being, sleep quality, testosterone concentration and neuromuscular function were reduced, suggesting longer recovery is required than anticipated by conditioning staff.

4.5 Conclusion

This is the first study to report the physiological demands of and responses to an international netball tournament, providing vital information for international coaches and conditioning coaches. Markers of fatigue increased following the performance of a single match, whilst markers of muscle damage and perceived well-being were further affected following consecutive matches. A varied recovery profile was apparent as recovery to baseline of all variables examined did not occur 62 h post-tournament. Mid-court positions performed higher internal intensity and accumulated greater Player Load^{TM} compared to goal-based positions, an important consideration for conditioning staff in order to individualise training to positional specific demands.

4.6 Practical applications

Findings highlight the individual activity and movement demands of the different positional groups, which taken together with previous literature, suggests training should be individualised around the demands, physiological and perceptual responses experienced during competitive match-play. As neuromuscular performance, fatigue and readiness to perform are negatively affected following a single match, with greater fatigue following a greater number of matches performed, recovery strategies should be employed to target the nature of fatigue experienced by players across a tournament. Indeed, as markers persisted following the tournament, strategies should also be employed in this period to assist recovery processes. As the different markers of fatigue have varied recovery profiles, perceived well-being, along with objective markers should be considered by the coaching team to decide upon the duration of recovery in addition to the subsequent training volume and intensity of training to be performed.

Chapter 5 Acute physiological and perceptual responses to a netball-specific training session in professional female netball players

5.1 Introduction

Netball is an intermittent team-sport with movement restrictions that yield unique activity and physiological demands that are position-specific (Birdsey et al., 2019; Young et al., 2016). Players regularly perform a variety of on-court training sessions, including game-based (aimed at replicating match-play movement demands, technical skills and decision making under pressure) and skills-based (aimed at developing technical skills including passing, catching, shooting and movement patterns) sessions in addition to on and off-court conditioning (Chandler et al., 2014), four to eight times per week. Additionally, at specific points in the season, competitive teams may play two matches per week, whilst performing regular training involving a mixture of components in order to maintain or improve specific fitness, skills and to refine match tactics (Young et al., 2016). In order to adapt to such stimuli, players must be able to perform to a high standard, and recover for subsequent training or competition (Bishop et al., 2008). However, whilst the Player Load™ demand of elite netball match-play has been reported (Birdsey et al., 2019; Young et al., 2016), in addition to internal load and Player Load™ of training (Chandler et al., 2014), limited data has profiled the fatigue and/ or recovery associated with netball-specific training.

While netball-specific training responses are absent, the acute post-exercise responses to training in other sports have been extensively reported following isolated strength (McCaulley et al., 2009), endurance (Anderson et al., 2016) and soccer (Sparkes et al., 2018) training, with a single observation following speed training (Johnston et al., 2015); all of which have application to the demands of netball players. However, as players perform training to improve aspects related specifically to match performance, sport-specific training sessions are key to fully understand the responses of netball players. Following soccer team-sport training, immediate increases in testosterone and decreases in cortisol concentrations have been observed in addition to a bi-modal recovery pattern of neuromuscular performance, with an initial decrease immediately post, partial recovery at two, and further impairment at 24 h post (Sparkes et al., 2018). However, in female players, a delayed endocrine response has been reported of 24 h, with responses evident up to 72 h post-training (Mascarin et al., 2018), whilst following field hockey training, exercise intensity influences the endocrine response (Crewther et al., 2015). A greater understanding of the acute responses to, and recovery profile from on-court netball training may assist coaches and conditioning coaches to effectively plan content of individual sessions, as well as the positioning of training within the week.

At present, there are limited reports upon the acute responses to team-sport training in females, whilst no data exists in response to netball-specific training. Knowledge of both the training stimulus, as well as the recovery response are necessary to prevent cumulative fatigue (Doma & Deakin, 2013) and allow recovery for adaptation. It is therefore imperative that coaching and conditioning staff have an understanding of the acute responses to specific training sessions to assist with effectively planning and optimising training. The purpose of this study was to characterise the neuromuscular, physiological, biochemical, endocrine and perceptual responses over a 24 h period to a netball specific training session performed by professional female netball players.

5.2 Methods

5.2.1 Participants

Fourteen female netball players (age: 23 ± 4 years, mass: 73.2 ± 8.0 kg, height: 1.8 ± 0.1 m) from a British domestic Superleague team (representing the highest tier of professional netball in the UK) were recruited for this study that was conducted during the 2016 pre-season period (after a two-month period requiring strength, speed, endurance and netball-specific training sessions for four to six times a week). As hormonal contraceptive use and menstrual cycle phase may influence the magnitude of neuromuscular and endocrine response rather than direction (Cook, Fourie, & Crewther, 2020; Romero-Parra, Cupeiro, et al., 2021; Romero-Parra, Rael, et al., 2021) no information was gathered regarding hormonal contraceptive use or menstrual cycle phase, and the variance in basal testosterone concentrations possibly reflects either, or both, of these factors. This study was approved by the Swansea University ethics committee (Appendix 3) and players were informed of the benefits and risks of the investigation prior to signing an approved informed consent document and health screening questionnaire and were made aware that all material would be anonymised. All mandatory health and safety procedures were complied with in completing this research study.

5.2.2 Design

This observational study was conducted over a 24 h period that followed an on-court netball-specific training session. Immediately prior to the training session baseline (Pre) samples of whole blood (creatine kinase concentrations; CK) and saliva (cortisol; C, and testosterone: T concentrations) were collected, countermovement jump (peak power output; PPO, PPO relative to mass; PPOrel, jump height; JH) testing was performed (preceded by a standardised warm-up), and perceived mood (adapted brief assessment of mood questionnaire: BAM+; Shearer et al., 2017) was recorded. The above measures were repeated two (+2h) and 24 h (+24h) post-training. Immediately post-training (+0h), the above measures were conducted, however countermovement jump testing was performed within five minutes of the end of the training session. Session ratings of perceived exertion (sRPE; Foster et al., 2001) together with differential rating of perceived exertion (dRPE; Weston et al., 2015) were taken instead of the BAM+ immediately following the countermovement jump testing at +0h. Exercise intensity was quantified by external (accelerometry) and internal (heart rate; HR, sRPE and dRPE) load metrics.

All players were prescribed a light conditioning training session the day before testing, with the testing day being the second training session of the week. In preparation for training, players were instructed to eat and drink as usual (i.e. a high carbohydrate meal to support carbohydrate availability for the training session) and consumed a standardised meal prescribed by the team nutritionist to support recovery (i.e. high in carbohydrates to replenish carbohydrate stores, in protein to support muscle protein resynthesis, and with fruit and vegetables as part of a balanced diet) immediately following the measurements collected post-session at +0h. Thereafter, players were instructed not to perform any further structured exercise following testing. The next day, 24 h post-training, players reported for follow-up testing (i.e., +24h) having prepared nutritionally as if they were attending another training session.

5.2.3 Netball-training session

The training session performed by players was 90 minutes in duration and took place entirely on-court, commencing at 16:30 h. This was a routinely performed training session by the team with the aim of developing or maintaining technical skills, movement patterns, physical conditioning, match tactics and decision making under pressure, whilst replicating the intensity experienced in match-play. Players performed a warm-up of approximately 20 minutes consisting of a team exercise involving short intermittent sprints, dynamic stretching, ball skills and netball-specific attacking and defending movements. Players then performed an exercise involving defenders aiming to intercept passes from the players in possession with the aim of developing decision making and technical skills under pressure. The training session progressed to the performance of scenario-specific match-play with three games lasting five to eight minutes interspersed with four to 11 minutes of recovery. This was performed by all players, aimed to replicate match-play intensity, involved specific scenarios aiming to develop key areas of netball performance and had been regularly performed by players.

5.2.4 Procedures

Mood

Perceived mood was collected using the BAM+ prior to the training session (at +0h), two hours post (+2h) and 24 h post (+24h). As well as an overall mood score, individual values were assessed for perceived muscle soreness and perceived fatigue. For more detail, please refer to chapter 3.5.

Endocrine response

Salivary hormone responses were assessed at each time-point, with players instructed to avoid eating food or drinking fluids other than water for 60 minutes prior to sampling to avoid contamination of samples. For more detail, please refer to chapter 3.3.

Creatine kinase response

Creatine kinase responses were assessed from capillary blood, sampled from the fingertip of the non-dominant hand. For more detail, please refer to chapter 3.4

Neuromuscular response

Players performed a standardised warm-up before performing countermovement jump testing to assess neuromuscular responses, apart from immediately post-exercise when practice jumps only were performed. Peak power output and jump height measures were calculated to assess responses of neuromuscular performance. For more detail, please refer to chapter 3.2.

Netball intensity

External load was quantified by use of accelerometry and players wore a heart rate monitor throughout to measure heart rate responses. Data were analysed for Player Load^{TM} (AU), Player Load^{TM} intensity (AU$\cdot$min^{-1}) and mean heart rate for the entire session, the entire session excluding breaks between drills (e.g., active periods only, excluding coaching interactions and recovery periods), and for the match-play portion excluding breaks between games. For more detail, please refer to chapter 3.7.

Ratings of perceived exertion

Immediately following the training session players recorded sRPE and indices of dRPE to assess perceived exertion of the training session. For more detail, please refer to chapter 3.6.

5.2.5 Statistical analyses

Data were analysed via a mixed effects linear model (SPSS v.21, Armonk, NY: IBM Corp.). Fixed effects in the model were time (Pre, +0h, +2h, +24h), with a random effect for player to account for the repeated measures nature of the study design. Uncertainty in our estimates is presented as 95% confidence intervals. Effects are presented as simple effect sizes (mean differences in raw units), with standard effect sizes (mean difference/pooled standard deviation; SD) and percentage change scores presented but not interpreted. We elected to do this as simple effect sizes are independent of variance and scaled in the original units of analysis (Baguley, 2009), which maximises the practical context of findings (Pek & Flora, 2018). Our interpretation of between-time point differences in all dependent variables was based on the width of the respective 95% confidence intervals for the mean difference, with no overlap of the confidence intervals being a clear difference.

5.3 Results

5.3.1 Endocrine responses

Descriptive training data are presented in Table 5.1. When compared to pre, there was a clear increase in testosterone concentrations at +0h, followed by a clear decrease at +2h, but no difference at +24h (Figure 5.1A). The standardised effect sizes (% changes) for the comparisons were 1.19 (+42%), -1.30 (-31%) and -0.58 (-16%). For cortisol concentrations, there was a clear increase at +0h but no difference at +2h or +24h (Figure 5.1B). The standardised effect sizes (% changes) for the comparisons were 0.95 (+70%), -1.24 (-40%) and -0.39 (-15%). For creatine kinase concentration, there was a clear increase at all time points (Figure 5.1C). The standardised effect sizes (% changes) for the comparisons were 1.64 (+31%), 1.87 (+38%) and 0.98 (+17%).

Table 5.1**:** Mean (± SD) of average heart rate, maximum heart rate and Player Load^{TM} of the entire training session, the active and the match-play portions, and sRPE and dRPE for the entire netball training session.

	Mean (± SD)
Mean HR (b·min^{-1})	147 (± 13)
Mean active HR (b·min^{-1})	167 (± 12)
Mean match-play HR (b·min^{-1})	171 (± 9)
Maximum HR (b·min^{-1})	192 (± 10)
Maximum match-play HR (b·min^{-1})	189 (± 9)
Total Player Load^{TM} (AU)	513 (± 81)
Active Player Load^{TM} (AU)	482 (± 78)
Match-play Player Load^{TM} (AU)	173 (± 35)
Total Player Load^{TM} intensity (AU·min^{-1})	5.6 (± 0.9)
Active Player Load^{TM} intensity (AU·min^{-1})	9.0 (± 1.5)
Match-play Player Load^{TM} intensity (AU·min^{-1})	8.1 (± 1.7)
sRPE (AU)	74 (± 22)
RPE-B (AU)	68 (± 24)
RPE-L (AU)	62 (± 27)
RPE-U (AU)	37 (± 21)
RPE-T (AU)	63 (± 25)

Abbreviations: SD: standard deviation; HR: heart rate; AU: arbitrary unit; sRPE: session rating of perceived exertion; dRPE: differential rating of perceived exertion; RPE-B: rating of perceived breathlessness; RPE-L: rating of perceived leg-muscle exertion; RPE-U: rating of perceived upper-body muscle exertion; RPE-T: rating of perceived cognitive/ technical demand.

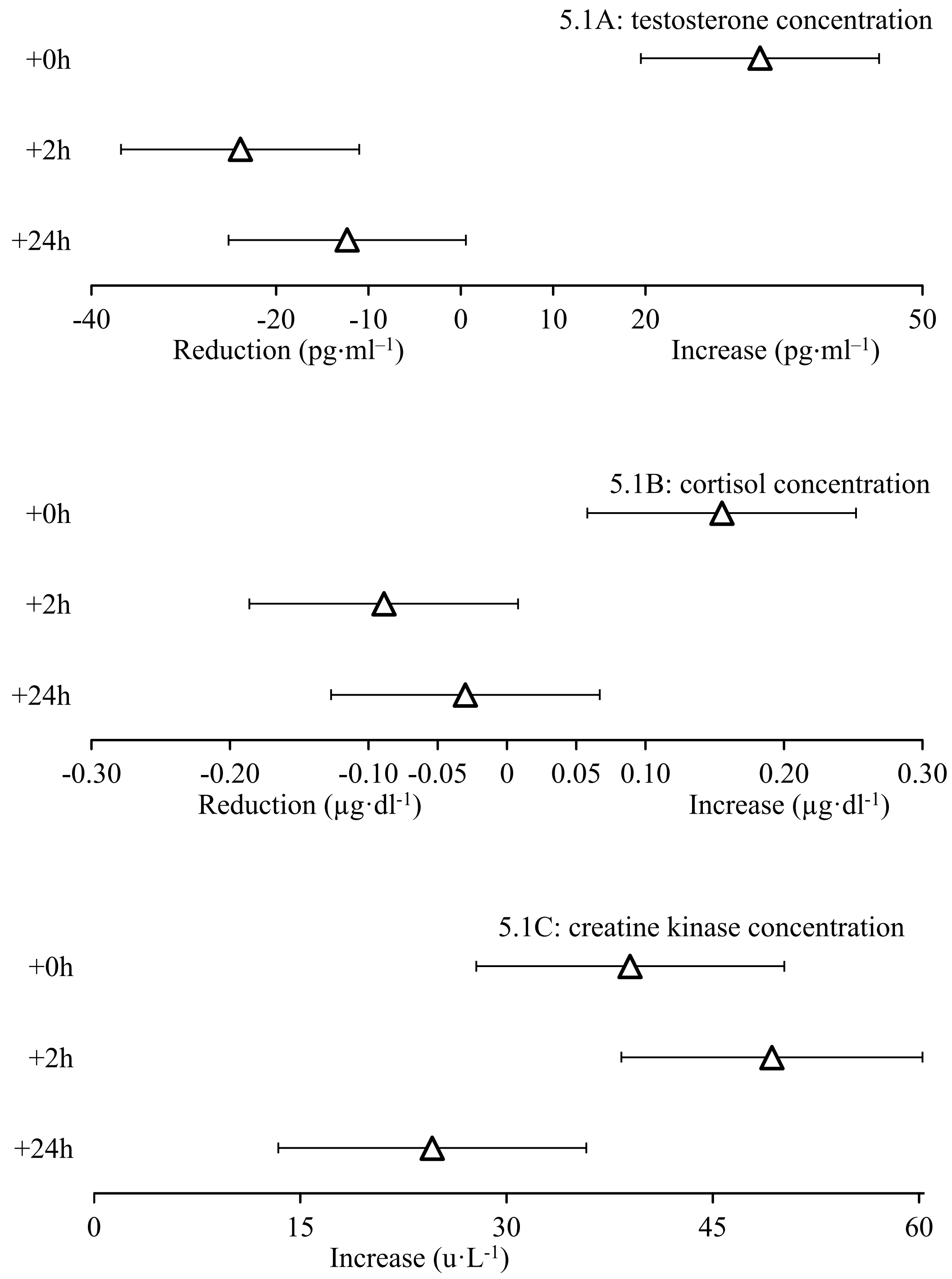

Figure 5.1A-C: Effect statistics (mean difference and 95% confidence intervals) for the comparison of testosterone (5.1A), cortisol (5.1B) and creatine kinase (5.1C) concentrations immediately (+0h), two (+2h) and 24 (+24h) hours following the performance of the training session compared to baseline. Zero (0) on the axis represents no difference between that time-point and baseline.

5.3.2 Neuromuscular responses

When compared to Pre, there was a clear increase in peak power output at +0h but no difference at +2h and +24h (Figure 5.2A). The standardised effect sizes (% changes) for the comparisons were 0.47 (+5%), 0.07 (1%) and -0.27 (-3%). For peak power output relative to mass, there was a clear increase at +0h, no difference at +2h followed by a clear decrease at +24h (Figure 5.2B). The standardised effect sizes (% changes) for the comparisons were 0.50 (+5%), -0.02 (0%) and -0.34 (-3%). For jump height, there was no clear difference at +0h or at +2h, but a clear decrease at +24h (Figure 5.2C). The standardised effect sizes (% changes) for the comparisons were 0.25 (+4%), -0.07 (-1%) and -0.39 (-6%).

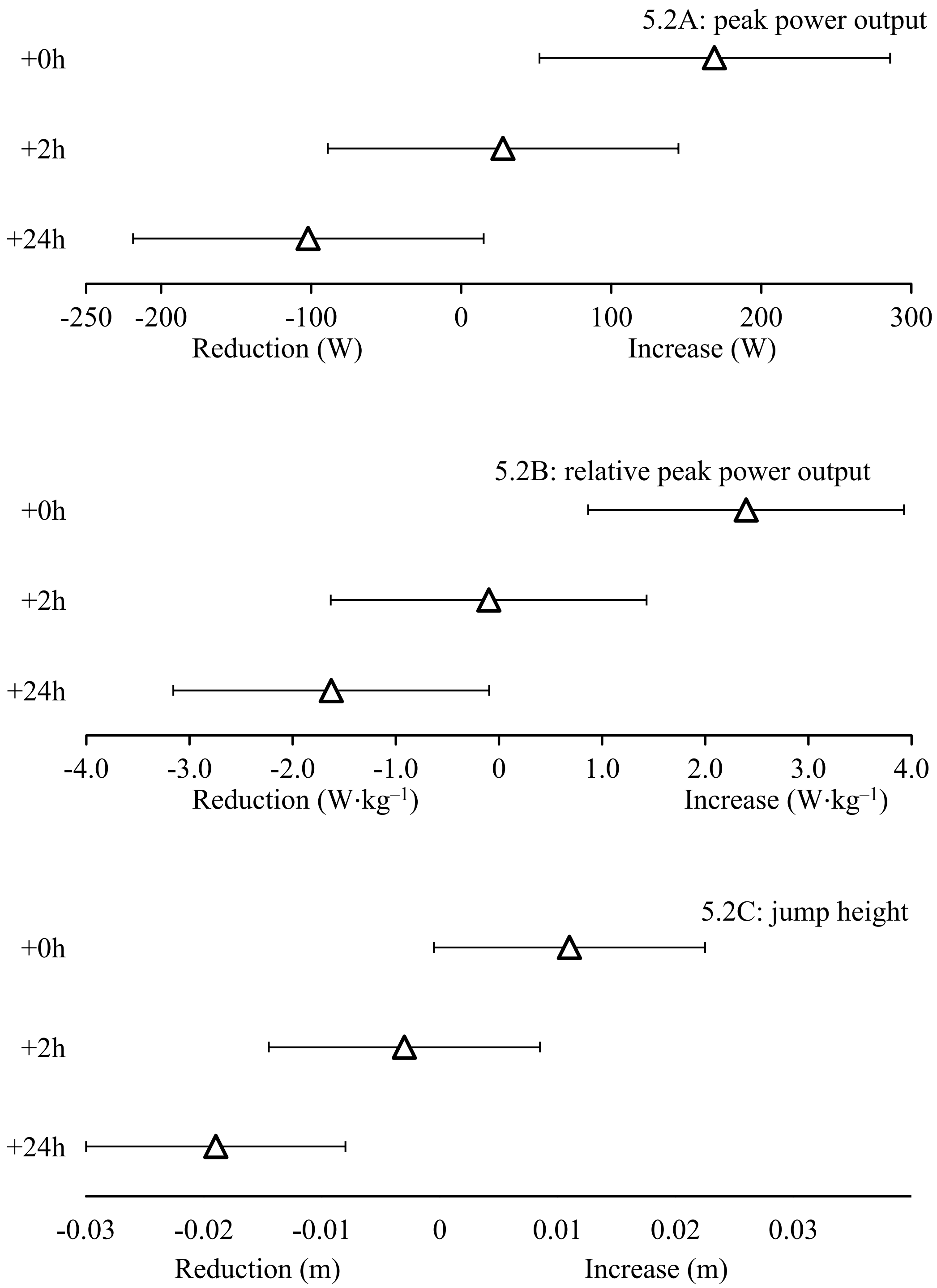

Figure 5.2A-C: Effect statistics (mean difference and 95% confidence intervals) for the comparison of peak power output (5.2A), peak power output relative to mass (5.2B) and jump height (5.2C) immediately (+0h), two (+2h) and 24 (+24h) hours following the performance of the training session compared to baseline. Zero (0) on the axis represents no difference between that time-point and baseline.

5.3.3 Mood responses

When compared to Pre, there was a clear decrease in overall mood score at +2h but no difference at +24h (Figure 5.3A). The standardised effect sizes (changes in raw units) for the comparisons were -0.84 (-20 AU) and 0.01 (+0 AU). For fatigue, there was a clear increase at +2h, but no difference at +24h (Figure 5.3B). The standardised effect sizes (changes in raw units) for the comparisons were 1.01 (+15 AU) and 0.13 (+2 AU). For soreness, there was a clear increase at +2h, but no difference at +24h (Figure 5.3C). The standardised effect sizes (changes in raw units) for the comparisons were 0.80 (+14 AU) and 0.06 (+1 AU).

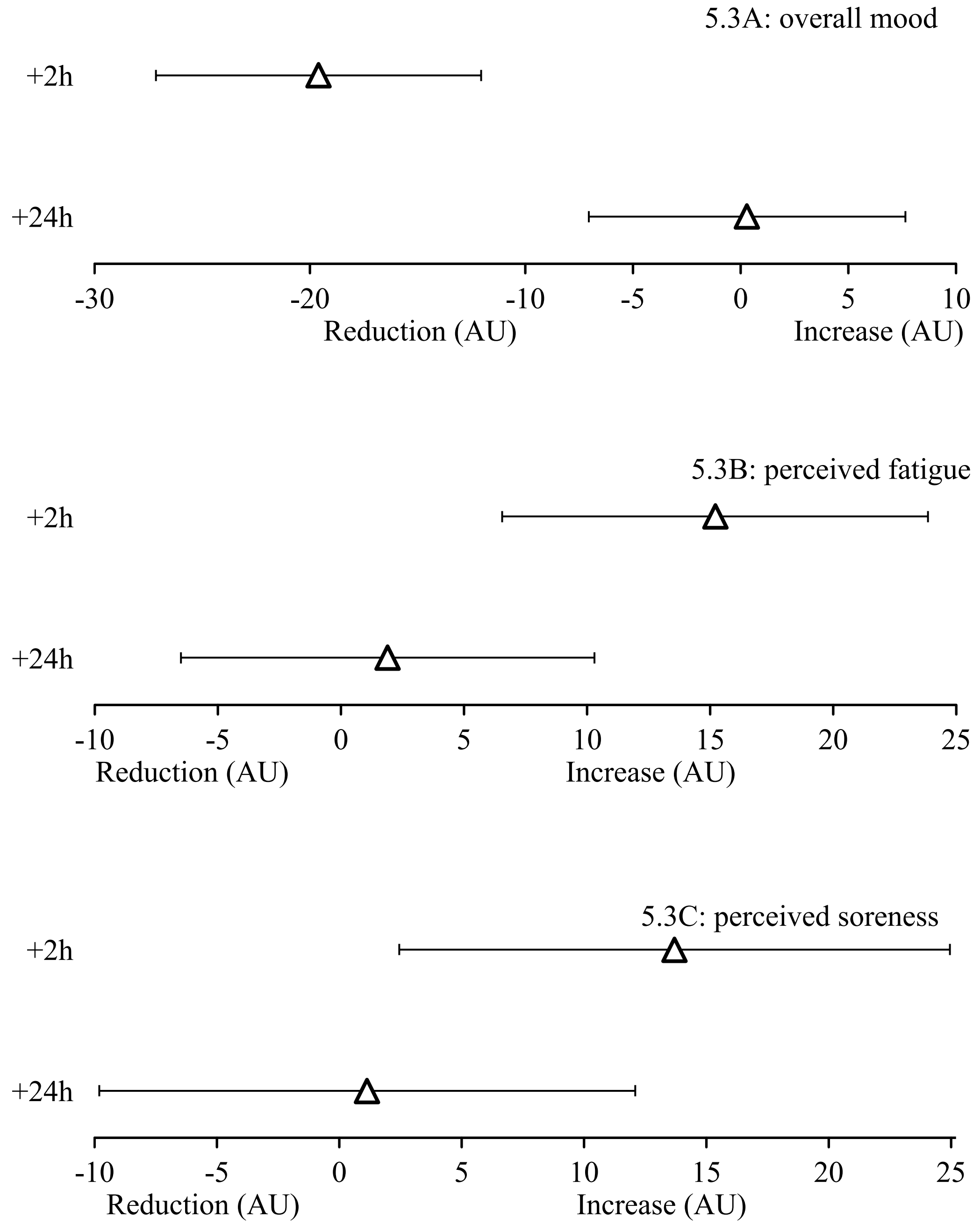

Figure 5.3A-C: Effect statistics (mean difference and 95% confidence intervals) for the comparison of overall mood (5.2A), fatigue (5.2B) and soreness (5.2C) immediately (+0h), two (+2h) and 24 (+24h) hours following the performance of the training session compared to baseline. Zero (0) on the axis represents no difference between that time-point and baseline.

5.4 Discussion

The aim of this study was to characterise the neuromuscular, physiological, biochemical, endocrine and perceptual responses (over 24 h) to a regularly performed netball-specific training session in professional female players. The primary findings highlighted that responses over 24 h differed according to the marker being examined. Markers were elevated at two hours post-exercise and a return to baseline was not achieved 24 h post-training for all variables examined. Accordingly, these data indicate that any training performed in the 24 h following a netball training session should be modulated to account for the residual effects of the previous training bout; findings which will likely be of interest to staff involved in the planning and periodisation of training for female netball players.

5.4.1 Immediate post-exercise responses

Immediately post-training, neuromuscular performance was increased in addition to higher testosterone and cortisol concentrations when compared to baseline. Hormonal responses to exercise can be influenced by training intensity, whilst the increase observed in the present study is similar to that observed after high intensity hockey training (Crewther et al., 2015), and following elite netball competitive match-play (O'Donnell, Bird, Jacobson, & Driller, 2018). This finding could be attributed to an increase in competitiveness and dominance behaviours (Edwards & Kurlander, 2010; O'Donnell et al., 2018), as well as energy provision and muscle tissue repair following exercise-induced muscle damage (Viru & Viru, 2004). Mean basal testosterone concentration in the present study was high (mean ± SD; 77.4 ± 23.0 $pg \cdot ml^{-1}$) in relation to a non-elite female population (Cook et al., 2012), but were in line with reports in elite female athletes (Cook et al., 2012, 2018). Additionally, as no control was in place for menstrual cycle phase or hormonal contraceptive use, exercise responses and recovery patterns may be influenced according to these factors (Crewther et al., 2015). Exercise-related increases in creatine kinase concentrations, proposed to be indicative of skeletal muscle damage (Cunniffe et al., 2010), have been reported to be associated with impaired neuromuscular function (Andersson et al., 2008). However, the findings of the present study show elevated neuromuscular performance despite an increase in creatine kinase concentration, similar to reports following Women's rugby sevens (Clarke et al., 2015); questioning the relationship between creatine kinase response and neuromuscular performance.

Following an exercise stimulus mechanisms of both fatigue and muscle potentiation coexist, with the resulting performance benefit dependent upon the balance of these two factors (Kilduff, Finn, Baker, Cook, & West, 2013). The increase in testosterone concentration at +0h observed in the present study may have positively influenced behaviour, contractile signalling and performance (Crewther et al., 2011), and subsequently positively influenced neuromuscular function to a greater extent than impairment through muscle damage or fatigue. Additionally, muscle temperature may have increased following the training session, along with induction of post-activation potentiation due to dynamic movements (Turner, Bellhouse, Kilduff, & Russell, 2015), greater than achieved following the standardised warm-up.

5.4.2 Two hours post-exercise responses

Two hours following the training session, cortisol concentrations and neuromuscular performance returned to baseline, whilst testosterone concentrations reduced below baseline values. Although reports highlight a varied acute testosterone and cortisol response following a variety of sport and exercise stimuli (Anderson et al., 2016; Johnston et al., 2015, 2016; McCaulley et al., 2009), the decrease in testosterone concentrations in the present study may be associated with circadian rhythm changes as previously reported (Kokalas et al., 2004). Cortisol concentrations could therefore be considered elevated in relation to the expected circadian rhythm response, which could highlight an increased catabolic state at this time-point. Additionally, creatine kinase concentration was elevated, and mood state negatively affected compared with baseline. Findings suggest, that if multiple training sessions are to be performed on the same day, as is often performed by team-sport players, including netball, then more than two hours should be provided to allow sufficient recovery of perceptual markers for subsequent performance.

5.4.3 24 h post-exercise responses

Whilst most variables recovered to baseline 24 h post-training, creatine kinase concentration remained elevated and markers of neuromuscular performance remained suppressed. Perceptual markers of fatigue and mood were not disrupted from performing this training session, with the same finding following soccer training (Sparkes et al., 2018). Reports following competitive matches report BAM+ to be effective for monitoring readiness to train and recovery and reduced following a single netball match in the study in chapter four. Therefore, findings suggest that players may have been conditioned to this regularly performed training session, resulting in no negative effect on perceived mood or perceived fatigue.

A similar decrease in neuromuscular performance at +24h has been reported following the performance of a handball-specific training session by elite, female players (Ronglan et al., 2006) and following soccer training in professional male players (Sparkes et al., 2018). Decreased neuromuscular function could be attributed to impaired excitation-contraction coupling resulting from low-frequency fatigue (McLellan & Lovell, 2012), with exercise-induced muscle damage and damage of type two muscle fibres (Byrne et al., 2004) contributing to the decrease. Performing subsequent training in a fatigued state can impair training performance (Highton et al., 2009), adaptation to training (Jones et al., 2016) and can result in greater fatigue (Doma & Deakin, 2013). Therefore coaches could take advantage of the recovered neuromuscular system within two hours post-training to perform high intensity, explosive movements, rather than the following day when this type of training may be impaired, with similar observations reported (Johnston et al., 2015; Sparkes et al., 2018).

5.4.4 Intensity of the netball-training session

Whilst reports of elite level competitive match-play are limited, the internal demands and Player Load^{TM} of the present training session were similar to that of match-play intensity observed in the study in chapter four. Across an international netball tournament, heart rate (mean ± SD: 170 ± 8.7 $b \cdot min^{-1}$), Player Load^{TM} (8.2 ± 2.2 $AU \cdot min^{-1}$) along with sRPE and dRPE were similar to that of the present study. Currently only two studies have described the internal load or Player Load^{TM} of netball training (Chandler et al., 2014; Young et al., 2016), with both studies reporting similar Player Load^{TM} between training session and competitive match-play. Collectively, findings of the present study suggest that the training session employed successfully replicated the movement demands and internal loads of international netball match-play (chapter four), with a similar relative intensity (training intensity compared with match-play intensity) to that reported across different standards of players (Chandler et al., 2014; Young et al., 2016).

5.5 Conclusion

This is the first study to report the neuromuscular, physiological, biochemical, endocrine and perceptual responses to a netball-specific training session performed by professional female netball players. Primary findings indicate that the training session successfully replicated match-play intensity, responses over the 24 h period varied according to the variable being examined, disturbances were evident at two hours post and that full recovery of all variables was not achieved within 24 h.

5.6 Practical applications

Findings highlight that the completion of a regularly performed training session, which replicated match-play intensity, resulted in impaired neuromuscular performance the next day, when players would typically perform a subsequent training session. This highlights that recovery, even when regularly performed training is completed, takes longer than coaches may expect, and that the residual effects of the prior training bout should be considered when planning subsequent training within 24 h. As perceptual responses were not different at +24h, despite impaired neuromuscular performance, this highlights the importance of monitoring neuromuscular performance in the days and hours following training.

Chapter 6 The neuromuscular, physiological, endocrine and perceptual responses to different training session orders in international female netball players

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6.1 Introduction

Netball in an intermittent team-sport with court movement restrictions yielding unique position-specific movement and playing demands (Young et al., 2016). This results in an intense, intermittent activity profile involving very short explosive movements, interspersed with short recovery periods (Fox et al., 2013). Mid-court positions perform at higher internal intensity and accumulate greater Player Load^{TM} than goal-based positions (Birdsey et al., 2019), whilst each position performs a unique set of locomotor and non-locomotor activities which contributes to the total load (Bailey et al., 2017). In order to prepare for these demands, players often perform multiple training sessions within a day (Simpson et al., 2020). This includes technical on-court training, on and off-court conditioning, in addition to strength training (Chandler et al., 2014; Simpson et al., 2020) in order to develop physical, technical and tactical aspects of match-play. As players perform training to improve unique aspects related to netball performance (Young et al., 2016) the applicability of findings from other team-sports may be limited. It is therefore imperative that responses to netball-specific training are fully understood, however, this is currently lacking.

In an attempt to overload specific variables that optimise physical performance preparation, professional team-sport athletes often perform multiple training sessions per day (Johnston et al., 2017; Tønnessen et al., 2015), including technical, tactical, speed, aerobic and strength-focused activities. Whilst some studies report positive adaptations to the performance of multiple training sessions, or training aims, in a concurrent training paradigm (García-Pallarés et al., 2009; Häkkinen et al., 2003), a reduced training effect (Jones et al., 2016; Sabag et al., 2018), proposed due to a failure to maintain training performance (Leveritt et al., 1999) and compromised molecular signalling (Baar, 2006; Hawley, 2009), may also occur. The physiological responses to, and fatigue experienced after, a training session is specific to the intensity (Seiler et al., 2007), volume (Lepers et al., 2002) and mode (Jones et al., 2017; Sparkes et al., 2020) of activities performed and can persist for several days (Anderson et al., 2016; Brownstein et al., 2017). Therefore, the ordering of training sessions within a concurrent training paradigm are important considerations when determining subsequent training performance (Johnston et al., 2017; Sparkes et al., 2020) and the ensuing adaptations (Jones et al., 2016; Sabag et al., 2018).

It has been demonstrated that prior exercise can influence subsequent physiological and neuromuscular function (Cook et al., 2014; Mcgowan et al., 2017; Russell et al., 2016), as well as performance (Johnston et al., 2017) via a range of mechanisms. Following morning swimming and resistance exercise, higher afternoon core temperature has been reported (six hours later), with an associated improvement in performance in male and female swimmers (Mcgowan et al., 2017); likely due to increased muscle temperatures (Mohr et al., 2004) and concomitant positive effects on neuromuscular function (West, Cook, Beaven, et al., 2014). Morning exercise can also attenuate the circadian rhythm associated decline in testosterone concentrations (Cook et al., 2014; Russell et al., 2016) and lead to an improvement in afternoon neuromuscular performance (Cook et al., 2014; Ekstrand, Battaglini, McMurray, & Shields, 2013; Johnston et al., 2017; Russell et al., 2016). Whilst this has typically been over a longer time period (e.g. 5-6 h between consecutive training sessions), speed training performance may be enhanced when preceded by strength training two hours prior (Johnston et al., 2017). When repeated, this improvement in training performance may lead to a greater adaptive response and improved competitive performance (García-Pallarés et al., 2009). However, as the performance of a prior training stimulus may also impair subsequent performance (Jones et al., 2017; Palmer & Sleivert, 2001) and strength development (Jones et al., 2016), it is clear that the understanding of these responses, as well as the organisation of training within a concurrent training paradigm, is important when targeting specific physiological and neuromuscular adaptations that seek to maximise training induced adaptation (García-Pallarés et al., 2009).

Netball has unique movement and playing demands, and as physiological responses are influenced by many factors (Lepers et al., 2002; Seiler et al., 2007; Sparkes et al., 2020), it is vital that responses to netball-specific training are fully understood. In preparing for the demands of international netball, it is commonplace to perform multiple within-day training sessions, however limited literature has identified if session order affects responses both during and after training sessions; data which has implications for programming. An understanding of the acute post-training fatigue and recovery responses to session order can allow the coach and conditioning coach to effectively plan training to optimise adaptation. Therefore, the purpose of this study was to compare the physiological, endocrine and perceptual responses to a training day consisting of both strength and netball-training sessions performed two hours apart, executed as both strength followed by netball (STR-NET), and netball followed by strength (NET-STR).

6.2 Methods

6.2.1 Participants

Eleven female netball players (age: 21 ± 1 years, mass: 76.8 ± 10.2 kg, height: 1.81 ± 0.07 m) from an U21 and senior international netball team were recruited for this study. All players had been members of the National World Class Performance programme for a minimum of one year, played for the U21 or Senior National team and were experienced in all forms of training and competition, including strength training. This study was performed during the 2018/19 pre-season period, after a four-week period of prescribed training as part of the squad's performance programme. This consisted of two sessions per day of strength, speed, endurance and technical netball-training sessions, performed in various combinations and orders, four days per week, to ensure that players were fully conditioned to the training demands involved in this study. Although players were instructed to monitor their menstrual cycle and provided information regarding hormonal contraceptive use and menstrual cycle phase, this was not controlled for. Ethical approval was gained from the Swansea University review board (Appendix 4). Players were informed of the purposes and procedures of the investigation prior to signing an informed consent document and health screening questionnaire and were made aware that all material would be anonymised. All mandatory health and safety procedures were complied with in completing this research study.

6.2.2 Design

This repeated measures cross-over study was conducted over a nine-day period consisting of the completion of regularly performed netball and strength-training sessions. On a given training day, players performed two training sessions, separated by two hours, with measures collected prior to training sessions one (PreS1) and two (PreS2), immediately post-sessions one (IPS1) and two (IPS1) and 20 h after session one (20P) (Figure 6.1). Measures were collected within 15 minutes of commencing or completing each training session. Two training days were performed on separate occasions, initially as strength training followed by netball training (STR-NET) and seven days later as netball training followed by strength training (NET-STR).

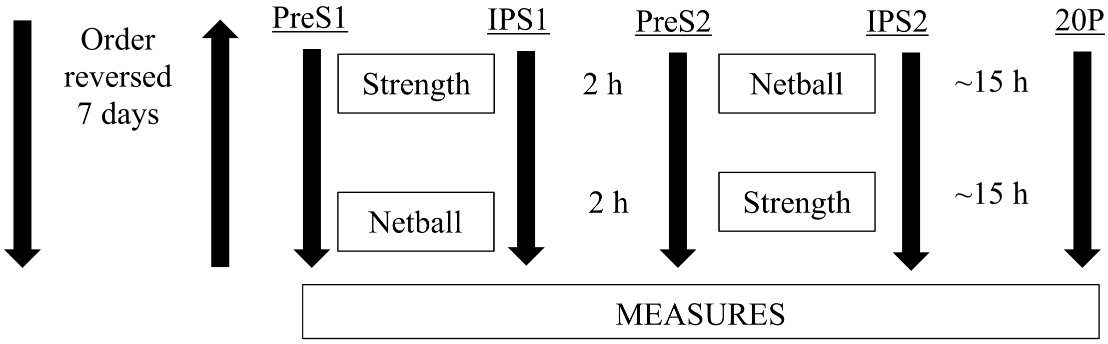

Figure 6.1**:** Schematic outlining the design of the study. Measures (salivary cortisol and testosterone concentrations, countermovement jump testing, perceived mood) were performed immediately before session one (PreS1), immediate post-session one (IPS1), two hours post-session one/ immediately before session two (PreS2), immediately post-session two (IPS2), 20 h post-session one (20P).

Measures included collection of saliva samples (cortisol and testosterone concentrations), recording of perceived mood (adapted brief assessment of mood questionnaire; BAM+; Shearer et al., 2017), and countermovement jump performance (peak power output; PPO, PPO relative to mass; PPOrel, jump height; JH, peak velocity; PV) testing. Netball loads were quantified externally (accelerometry) and internally (heart rate; HR, session ratings of perceived exertion; sRPE, and differential ratings of perceived exertion; dRPE). Testing was performed on the first training day of the week (following a rest day) and training prescribed to players throughout this period was the same leading up to both testing days.

Players reported to the first training session of the day at approximately 12:30 h to perform a strength-training session and were instructed to eat and drink to prepare as usual for training, as prescribed by the team nutritionist (i.e. a high carbohydrate meal to ensure high carbohydrate availability for the training session). Following completion of the training session, players had a two-hour break, during which time they ate and drank following the direction of the team nutritionist (i.e. a meal high in carbohydrates to replenish carbohydrate stores, in protein to support muscle protein resynthesis, and including fruit and vegetables as part of a balanced diet), to recover from, and prepare for, the second training session of the day, which was an on-court technical netball-training session. Thereafter, players were instructed not to perform any further structured exercise following testing. Players reported the following morning at 08:00 h, approximately 20 h post training-session one (20P), for testing, having prepared nutritionally as if they were attending another training session (i.e. a high carbohydrate meal to support carbohydrate availability). Due to the nature of working with an international netball-team, and numbers required for training purposes, no randomisation took place. As such, on a given day, all players performed training in the same order, with strength followed by netball performed first (STR-NET), and the reverse order performed the following week (NET-STR). Both training days involved the same training sessions, same content, with only the order differing between trials.

6.2.3 Netball-training session

The on-court netball-training session had a duration of 107 min (± 2.8 min). This was a routinely performed session by the team, which had featured regularly in the pre-season period, with the aim of developing technical skills, movement patterns and decision making. Initially, players performed a court-based warm-up of 19.7 min (± 0.9 min), consisting of team-based exercises involving changes of direction, short sprints, dynamic stretching, ball skills and netball-specific movements. Four technical drills were then performed, focussed around creating and using options. This progressed from one on one in a small square (approximately three by three metres) to two on two in a larger space (approximately four by four metres) aiming to create space to both make and receive a pass from a feeder outside the square. Next, this was performed in the goal circle, with the aim of scoring, with the final drill involving two attackers taking the ball past two defenders in each third, before passing the ball to a goal shooter. For both the STR-NET and NET-STR trials, the same session was performed.

6.2.4 Strength-training session

The strength-training session had a duration of 58.8 min (± 2.5 min) and consisted of warm-up exercises, followed by three sets of six repetitions of two upper-body (bench press, supine row) and two lower-body (a combination of reverse lunge, Romanian dead lift, leg press) exercises. This was performed at 85% of one-repetition maximum with four-minutes recovery between sets and had been regularly performed by players throughout this training period and was repeated across both trials.

6.2.5 Procedures

Mood response

Perceived mood was collected using the BAM+ at all time-points. An overall mood score was calculated at baseline, and at 20P, whilst individual values were assessed for perceived muscle soreness, perceived fatigue and perceived motivation at each time-point. For more detail, please refer to chapter 3.5.

Endocrine response

Salivary hormone responses were assessed at each time-point, with players instructed to avoid eating food or drinking fluids other than water for 60 minutes prior to sampling to avoid contamination of samples. For more detail, please refer to chapter 3.3. Individual testosterone and cortisol concentrations were assessed, as well as the ratio of testosterone and cortisol concentrations. The testosterone to cortisol is a marker of anabolic and catabolic balance (Elloumi, Maso, Michaux, Robert, & Lac, 2003; Viru & Viru, 2004) and is sensitive to physical demands and recovery such as in response to soccer and rugby match-play (Elloumi et al., 2003; Rowell, Aughey, Hopkins, Stewart, & Cormack, 2017).

Neuromuscular response

Players performed a standardised warm-up before performing countermovement jump testing to assess neuromuscular responses, apart from immediately post-exercise when practice jumps only were performed. Peak power output, peak velocity and jump height measures were calculated to assess responses of neuromuscular performance. For more detail, please refer to chapter 3.2.

Netball intensity

External load was quantified by use of accelerometry, with players using the same unit for each training session. Data was analysed for Player Load^{TM} for the entire training session. Players wore heart rate monitors throughout each training session, with heart rate recorded at beat-to-beat intervals. Heart rate data was analysed for the entire training session. For more detail, please refer to chapter 3.7.

Ratings of perceived exertion

Immediately following netball and strength-training sessions players recorded sRPE and indices of dRPE to assess perceived exertion. For more detail, please refer to chapter 3.6.

6.2.6 Statistical analyses

Visual inspection of the residual plots revealed evidence of heteroscedasticity; therefore, analyses were performed on log-transformed data for all variables apart from HR, BAM+, sRPE and dRPE. Data were analysed via a mixed effects linear model (SPSS v.21, Armonk, NY: IBM Corp.). Fixed effects in the model were order (STR-NET, NET-STR), with players included as a random effect with random intercept to account for the repeated measures nature of the study. Effects (differences between NET-STR and STR-NET) are presented and interpreted as simple effect sizes, either in raw or percent units. Standardised effect sizes (mean difference/pooled standard deviation; SD) are also presented but not interpreted. This was done as simple effect sizes are independent of variance and scaled in the original units of analysis (Baguley, 2009), which maximises the practical context of findings (Pek & Flora, 2018). A clear between-order difference in all dependent variables was declared when the 95% confidence interval for the difference did not include zero.

6.3 Results

6.3.1 Neuromuscular responses

Training-session order responses for all variables are represented in Table 6.1. For all variables, comparisons are made to PreS1. Clear differences were observed between trials, with a greater increase following NET-STR for PPO (standardised effect size; 95%CI: 2.8; 1.5-2.5), PPOrel (2.8; 1.5-3.8), JH

(2.4; 1.2-3.4) and PV (2.4; 1.2-3.4) at IPS1 compared with STR-NET (Figure 6.2A-D). At PreS2, a greater increase was observed following NET-STR for PPOrel (1.4; 0.4-2.2), JH (1.2), PPO (1.2; 0.3-2.1) and PV (1.0; 0.1-1.9) compared with STR-NET. At IPS2, a greater increase was observed following STR-NET for PPO (0.9; 0.0-1.8) and PPOrel (0.8; 0.1-1.6) compared with NET-STR. At 20P, a greater decrease following STR-NET was observed for JH (1.4; 0.4-2.3), PV (1.4; 0.4-2.2), PPOrel (1.2; 0.2-2.0) and PPO (1.1) compared with NET-STR. All other between-order differences were not clear.

Table 6.1: Mean (± SD) of endocrine function (T, C, T:C), countermovement jump variables (PPO, PPOrel, JH, PV) and well-being (mood, fatigue, soreness, motivation) for SRT-NET and NET-STR before (PreS1) and immediately after (IPS1) session one, before (PreS2) and immediately after (IPS2) session two and 20 hours post-session one (20P).

	PreS1	IPS1	PreS2	IPS2	20P
STR-NET					
T (pg·ml^{-1})	82.5 ± 34.5	91.2 ± 25.8*	69.7 ± 20.7	117.3 ± 44.3*	85.3 ± 29.1
C (µg·dl^{-1})	0.18 ± 0.07	0.18 ± 0.11*	0.11 ± 0.04*	0.34 ± 0.33*	0.75 ± 0.52
T:C	489 ± 215	665 ± 332	686 ± 308*	550 ± 389	148 ± 79
PPO (W)	3895 ± 538	3812 ± 611*	3793 ± 519*	3996 ± 610*	3715 ± 536*
PPOrel (W·kg^{-1})	50.9 ± 4.8	49.7 ± 5.6*	49.4 ± 5.3*	51.9 ± 5.8*	48.2 ± 4.5*
JH (m)	0.32 ± 0.04	0.30 ± 0.04*	0.29 ± 0.03*	0.31 ± 0.04	0.29 ± 0.04*
PV (m·s^{-1})	2.61 ± 0.13	2.53 ± 0.12*	2.54 ± 0.13*	2.60 ± 0.14	2.49 ± 0.14*
Mood (AU)	35 ±28	-	-	-	12 ± 28
Fatigue (AU)	38 ± 25	47 ± 15	48 ± 13	61 ± 14	61 ± 22
Soreness (AU)	36 ± 28	56 ± 18	58 ± 18	57 ± 17	62 ± 16
Motivation (AU)	63 ± 16	65 ± 15	56 ± 18	56 ± 18	49 ± 20
NET-STR					
T (pg·ml^{-1})	69.2 ± 16.5	108.7 ± 28.8	67.2 ± 20.5	67.5 ± 29.4	75.4 ± 20.1
C (µg·dl^{-1})	0.16 ± 0.08	0.21 ± 0.12	0.15 ± 0.07	0.11 ± 0.04	0.57 ± 0.20
T:C	532 ± 261	577 ± 238	532 ± 261	643 ± 220	147 ± 57
PPO (W)	3879 ± 516	4171 ± 410	3966 ± 543	3819 ± 501	3857 ± 466
PPOrel (W·kg^{-1})	50.4 ± 4.8	54.3 ± 4.9	51.5 ± 5.4	49.7 ± 4.7	50.1 ± 4.9
JH (m)	0.30 ± 0.05	0.32 ± 0.03	0.31 ± 0.03	0.29 ± 0.03	0.30 ± 0.03
PV (m·s^{-1})	2.57 ± 0.17	2.63 ± 0.12	2.57 ± 0.17	2.53 ± 0.12	2.55 ± 0.11
Mood (AU)	26 ± 29	-	-	-	9 ± 19
Fatigue (AU)	39 ± 21	55 ± 16	50 ± 20	58 ± 11	56 ± 14
Soreness (AU)	29 ± 18	44 ± 22	51 ± 19	60 ± 14	51 ± 11
Motivation (AU)	58 ± 19	54 ± 16	51 ± 14	45 ± 16	52 ± 13

Abbreviations: SD: standard deviation; T: testosterone concentration; C: cortisol concentration; T:C: testosterone to cortisol ratio; PPO: peak power output; PPOrel: peak power output relative to mass; JH: jump height; PV: peak velocity; Mood: overall mood score from brief assessment of mood +; Fatigue: perceived fatigue; Soreness: perceived muscle soreness; Motivation: perceived motivation. *denotes clear between order difference for trials between STR-NET and NET-STR

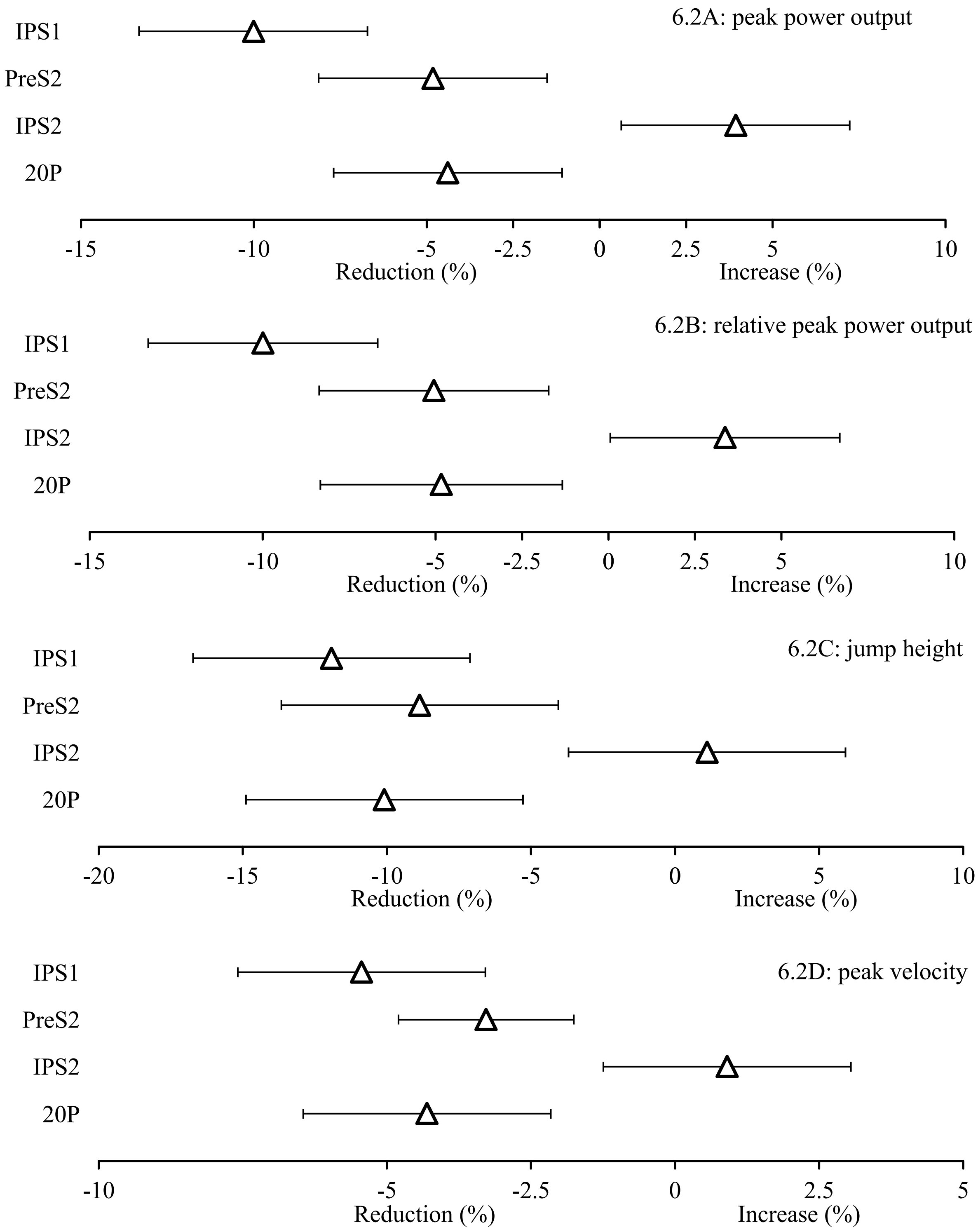

Figure 6.2A-D**:** Effect statistics (mean difference in percent and 95% confidence intervals) for the comparison of peak power output (6.3A), relative peak power output (6.3B), jump height (6.3C) and peak velocity (D) at immediately post-session one (IPS1), pre-session two (PreS2), immediately post-session two (IPS2) and 20 hours post-session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

6.3.2 Endocrine responses

At IPS1, greater increases following NET-STR were observed for testosterone (1.3; 0.2-2.2) (Figure 6.3A) and cortisol concentrations (0.8; 0.1-1.7) (Figure 6.3B) compared with STR-NET. A greater decrease was observed following STR-NET for cortisol concentration (1.0; 0.0-1.9), and a greater increase for T/C ratio (1.1; 0.2-2.0) (Figure 6.3C) at PreS2 compared with NET-STR. At IPS2, greater increases in testosterone (1.4; 0.4-2.4), and cortisol (1.0; 0.0-1.8) concentrations were observed following STR-NET compared with NET-STR. All other between-order differences were not clear.

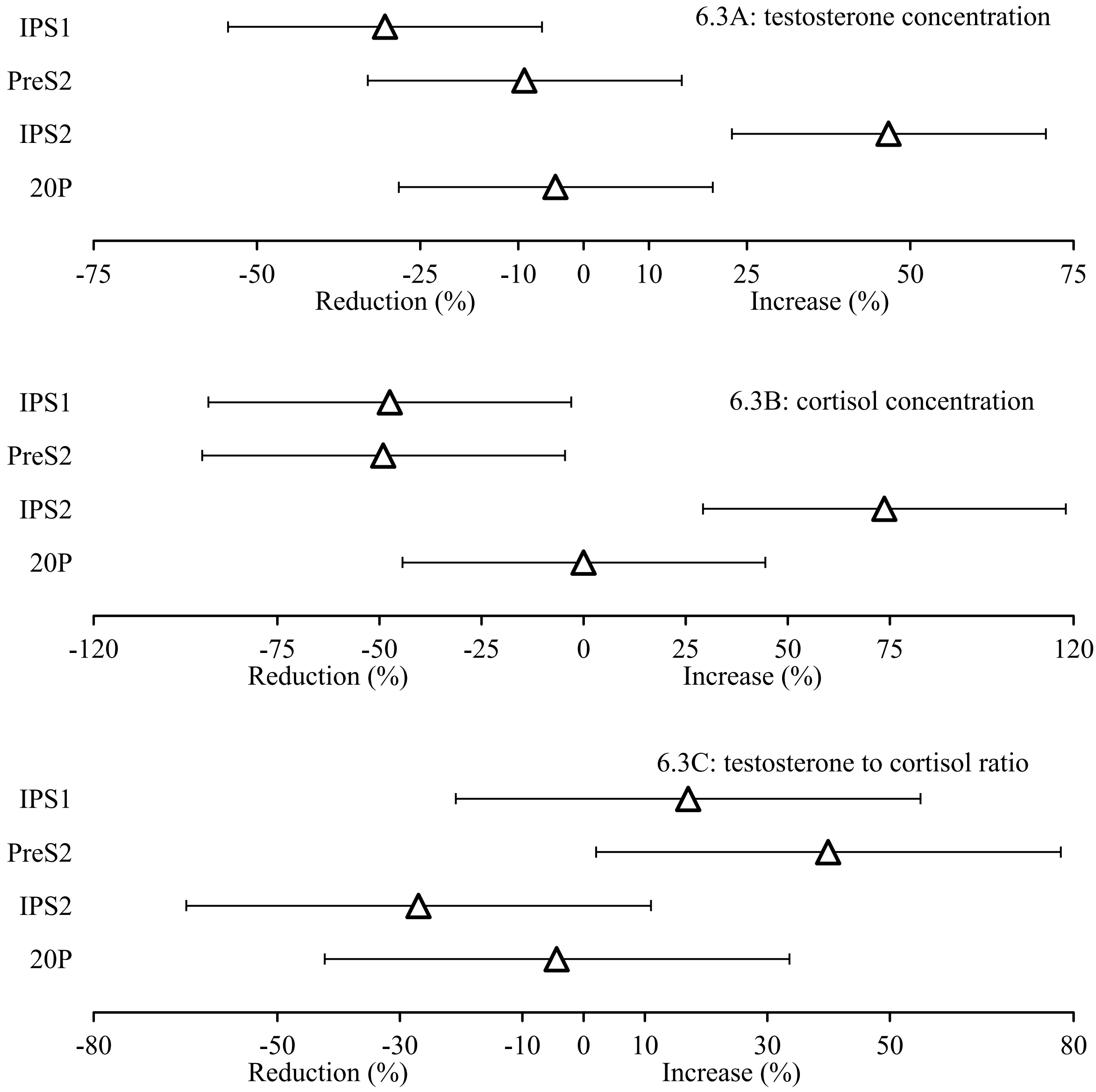

Figure 6.3A-C: Effect statistics (mean difference in percent and 95% confidence intervals) for the comparison of testosterone concentration (6.3A), cortisol concentration (6.3B) and testosterone to cortisol ratio (6.3C) at immediately post-session one (IPS1), pre-session two (PreS2), immediately post-session two (IPS2) and 20 hours post-session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

6.3.3 Mood responses

There were no clear differences between trials for soreness, fatigue, motivation or overall mood at any time-points (Figure 6.4A-D).

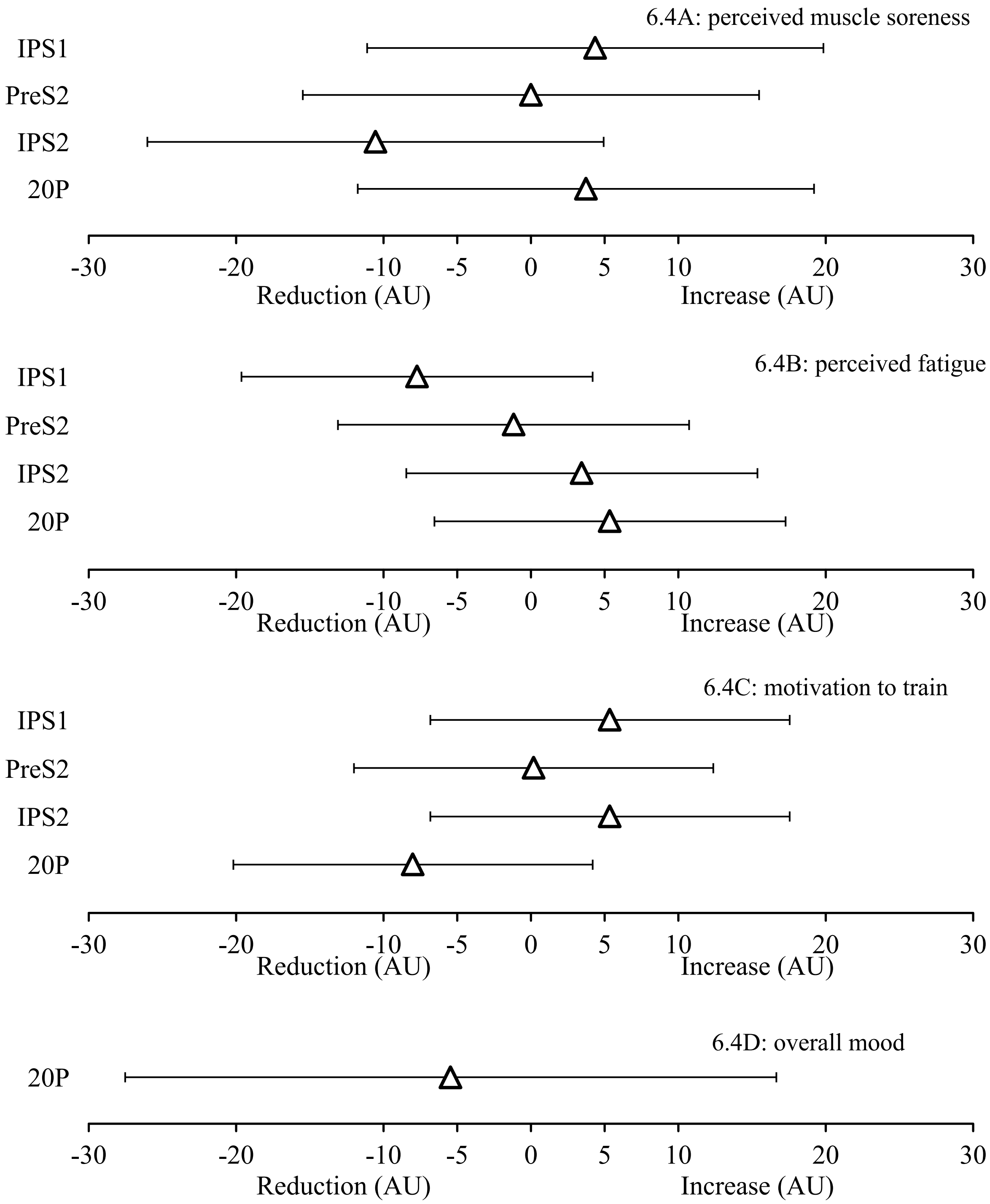

Figure 6.4A-D: Effect statistics (mean difference in arbitrary units [AU] and 95% confidence intervals) for the comparison of STR-NET compared with NET-STR for perceived muscle soreness (6.4A), perceived fatigue (6.4B), motivation to train (6.4C) and overall mood (6.4D) at immediately post-session one (IPS1), pre-session two (PreS2), immediately post-session two (IPS2) and 20 hours post-session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline. Overall mood is only compared at 20P.

6.3.4 Training session responses

Data for the training sessions are presented in Table 6.2. There were no clear differences between trials for sRPE (Figure 6.5A) or dRPE (Figure 6.5B-E) for the netball-training session. For strength training, a clear difference was observed with a greater RPE-T (1.0; 0.1-1.9) following NET-STR compared with STR-NET (Figure 6.5E). There were no clear differences between trials for Player Load^{TM} of netball, maximum HR and average HR.

Table 6.2: Mean (± SD) of internal load (mean HR, maximum HR) and Player Load^{TM} of the netball-training session, and perception of effort (sRPE, RPE-B, RPE-L, RPE-U, RPE-T) for the netball and strength-training sessions for both STR-NET and NET-STR.

	Netball training		Strength training	
	STR-NET	NET-STR	STR-NET	NET-STR
Mean HR (b·min^{-1})	147 ± 8	143 ± 13	-	-
Maximum HR (b·min^{-1})	197 ± 3	197 ± 3	-	-
Player Load^{TM} (AU·min^{-1})	4.0 ± 0.4	4.1 ± 0.5	-	-
Player Load^{TM} (AU)	424 ± 41	447 ± 52		
sRPE (AU)	58 ± 9	53 ± 14	47 ± 11	51 ± 12
RPE-B (AU)	48 ± 12	44 ± 21	29 ± 20	31 ± 14
RPE-L (AU)	49 ± 15	45 ± 15	56 ± 10	59 ± 8
RPE-U (AU)	29 ± 11	31 ± 13	40 ± 15	49 ± 10
RPE-T (AU)	52 ± 11	46 ± 13	25 ± 9	40 ± 18

Abbreviations: SD: standard deviation; STR-NET: strength followed by netball session order; NET-STR: netball followed by strength session order; HR: heart rate; sRPE: session rating of perceived exertion; RPE-B: perceived breathlessness; RPE-L: perceived leg-muscle exertion; RPE-U: perceived upper-body muscle exertion; RPE-T: perceived cognitive/ technical demand.

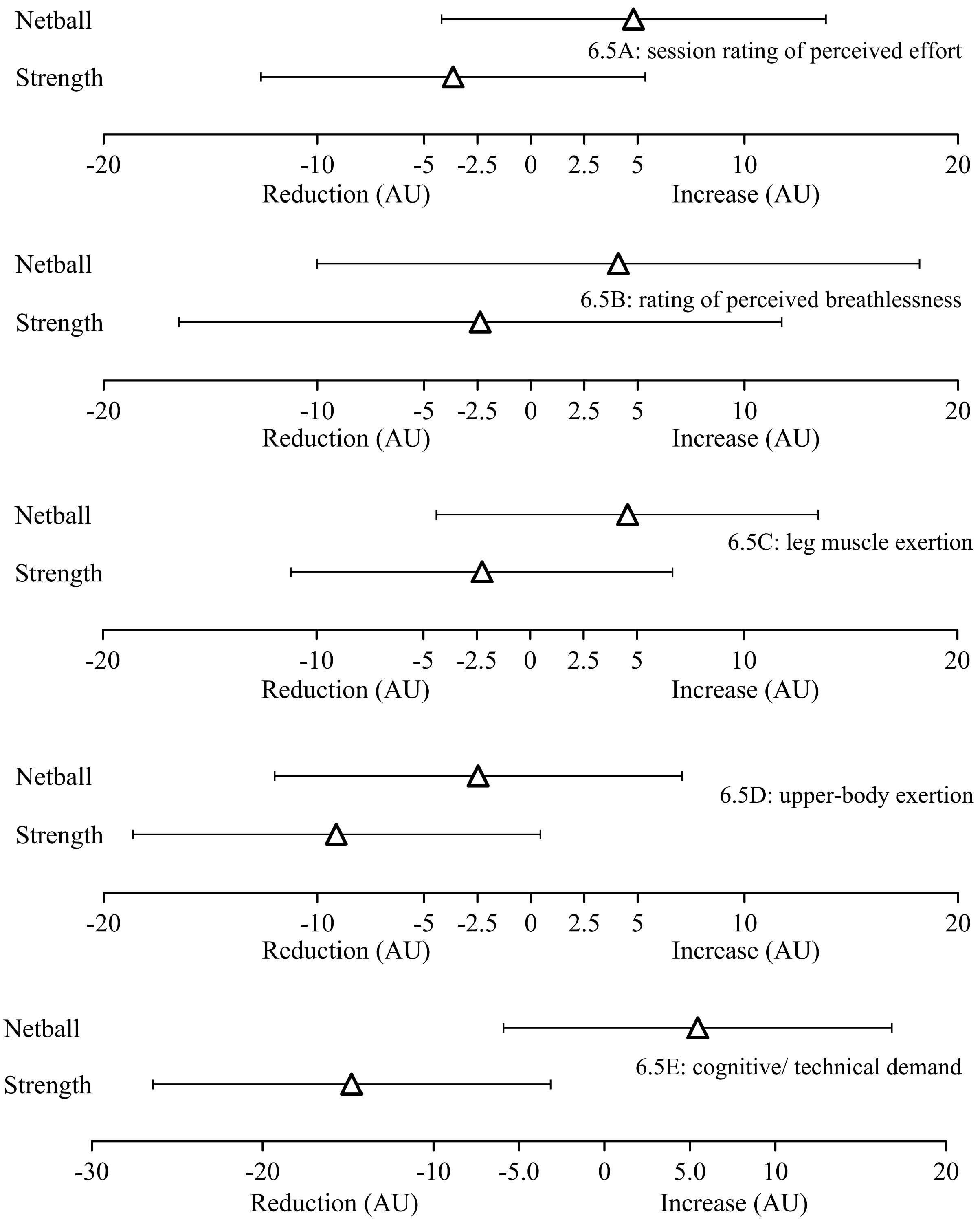

Figure 6.5A-E: Effect statistics (mean difference in arbitrary units [AU] and 95% confidence intervals) for the comparison of STR-NET compared with NET-STR for session rating of perceived exertion (6.5A), rating of perceived breathlessness (6.5B), leg-muscle exertion (6.5C), upper-body exertion (6.5D) and cognitive/ technical demand (6.5E) at immediately post-session one (IPS1), pre-session two (PreS2), immediately post-session two (IPS2) and 20 hours post-session one (20P) compared to baseline for STR-NET compared with NET-STR. Zero (0) on the axis represents no difference between trials at that time-point compared with baseline.

6.4 Discussion

This is the first study to examine the influence of training-session order on the acute neuromuscular, endocrine and perceptual responses in international female netball players. Primary findings highlight that responses both during and after were influenced by the ordering of strength and netball-specific training sessions. Neuromuscular performance and cortisol concentrations were higher prior to commencing the second training session of the day, and neuromuscular performance was higher the following day, in the NET-STR order compared with STR-NET. Accordingly, these data indicate that training-session order is an important consideration when planning training and in order to avoid performing training in a sub-optimal state, technical-netball training should precede strength training.

6.4.1 Immediate post-exercise responses

The performance of NET-STR resulted in an increase in neuromuscular performance (PPO, PPOrel, JH and PV) testosterone and cortisol concentrations at IPS1 compared with that following STR-NET. Following an exercise stimulus, mechanisms of both fatigue and potentiation coexist, with the balance of these factors determining the performance benefit (Kilduff et al., 2013). It is therefore possible that the greater increase in testosterone concentrations following netball training, perhaps resulting from an increase in competitive and dominance behaviours from playing against peers (Edwards & Kurlander, 2010), may have positively influenced behaviour, contractile signalling and performance (Crewther et al., 2011). This in turn may have had a positive impact on neuromuscular function, to a greater extent than acute impairment by either muscle damage or fatigue, compared with responses to strength training. Additionally, muscle temperature may have increased to a greater degree following netball training, along with induction of post-activation potentiation due to dynamic movements (Turner et al., 2015), greater than achieved following strength training.

6.4.2 Two hours post-exercise/ pre-training session two responses

Prior to commencing the second training session of the day (PreS2), neuromuscular performance was enhanced, and cortisol concentration increased in the NET-STR versus STR-NET trial. Multiple mechanisms may have contributed to the differences in neuromuscular performance observed. Cortisol has been proposed to work in tandem with testosterone to impact neuromuscular performance (Crewther, Obmiński, et al., 2018), and may have exerted a positive impact in the present study. The greater volume, intensity or type of exercise performed in netball training could have also led to greater increases in core (Mcgowan et al., 2017) and muscle temperatures than that of strength training, resulting in improved neuromuscular function (West, Cook, Beaven, et al., 2014). Moreover, repeated high intensity concentric and eccentric contractions involved in strength training could have led to a greater impairment of excitation-contraction coupling compared to netball training, resulting from low-frequency fatigue (McLellan & Lovell, 2012), with exercise-induced muscle damage and damage to type two muscle fibres (Byrne et al., 2004) contributing to the decrease. Performing subsequent training with impaired neuromuscular performance can impair subsequent training performance (Highton et al., 2009) and adaptation to training (Jones et al., 2016). Findings therefore suggest that to avoid compromising subsequent training performance, netball training should be performed prior to strength training.

6.4.3 Training session intensity

No differences were observed between trials for Player Load^{TM} or internal intensity of the netball-training session. Despite reduced neuromuscular performance, prior strength training had no impact upon playing intensity of netball, similar to that reported in football (Sparkes et al., 2020). Whilst players may have compensated to maintain the required intensity, playing intensity was maintained without any change to heart rate or perceived effort, suggesting that the prior strength training had no effect on subsequent netball-training performance. It should be noted however, that the aims of the netball-training session were technical in nature, and therefore the impact of prior exercise on more maximal type exercise is unclear and warrants further investigation. Perceived technical/ cognitive demands of the strength-training session were increased when preceded by netball. Whilst this does not indicate players were overly exerted, coaches and conditioning coaches should be aware of this when planning training and modify technically challenging exercises based on individual player’s needs.

6.4.4 20 h post-exercise responses

When players reported for training at 20P, neuromuscular performance was reduced following STR-NET compared with NET-STR, whilst markers of endocrine function and mood were similar. Following speed and strength training (Johnston et al., 2017), and small-sided games and strength training (Sparkes et al., 2020), training-session order had no impact on neuromuscular performance the following day in elite male players. However, endurance running performance was impaired when strength training preceded running training relative to the opposite order (Doma & Deakin, 2013). A difference between these findings may be due to recovery of neuromuscular performance before commencement of subsequent training, whereby greater fatigue was experienced when training was performed without recovery of neuromuscular performance (Doma & Deakin, 2013). The present study supports these findings and suggests that recovery of neuromuscular performance prior to the performance of subsequent training may influence the associated recovery profile. Importantly, no differences were observed between trials at 20P (or at PreS2) for any perceptual marker of fatigue, despite reduced neuromuscular performance. This highlights the importance of utilising objective, in addition to subjective, markers of fatigue and readiness to train, to understand responses to, and recovery from, training.

6.5 Conclusion

This is the first study to report the influence of sequencing of strength and netball training within a day on the acute neuromuscular, endocrine and perceptual responses in international female netball players. Sequencing of training impacted neuromuscular performance and endocrine function within the training day, and neuromuscular performance the following day, without impact upon training performance or perceptual responses.

6.6 Practical applications

As it is important that all training sessions are performed optimally in order to maximise training performance and adaptation (García-Pallarés et al., 2009; Tan, 1999), findings highlight that the sequencing of training sessions is an important consideration in well-trained, international-standard netball players. In order to perform both training sessions within a training day optimally, and to maximise training adaptation, technical-netball training should be performed prior to strength training, with a two-hour recovery period being sufficient. This not only permits both training sessions to be performed optimally, but also results in greater neuromuscular performance the next day, compared with the opposite order. As there were no differences in perceptual markers between training-session order, this highlights the need for coaches and conditioning coaches to monitor neuromuscular performance in the hours and days following training to fully understand fatigue and readiness to train.

Chapter 7 Synthesis of research findings

7.1 Synthesis

In the following synthesis the main findings of the three experimental chapters and their practical application to coaches and conditioning coaches will be discussed in relation to the main themes of this thesis. These themes mainly include the internal demands and Player Load^{TM} of international netball training and competition (study one and two), the neuromuscular responses to netball training and competition (study one and two), and the impact of training-session order upon neuromuscular performance (study three).

External & internal demands of international netball

A review of the literature highlighted a lack of studies reporting the external demands of international netball match-play, with no reports of the internal demands of netball at elite or international standard (Figure 2.21). Only two studies had reported the demands of high-level match-play; via use of notational analysis in international (Fox et al., 2013) and use of accelerometry in elite-standard (Young et al., 2016) match-play. However, both were conducted prior to rule changes in January 2016 (2009-2010 season and 2014 season for both studies respectively), which aimed to reduce stoppages and increase the speed and intensity of match-play, which may limit applicability to the current game. Additionally, these matches were played as discrete matches, as opposed to over consecutive days, as required in tournaments, such as the netball World Cup. Chapter four therefore investigated these demands across a series of matches as part of an international netball tournament. The main findings were that mid-court positions performed at a higher Player Load^{TM} intensity (Table 4.3) compared with goal-based players, agreeing with studies in elite (Young et al., 2016) and State-level (Cormack et al., 2014) match-play. However, it was also found that these positions not only likely covered a greater distance (Aughey, 2011), or performed more position specific activities (Bailey et al., 2017), but also experienced greater overall and localised perceived effort and greater cardiorespiratory stress. This suggests that mid-court players both perform and perceive to be performing at a higher intensity than goal-based players.

Match results included a win (49 points to 36 points), win (54 points to 38 points) and loss (42 points to 81 points) for matches one to three respectively. Wins were played against lower ranked opponents (World rankings as defined by the international Netball Federation at the time of the tournament), whilst the loss was against a higher ranked opponent. Although Player Load^{TM} was not different between matches, with trivial differences observed (Table 4.2), it is likely that the types of activities performed varied (e.g. more off-ball guarding and defending in a loss) and resulted in load accumulated differently

(Bailey et al., 2017). It has been reported that Player Load^{TM} of sub-elite netball match-play differs for playing standard (State level and recreational level), with higher load accumulated at a higher playing-standard (Cormack et al., 2014). However, findings of the present study suggest that whilst accelerometry does not discriminate between opposition standard or match outcome, internal measures of heart rate and perception of effort are sensitive, with higher values observed against higher ranked opponents. Global rating of perceived effort was greater for match three than two (higher and lower ranked opponents respectively) but was not different between matches one and three (lower and higher ranked opponents respectively), with similar findings for mean heart rate. However, differential perception of effort clearly demonstrated higher perceived effort against the higher ranked opponent across all indices, suggesting greater sensitivity than the global measure of session rating of perceived exertion. In professional soccer, greater RPE-L and RPE-T (but not RPE-B) have been reported following the performance against a higher ranked opponent, whilst match outcome was not an influence (Barrett, McLaren, Spears, Ward, & Weston, 2018). Findings of the present study therefore suggest that differential rating of perceived effort is a more sensitive marker of exertion than accelerometry or global session rating of perceived exertion. As it is important to condition players to meet the demands of the highest intensity that maybe experienced, differential rating of perceived effort offers more insight in to the demands of international match-play, than accelerometry alone.

Practical application of findings

These findings provide detailed information regarding the physical preparation of players for coaches and conditioning coaches, which was limited to that of movement demands or Player Load^{TM} only, in order to optimally condition players for the specific demands imposed. For example, mid-court players may need to not only cover a greater distance in training to be conditioned for the movement demands of match-play but may also need to experience a higher perception of effort of the lower-limbs, and of breathlessness for example, along with a higher heart rate to become accustomed to these sensations. This enables staff to design, prescribe and monitor position-specific training sessions, or aspects of training sessions, enhancing conditioning for match-play which may lead to an improvement in performance. Whilst accelerometry is a commonly used method to quantify the training demands of several sports, including netball, these findings highlight the shortcomings with the use of an external measure of load and exertion solely. As it is important that players are conditioned for the highest intensity that may be experienced during match-play, this highlights the importance of various measures, including internal and external, to fully understand the demands. It is therefore important that coaches and conditioning staff monitor heart rate and differential rating of perceived exertion to understand further aspects of conditioning, and to fully prepare players for match-play demands. Indeed, both heart rate and ratings of perceived exertion are relatively cheap and easy to administer compared with accelerometry, provide important information in the physical preparation of players and should be combined with accelerometry to monitor training in elite or international netball.

Responses to the tournament

Whilst being well conditioned to perform for a single match is important, in a tournament players are required to perform matches across consecutive days with limited recovery. In chapter four, for the first time, the responses to a single and to consecutive matches were examined, along with the recovery profile three days post-tournament. Neuromuscular, endocrine, biochemical and perceptual fatigue was evident following a single match, whilst the performance of a subsequent match resulted in cumulative fatigue for markers of muscle damage, perceived fatigue and muscle soreness (Table 4.1). In the only study in elite netball, a reduction in jump height and peak velocity, and increase in perceived fatigue and muscle soreness was reported 24 h following the performance of a single netball match, with unclear differences at 36 h post (Wood et al., 2013). However, several aspects of this study may limit applicability. Firstly, only six players were observed, all of which played the entire match. Secondly, an 80 minute match was played, which is inconsistent with the four 15 minute quarters currently played across all standards of netball. Therefore, whilst findings suggest a reduction in neuromuscular performance and increase in perceived fatigue for up to 36 h, the applicability to international netball, played over 60 minutes, with substitutions of players to manage fatigue, is questionable.

In chapter four, neuromuscular performance decreased after the performance of match one and remained reduced without further decline following match two. However, perceived fatigue, muscle soreness and muscle damage accumulated across the tournament. Similar reductions in jump height have been reported following a soccer match (Andersson et al., 2008), whilst following a rugby sevens tournament, no reduction in repeated jump performance has been observed (Clarke et al., 2015). Whilst the assessment of neuromuscular performance by use of countermovement jump testing is related to athletic performance (Cronin & Hansen, 2005; Requena et al., 2009), and reflects changes in neuromuscular function (Nibali et al., 2013) the origin of fatigue cannot be determined. Reports following a competitive soccer match suggest prolonged peripheral and central fatigue is experienced, requiring up to 48 h for full recovery (Rampinini et al., 2011), whilst a further study reported significant central fatigue post-match, returning to baseline at 72 h post (Brownstein et al., 2017). As metabolic mechanisms of peripheral fatigue recovery rapidly (Allen et al., 2008), it is likely that the reduced neuromuscular performance experienced after the first match is due to an increase in muscle inflammation (Dousset et al., 2007), altered excitation-contraction coupling, damage to type two muscle fibres and altered calcium handling, as a consequence of sprinting, change of direction and eccentric muscle contractions (Skurvydas et al., 2016) involved in netball match-play.

Following the performance of a second match, there was no further decrease in neuromuscular performance, whilst creatine kinase activity, perceived soreness and fatigue further increased. A similar observation has been reported during a basketball tournament (Montgomery et al., 2008). State-level male players performed three matches on consecutive days, with a decrease in countermovement jump height following match one, remaining reduced without further decrement across the tournament, despite accumulated perceived fatigue and muscle soreness. The lack of accumulated neuromuscular fatigue in the present study may be due to several factors. Players may have been highly conditioned and accustomed to the required movement demands, limiting the level of muscle damage and neuromuscular fatigue experienced. Differences in strategy, player selection and in tactics, including managing the score-line, may have contributed. Additionally, differences in time of commencing the match and, hence finishing time may have been a factor.

Whilst Player Load^{TM} was not different between match one and two this does not distinguish between the types of activity performed, with many activities contributing to accelerometry load (Bailey et al., 2017). As such, players may have performed different activities and movements in the second match that were less fatiguing, or sub-maximal, resulting in less muscle damage and fatiguing consequences. Players also performed different proportions of each match compared with others. For example, some played the entire first match, followed by only two quarters of the second, whilst others performed the opposite. Indeed, the score-line in the second match was more comfortable than the first, which may have allowed substitutions more readily, spreading the playing demands across more players. As such coaching staff may have rotated players, in order to manage fatigue across the squad, in an attempt to ensure key players were as fresh as possible for the final match against a higher ranked opponent the next day. Players may have also sensed the lower standard of opponent, and managed energy expenditure to maintain an appropriate score-line as well as fatigue.

The late commencement of the first match (19:00 h) in comparison to match two (15:30 h) may have also been a contributing factor, impairing subsequent recovery processes. It has been reported that the performance of night-time matches (commencing after 18:00 h) reduces sleep quality, sleep duration and results in poorer perceived recovery compared with day-time matches (commencing before 18:00

h) in elite soccer players (Fullagar et al., 2016). Whilst perceived sleep quality in the present study was reduced following match one, this remained reduced following match two. Additionally, cortisol concentrations were reduced following the first match and returned to baseline following the second match (Table 4.1). The reduced recovery period post-match; due to later commencement and finishing of exercise resulting in less time before bed-time to implement recovery strategies and relax, along with reduced sleep quality, may have contributed to compromised recovery process and impact on endocrine function and neuromuscular performance. In turn, the earlier commencement of match two may have allowed the body's recovery processes and return to homeostasis to occur earlier in the afternoon. Additionally, this may have allowed recovery strategies to be implemented more effectively, leading to no further impact on endocrine function, or further reduction in neuromuscular performance despite further impaired perceived recovery.

Recovery post-tournament

Unfortunately, due to other commitments, at the end of the tournament, players departed and returned home that evening. Due to these logistical constraints, no further measurements were obtained following the third match. As this match had the highest perceived effort and was against a higher ranked opponent it is unclear what impact this may have had on the fatigue markers. Three-days post-tournament disturbances in perceptual, physiological and neuromuscular performance were still evident, suggesting players had yet to fully recover (Table 4.1). This time-point was chosen as this was when players returned to training. As no further measurements were observed, such as four or five days post-tournament, it is unclear how long would be required for recovery of all aspects of fatigue. Following a two-day rugby sevens tournament, five days was sufficient for creatine kinase activity to return to baseline, however at this time-point neuromuscular performance remained impaired (West, Cook, Stokes, et al., 2014). Following a single soccer match, jump height has reported to remain decreased for up to 69 h post (Andersson et al., 2008), whilst a further study reported prolonged central fatigue following a soccer match, returning to baseline at 72 h post (Brownstein et al., 2017). However, the degree of neuromuscular fatigue in the study by West et al. (2014) was considerably greater than in the present study (15-26% compared with 3-4%), which may affect the associated recovery profile. Findings of the present study are therefore in line with previous reports. Whilst 62 h is a sufficient period of time for creatine kinase activity and muscle soreness to recover, restoration of neuromuscular function may require a longer recovery period.

Practical application of findings

These findings provide detailed information regarding the fatigue experienced following both a single and series of international netball matches, and the recovery profile following 62 h of recovery. Training should be designed to condition players towards meeting the demands of tournament match-play, in addition to the fatiguing consequences, in order to become more resilient under tournament conditions. Training should therefore be designed to overload key components, to bring about the desired fatiguing responses and build players' resilience to the fatiguing consequences. Coaches should monitor markers of fatigue to understand these responses, including perceptual and objective markers, including neuromuscular performance. Recovery strategies should also be employed to target the specific fatiguing consequences experienced during competitive tournaments. For example, cold water immersion can reduce neuromuscular fatigue and perceived soreness (Montgomery et al., 2008), whilst active recovery and compression positively influence markers of muscle damage (Gill, Beaven, & Cook, 2006). Late commencement of matches may interfere with recovery processes and influence endocrine function. Recovery strategies for evening matches should therefore be carefully implemented. The time required to fully recover in this study following the tournament was longer than coaches had planned. As it is important that players are permitted recovery periods before commencing subsequent training, coaches should therefore monitor perceptual markers and neuromuscular performance following matches in order to understand the time course of recovery and to prescribe training appropriately. As markers had not returned to baseline within the observed time-frame, this highlights the importance of employing recovery techniques not only during the tournament, but in the ensuing recovery period as well.

Limitations and future direction for research

Unfortunately, due to logistical considerations no measurements were taken following the third match or following further recovery from 62 h post-tournament. Future research could therefore investigate the responses to a greater number of matches played within a tournament, such as the Netball World Cup (eight matches in 10 days), as well as assess responses until all markers return to baseline to characterise the full recovery timeline. As fatigue accumulates throughout a tournament, future research could investigate the impact that recovery strategies may have on specific markers of fatigue in order to improve competitive performance. Additionally, relationships between playing/ positional demands and fatiguing responses could be investigated, to provide greater information on individual needs for conditioning and recovery interventions. Due to both the logistics of an International netball tournament, and player numbers, menstrual cycle and hormonal contraceptive use were not accounted for in this study. Future research could therefore investigate the impact of menstrual cycle phase and hormonal contraceptive use on responses to consecutive matches.

Responses to netball-training

Whilst several studies have reported the heart rate response and Player Load^{TM} of netball-specific training sessions (Bailey et al., 2017; Chandler et al., 2014), the review of literature highlighted a lack of studies reporting the post netball-training responses of any playing-standard. Whilst chapter four described the positional-specific and tournament demands of international match-play, providing important information to coaches in the physical preparation of players, it is also important that the daily training organisation is understood to permit optimal planning of training, and therefore optimal training adaptation (García-Pallarés et al., 2009). Chapter five therefore examined the neuromuscular, endocrine, biochemical and perceptual responses over 24 h to a regularly performed netball-training session. The main findings highlighted that neuromuscular function (Figure 5.2A-C), had returned to baseline within two hours post-training, but was impaired at 24 h post, without changes to mood (Figure 5.3A-C) or endocrine function (Figure 5.1A-C) similar to that following soccer (Sparkes et al., 2018) and speed (Johnston et al., 2015) training.

However, unlike the aforementioned studies which observed an immediate post-exercise reduction in neuromuscular performance, immediately post-training neuromuscular performance was enhanced above that of baseline. In the present study and that of Sparkes et al. (2018), players completed exercise they were accustomed to. This therefore does not explain the differences immediately post-exercise. Instead, the different movement patterns involved, with shorter, more explosive movements interspersed with periods of recovery in netball, may explain this difference. It may be that the exercise associated increase in muscle temperature (Sargeant, 1987; West, Cunningham, Finn, et al., 2014) along with increase in testosterone concentrations (Crewther et al., 2011) from competitiveness and dominance behaviours (Edwards & Kurlander, 2010; O'Donnell et al., 2018), increased neuromuscular function to a greater extent than any fatiguing mechanisms, for example the accumulation of metabolites (Allen et al., 2008). Additionally, the final portion of the netball-training session involved scenario specific match-play. As a consequence of this type of activity, when one team is attacking, only the attackers and the opposition defenders are active, permitting other players to recover. This may have limited the fatigue experienced over the final portion of the training session and contributed to this difference between studies.

Following a recovery period of two hours, neuromuscular performance had returned to baseline (Figure 5.2A-C). Similar findings have been reported following soccer (Sparkes et al., 2018) and speed (Johnston et al., 2015) training, suggesting two hours as a suitable period for recovery of neuromuscular performance. However, perceived muscle soreness, fatigue and overall mood were impaired at this time-point, with an increase in creatine kinase activity. It has been proposed that the inflammatory response to muscle damage impairs neuromuscular performance, rather than the muscle damage itself (Dousset et al., 2007), which is initiated after two to six hours (Armstrong, 1990). This therefore explains, why, despite an increase in creatine kinase activity and perceived soreness, neuromuscular performance was not negatively affected at this time-point. Two hours was chosen as reports suggest recovery is achieved at this time-point (Johnston et al., 2016; McCaulley et al., 2009; Sparkes et al., 2018), and also was approximately the recovery duration employed by this team when performing multiple training sessions within a day. However, as no observations were made prior to this, it is unclear as to at what time point neuromuscular performance returned to baseline following the initial increase. Similarly, as no observations were made following this, it is unclear when perceptual markers of readiness to train may have returned to baseline.

At 24 h post-training, neuromuscular performance was reduced (Figure 5.2A-C), a similar finding to the aforementioned studies following team-sport training (Johnston et al., 2015; Sparkes et al., 2018). Although a regularly performed training session was performed, and as such players were conditioned to the movements and intensity of exercise, it is noteworthy that neuromuscular fatigue is still evident. This is likely due to an increase in muscle inflammation (Dousset et al., 2007) and altered excitation contraction coupling due to damage to type two muscle fibres (Skurvydas et al., 2016), from eccentric muscle actions, changes of direction and landing, as required in netball training. At this time-point players performed a subsequent training session. As such, no further observations were made, and it is therefore unclear what time is required to achieve recovery of neuromuscular performance.

The training session employed successfully replicated the match-play demands observed in chapter four, with similar Player Load^{TM}, heart rate and perceptual demands when excluding breaks between activity (i.e. recovery periods or coaching interactions). However, despite this similarity of load and intensity between the two modalities, the responses experienced 24 h post-exercise differed. For example, whilst jump height was reduced to a similar extent following training and International match-play (-6% vs. -4% for training and matc-play respectively), testosterone and cortisol concentrations, overall mood and perceived fatigue were decreased only following match-play, in addition to a greater increase in creatine kinase activity (+27% vs. +72% for training and match-play respectively) compared with that following training. This difference in response may be due to overall playing intensity, for example a similar total Player Load^{TM} was performed for both the training session and match-play (513 ± 81 AU vs. 520 ± 137 AU for training and match-play respectively), yet the training session was 50% longer in duration (90 min vs. 60 min). Alternatively, the environment the players performed in and performance importance (i.e. home training venue vs. International tournament) may have influenced responses, as acute endocrine responses are influenced by home or away competition (Cunniffe, Morgan, Baker, Cardinale, & Davies, 2015), match importance (Moreira et al., 2013) and training versus competition (Haneishi et al., 2007). These findings therefore show, that whilst the countermovement jump is a suitable marker to characterise changes in neuromuscular performance following netball activity, further monitoring including perceptual markers or endocrine function should be included to fully understand the ensuing fatiguing responses.

Practical application of findings

These findings provide important information regarding the planning of training and are the first to report the responses to a netball-training session at any playing standard. As neuromuscular performance is reduced at 24 h post, findings suggest that two hours post-training may be a more suitable period to perform explosive training, where neuromuscular performance is an important component, rather than the following day. As perception of fatigue is increased at this point, strategies could be employed to counter this, for example with the use of caffeine, or motivation from the coach. This would ensure that players feel ready to perform explosive activity and are able to take advantage of the enhanced neuromuscular performance. The organisation of training in this way, as opposed to performing demanding training the following day, may enhance training performance and lead to increased adaptation (García-Pallarés et al., 2009; Tan, 1999) and athletic performance. Additionally, a longer recovery period is required than coaches perceive following netball-training. Therefore, even following a regularly performed training session, whereby players are conditioned to the demands, subsequent training demands should be considered, and modulated based on players' fatigue. As perceptual markers of fatigue and neuromuscular performance did not follow the same recovery profile, this further highlights the need for neuromuscular performance to be monitored in the hours and days following training.

Limitations and future direction for research

Unfortunately, due to player availability and training schedules no further measurements were permitted beyond 24 h post-training. Future research could therefore monitor these responses for a longer period to fully characterise the recovery profile. Additionally, this study characterised the response to a single training session. In order to further support coaches and conditioning coaches, future research could characterise the responses to training sessions of intensity, volume or types of activities performed to provide a greater understanding of the responses to a variety of training stimuli. As players often perform consecutive days of training, and as performing training in a fatigued state can lead to cumulative fatigue (as seen in chapter six), the responses to a series of training days could also be investigated to provide greater information on overall weekly programming. As chapter four demonstrated, physical demands differ between playing positions. The final portion of the training session involved match-play, which therefore likely included positional specific movement and activity demands. This may have resulted in positional specific responses to the training session, which could be further investigated in future research to provide a more detailed understanding of the positional specific responses to a variety of training sessions.

Training-session order

As players regularly perform training days consisting of multiple training sessions in order to enhance several aspects of conditioning concurrently, chapter six aimed to characterise responses to training-session order when strength and netball training were performed within the same training day. When comparing responses prior to commencing the second training session of the day, neuromuscular performance (Figure 6.2A-D) was enhanced following NET-STR, compared with that following STR-NET, without any difference in perceptual responses (Figure 6.4A-D). The following day, 20 h post-training session one, neuromuscular performance was reduced following STR-NET, compared with NET-STR, without difference in perceptual responses.

Training-session order effects within the day

As it is important that all training sessions are performed well for optimal adaptation (García-Pallarés et al., 2009; Tan, 1999) it is important that training-session order is optimised within the training day. Findings of the present study are in contrast to that previously reported in male team-sport players (Johnston et al., 2017). Following either resistance or speed training (six x 50 m maximal sprints with five minutes recovery between sprints), neuromuscular performance had recovered following an initial post-exercise decrease and was not different between trials at two hours post-training; likely due to removal of metabolites (Allen et al., 2008). However, in the present study, neuromuscular performance was enhanced following NET-STR in comparison to STR-NET.

In swimming, enhanced afternoon performance has been reported following morning training (Mcgowan et al., 2017). When swimmers performed morning training, consisting of varied intensity swimming exercise, or swimming and land-based resistance exercise, afternoon (six hours later) swim performance was improved, with an associated increase in core temperature (Mcgowan et al., 2017). It is therefore possible that in the present study the greater volume of exercise performed in the netball-training session could have led to a greater increase in core (Mcgowan et al., 2017) and muscle (Mohr et al., 2004) temperature than that of strength training, resulting in improved neuromuscular function (Sargeant, 1987; West, Cook, Beaven, et al., 2014). Morning strength (Cook et al., 2014; Russell et al., 2016) and sprint training (Russell et al., 2016) have been shown to reduce the circadian rhythm associated decline in testosterone concentration, leading to an increase in afternoon testosterone concentration and neuromuscular performance. In the present study, testosterone concentrations were not different between trials (Figure 6.3A-C), therefore this seems unlikely to be a contributing factor to the differences observed. However, cortisol works in tandem with testosterone to impact neuromuscular function (Crewther, Obmiński, et al., 2018), and was elevated following NET-STR compared with STR-NET (Figure 6.3), which may have exerted a positive impact on neuromuscular performance (Crewther, Obmiński, et al., 2018). Additionally, it could be that the eccentric muscle contractions involved in the strength training session, although accustomed and regularly performed, may have resulted in inflammation and neuromuscular fatigue (Dousset et al., 2007). Therefore, NET-STR may have resulted in a greater enhancement of neuromuscular performance compared with STR-NET, through positive effects of muscle temperature (Mcgowan et al., 2017; West, Cook, Beaven, et al., 2014) endocrine function (Crewther, Obmiński, et al., 2018) and reduced inflammation (Dousset et al., 2007).

Training session order effects on the following day

Neuromuscular performance was reduced following STR-NET at 20 h post, compared with NET-STR (Figure 6.2A-D), without any impact on mood or endocrine function. Previous studies have reported no effect of training session order at this time-point on neuromuscular performance, endocrine function or perceptual responses (Johnston et al., 2017; Sparkes et al., 2020). However, effects have been reported when endurance running and strength training have been combined within the same training day (Doma

& Deakin, 2013). When strength training was performed first, neuromuscular performance had not recovered within six hours, when participants then performed an endurance running session. The endurance running session was likely performed in a pre-fatigued state, resulting in accumulated fatigue across the session and greater impairment in performance the following day, compared with the opposite order. This could explain the findings in the present study, whereby players commenced the netball-training session in a fatigued state in the STR-NET trial. This may have resulted in a greater increase in muscle inflammation (Dousset et al., 2007) and altered excitation contraction coupling due to damage to type two muscle fibres (Skurvydas et al., 2016), from the eccentric muscle actions involved in the netball training. In contrast, when players performed NET-STR, both sessions were performed without impairment to the neuromuscular system, resulting in less accumulated fatigue than STR-NET.

The netball training sessions performed in chapters five and six were performed by a similar standard of players, however differed with regards to the aims (i.e. to replicate match-play vs. technical in nature for chapter five and six respectively) and duration (90 min vs. 107 min). Indeed, the demands differed between sessions, with lower total Player Load^{TM} (435 vs. 513 AU), Player Load^{TM} intensity (4.1 vs 5.6 AU·min^{-1}) and perceived exertion (sRPE and dRPE) for chapter six compared to chapter five, whilst mean heart rate was similar (147 vs. 147 b·min^{-1}). Additionally, responses to the training session differed depending on the marker examined. For example, testosterone concentrations were reduced two hours post-training in chapter five, yet remained similar in chapter six, whilst cortisol concentrations, neuromuscular performance and mood responses had a similar response between chapters. As responses are similar for many markers examined it would appear that players were similarly stressed by the sessions and conditioned for the imposed load. Testosterone concentrations showed a marked difference between training sessions, however this may be due to circadian rhythm changes in basal concentrations (training in chapter five commented at 16:30 h vs. 12:30 h), with a typical decrease observed from 12:00 h to 16:00 h (Teo, McGuigan, et al., 2011) influencing post-exercise responses.

Practical application of findings

It is important that all training sessions are performed optimally in order to maximise training performance and adaptation (García-Pallarés et al., 2009; Tan, 1999). Therefore, when strength training and technical netball training are to be performed within the same day, netball should precede strength training, with a two-hour recovery period being sufficient. This order of training permits both training sessions within the day to be performed well, and also minimises fatigue the following day. Training performance has been linked with adaptative responses; therefore, this order of training may enhance training adaptation, improve physical conditioning, and lead to an improvement in performance. A consistent finding across chapters five and six is that no differences in perceptual markers were observed, in spite of changes to neuromuscular performance. This highlights the need for neuromuscular performance to be monitored by coaches and conditioning coaches in the hours and days following training, to understand fatigue and readiness to train. Finally, it should be noted that this study involved the performance of a technical netball training session, where the aims were to stress technical and tactical aspects of netball performance, rather than physical conditioning. Further investigation is warranted with regards to the impact of training session order on a combination of strength training and a physically challenging netball training session.

Limitations and future direction for research

This study involved the performance of a technical-based netball training session, and as such whilst it was physically demanding, it is unclear whether performance of a more maximal, physically demanding training session would be influenced by prior strength training. Future research could therefore investigate the responses to a variety of training sessions, such as strength training combined with high intensity netball training, physical conditioning, or two netball training sessions performed within the same training day. As fatigue was evident two hours following the strength training session in comparison with that following netball training, the impact of a longer recovery period could be investigated. Menstrual cycle phase and hormonal contraceptive use was not controlled for or investigated within this study. Future research could therefore investigate the impact this may have upon the acute responses to training session order. As training performance is linked with adaptation, future research could investigate the adaptive response to a netball training programme including different orders of training.

Appendices

Appendix 1: Brief assessment of mood + (Shearer et al., 2017).

NAME: DATE:

Below are 10 questions we would like you to answer concerning how you feel. These questions are answered by indicating your feelings on a continuous line that ranges from ‘not at all’ to ‘extremely.’ Please read each one carefully then put a vertical line along the line that best describes HOW YOU FEEL RIGHT NOW in relation to your sport. Make sure you answer every question.

E.g. Not at all Extremely

1. How angry do you feel? Not at all Extremely
2. How confused do you feel? Not at all Extremely
3. How depressed do you feel? Not at all Extremely
4. How fatigued do you feel? Not at all Extremely
5. How tense do you feel? Not at all Extremely
6. How alert do you feel? Not at all Extremely
7. How confident do you feel? Not at all Extremely
8. How sore do your muscles feel? Not at all Extremely
9. How motivated to train do you feel? Not at all Extremely
10. How well do you feel you have slept? Not at all Extremely

Appendix 2: Ethical approval documentation for study one

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with A-STEM and College of Engineering Safety Policy, all research undertaken by staff or students linked with A-STEM must be approved by the A-STEM Ethical Committee.

RESEARCH MAY ONLY COMMENCE ONCE ETHICAL APPROVAL HAS BEEN OBTAINED

The researcher(s) should complete the form in consultation with the project supervisor. After completing and signing the form students should ask their supervisor to sign it. The form should be submitted electronically to Prof Mike McNamee ([redacted] and Dr Melitta McNarry [redacted]

Applicants will be informed of the Committee's decision via email to the project leader/supervisor.

1. TITLE OF PROJECT

The relationship between physical characteristics and match demands of international Netball.

2. DATE OF PROJECT COMMENCEMENT AND PROPOSED DURATION OF THE STUDY

Start date April 10th 2016. Duration approximately 18 months

3. NAMES AND STATUS OF RESEARCH TEAM

Laurence Birdsey – PhD student, Swansea University
Professor Liam Kilduff – Supervisor, Swansea University
Natalie Williams – PhD Student, Swansea University

4. RATIONALE AND REFERENCES

Although netball has been played across the world at an elite level for many years, few studies have characterised the movement or physical demands at the elite level (Otago, 1983; Fox *et al*., 2013;) or at the highest standard domestic league (Davidson and Trewartha, 2008), whilst the physiological cost of elite netball has not been reported. Understanding the demands and physiological consequence of a single or series of netball matches in elite players is vital to improve performance through the development of targeted physical development programmes, to inform athlete profiling as well as effective recovery strategies.

Fox *et al*. (2013) characterised the activity profile of elite Australian netball players in international netball and found positional differences in relation to the proportion of time spent active, the types of activity performed, length of activities performed and work to rest ratio. Although not at international level, Davidson and Trewartha (2008) found similar position specific demands through the analysis of several Super league matches. Distance covered by players differed greatly, with centres covering approximately 8 km during a match, whilst defenders covered approximately 4.2 km. This was achieved through defenders spending a greater proportion of time standing still, and less time spent jogging or running (Davidson and Trewartha, 2008). These findings suggest that position specific training is crucial for not only enhancing the skills required for game play, but also for conditioning players to the specific positional demands (Fox *et al*., 2013).

Recent rule changes may make previous research in this area is obsolete. Teams can no longer call injury breaks (often used tactically with each team able to and regularly use a 2 minute injury break during each quarter) potentially meaning far more work is performed by players with less rest. Indeed, it is extremely common for each team to call a 2 minute injury break during each quarter, meaning a total of 4 minutes of break during each 15 min quarter. This may affect the work to rest ratios, activity profile and distance covered as mentioned above, and may impact upon the required conditioning level of the players, as well as training needing to be performed.

To date, no studies have investigated the physiological demands of playing an elite netball match. The aforementioned studies were based only on movement of players from video, with a researcher categorising play in to specific activities, without any physiological measure such as heart rate measured during play. Additionally, unlike in other sports such as in rugby (West *et al*. ,2014), the hormonal response has not been measured following a single game, or series of games as would be experienced in a competition. Wood *et al*. (2013) assessed the time course of changes in neuromuscular function and markers of well-being in elite netball players following a netball match. Neuromuscular function was found to be reduced for 24 h post-match, and returned to baseline at 36 h post, however no other physical or physiological measures were taken. Players will often perform several matches with only 24 to 48 h recovery between performances, and in an upcoming tournament will play 3 matches in 3 days. Therefore, knowledge of hormonal, neuromuscular, and inflammatory responses following both a single and series of matches is important in order to develop optimal recovery strategies and training programme design (West *et al*., 2014).

Athletes and coaches spent vast amount of time both planning and performing training in order to improve competitive performance. Recently, Ross *et al*. (2016) investigated the relationship between physical characteristics, such as 40 m sprint time, bench press and aerobic capacity, and match performance in rugby sevens. The authors established relationships, such as a decrease in 10 m sprint time by 0.05 s was associated with a 40% increase in line breaks per match. This sort of analysis has yet to be performed in netball, however would be vital to a coach to develop targeted physical development programmes, inform player profiling (Ross *et al*., 2015) and understand what physical characteristics need to be improved to impact on a specific style of game play.

Therefore the aims of this study are to characterise the match demands of elite netball, describe the physiological consequence of both a single and series of international netball matches and to describe the relationship between physical characteristics and match performance in international netball.

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5. OBJECTIVES

The objectives of the study are:

- To characterise the movement demands of international netball.
- To identify the physiological consequences of performing both a single and a series of international netball matches.
- To identify the recovery timeline following a single and series of international netball matches.
- To describe the relationship between physical characteristics and match performance in international netball players.

6.1 STUDY DESIGN

The study will be conducted as a single group, observational study with no intervention. The aims are to characterise how players respond to the netball matches and the demands placed upon them during the matches by collecting a variety of data before, during and after the matches, and by performing a battery of fitness tests that they regularly perform throughout the season.

6.2 STUDY DESIGN

The study group will consist of members of the Welsh Netball team aged 18-35 years and includes females only. All participants will read the participant information sheet, provide written consent, and complete a health screening questionnaire prior to testing.

Once the above has been completed and it is established there are no reported health risks to participate participants will perform a battery of fitness tests to assess several components of netball related fitness. Participants will be familiar with these tests as part of the normal testing procedures and as such no familiarisation will be required.

Match demands will be monitored at a competition held over three days with one match performed each day. The day of travelling to the competition, each morning whilst there, after each game, and upon return from the competition players will report to the researchers to provide a saliva and blood sample, perform a series of countermovement jumps and complete a short questionnaire. During the three matches participants will be required to wear a small GPS and accelerometer unit as well as a heart rate monitor. Prior to the competition participants will have an opportunity to familiarise themselves with this equipment during training as this data will be recorded during 3 days of training prior to the competition.

6.3 PARTICIPANT RECRUITMENT

Participants will be members of the Senior Welsh Netball squad, training for and competing at Netball Europe 2016. All participants will be aware that their involvement is their own choice; will have the option of taking part in tests as well as wearing equipment during matches and that being part of this study will have no influence on team selection. Additionally, participants can withdraw at any point of the study, without penalty or detriment to present or future team selection. All information will be anonymous, personal information not shared and data reported only as group averages to all those other than the Welsh netball coaching team. Data will be analysed after the competition and as such performance related data will only be shared with the Welsh netball coaching team after the competition has finished in order to improve subsequent team performance. Therefore, the withdrawal by an athlete, or an athlete's performance in the administered tests, will have no influence on team selection for this event. Personal information will not be shared outside of the research team.

6.4 DATA COLLECTION METHODS

On arrival participants will complete the ACA/ACSM health-screening questionnaire, consent form and read the participant information sheet.

Fitness tests

Once it has been established there are no reported health risks to participate, participants will have their height and mass measured and recorded. Participants will then perform a series of fitness tests to assess power and strength of the lower limbs, aerobic capacity, agility and sprint performance. Tests include drop jump, broad jump, countermovement jump (CMJ), isometric mid-thigh pull, yo yo, Illinois agility, wall pass, 505 agility and 10 m sprint.

Netball match demands

The morning of travelling, each morning at the competition, following each match and upon return from the competition participants will report for measures to be taken, a total of eight times. This includes mass, a capillary blood sample (for analysis of blood lactate concentration, creatine kinase, C reactive protein, IL-6, IL-10, TNF alpha), a saliva sample (for analysis of testosterone, cortisol, IGA), the performance of a series of countermovement jumps as well as the completion of a short questionnaire regarding areas related to fatigue and recovery such as sleep, fatigue and muscle soreness. Participants will also be asked to provide details around their current menstrual cycle phase and hormonal contraceptive use.

During the three netball matches players will be required to wear a heart rate monitor and GPS unit to record heart rate, movement around the court and accelerations / decelerations. This equipment will also be offered to players to wear at several training days prior to the competition to familiarise themselves with wearing the devices. During this time data will be collected in the same way as detailed for competition analysis. In order to characterise activities and distinguish between different velocities for each player, particpants will be required to perform a series of timed 40 m sprints to establish maximum speed over this distance. Following a suitable warm up players will perform 4 – 8 x 40 m sprints as quickly as possible with 3-5 minutes rest between efforts.

Physiological measures

Blood sample – this will be measured each morning and evening upon reporting to the researchers, as well as prior to and after travelling to the competition. To record blood lactate levels, capillary blood samples will be taken from the finger and will be analysed using an automated lactate analyser for blood lactate (Biosen C-line Sport, EFK – diagnostic GmgH, Barleben, Germany). Davidson et al., (2000) has previously reported that the Biosen Lactate Analyser can provide valid, fast and reliable measure of blood lactate. Additionally, a 600 µL sample will be collected in a capillary tube and immediately centrifuged (Labofuge 400R, Kendro Laboratories, Germany) at 3000 rpm for 10 min for the extraction of plasma, which will be subsequently stored at −20^{o}C. The plasma samples will be left to thaw before 6 µL is used in the analysis of Creatine kinase using a semi-automated analyzer (Daytona Plus; Horiba Medical, UK). Sample testing will be carried out in duplicate. Analysis of other variables such as CRP, TNF alpha and IL-6, IL-10 will be performed as per the manufacturer's instructions.

Saliva sample – Participants will be asked to provide a sample of saliva for a timed period of 2-3 minutes into a sterile container each morning and after each match, and before and after travelling. Samples will be stored at **–**20°C until assay. Salivary steroid samples will be taken in this study as they are minimally invasive and have the advantage of reflecting free steroid concentrations, and are reported to be more physiologically relevant than total blood levels. To minimize the possibility of any blood contamination of saliva, which would result in an overestimation of hormone concentrations, the participants will be advised to avoid brushing their teeth, drinking hot or coloured fluids or eating hard foods (e.g. apples) in the 2 h before providing their sample. Saliva samples will be analysed in duplicate for testosterone, cortisol and IGA using commercial enzyme-immunoassay kits as per manufacturer's instructions (Salimetrics Europe Ltd., Suffolk, U.K.).

Testing measures

CMJ

For the measurement of CMJ peak power output (PPO), testing will be complete on a portable force platform (Kistler Instruments Ltd., Farnborough, United Kingdom). To isolate the lower limbs, participants will stand with hands placed on hips throughout the whole movement. After an initial stationary phase of at least 2 s in the upright position, for the determination of body mass, participants will perform a CMJ, dipping to a self-selected depth and then exploding upwards in an attempt to achieve maximum height. Participants will land back on the force platform and keep their arms on hips throughout the movement. Participants will be required to complete 3 maximum jumps with 1.5 min rest between efforts; PPO will then be calculated as detailed by West *et al*. (2011).

Isometric mid-thigh pull (IMTP)

The IMTP test will be carried out with the participants standing on a portable force platform (Kistler Instruments Ltd., Farnborough, United Kingdom), which will be positioned on the floor centered under the bar of a power rack. Participants will be positioned so that they assume a body position similar to that of athletes completing the second pull of a power clean with a flat trunk position and their shoulders in line with the bar. This position will allow athletes to maintain a knee angle of approximately 120–130^{o}. The bar height can be fixed at various heights above the force platform, to accommodate different sized participants, and the rack will be anchored to the floor. Once the bar height is established, the participants will stand on the force platform and will be instructed to pull as hard and as fast as possible on the bar for a period of approximately 5 seconds. The portable force platform will be used to measure the vertical component of the ground reaction force (GRF) of the participants during performance of a maximal effort IMTP. A sample rate of 1,000 Hz and a vertical force range of 20 kN will be used for all trials. West et al. (2011) provides evidence that the IMTP test can be used to measure maximal strength and explosiveness, both of which are related to jump and sprint acceleration performance.

Broad jump
Participants will start with their toes behind a line and once ready will perform a horizontal jump as far as they can. Upon landing participants must be able to stand still without taking extra steps or losing balance. Participants will be required to perform 3 jumps with 1.5 min rest between efforts.

Drop jump
Participants will stand on a box raised 30 cm above a portable force platform (Kistler Instruments Ltd., Farnborough, United Kingdom) with hands on their hips. Once ready participants will step off with a single leg, land on the force platform with both legs and jump to achieve maximum height as quickly as possible with minimum contact time. Participants will then land back on the force platform with their hands on hips throughout the whole movement. This test will also be performed in the same way however landing and jumping with a single leg from a height of 20 cm. Three trials will be performed of each with 1.5 min between trials.

Wall pass
Participants will stand 3 m from a wall, with the aim of passing the ball with 2 hands against the wall as many times as possible in 60 s. The ball must be caught with two hands to be counted as a successful pass.

Yo Yo
A distance of 20 m with a 2.5 m run off zone will be marked out for this test. Players will be required to run the 40 m shuttle (20 m there and back) in time with a series of beeps, followed by a rest period of 5 s where players will be required to walk 5 m (2.5 m there and back) in the run off zone. The time between the beeps progressively decreases between repetitions, requiring participants to cover the distance at a progressively faster speed. Participants will be required to continue to run in time with the beats until volitional exhaustion.

505
From a stationary standing position, participants will be required to run 15 m, turn 180^o and run a further 5 m in order to cover the distance as quickly as possible. Timing gates (Brower timing systems, Utah, USA) will be set up to measure the time taken to cover 10 m performed as the 5 m both towards and away from the 180^o turn.

Illinois agility
Participants will be required to run a series of shuttles including turning and running around cones as quickly as possible. The course is 10 m in length and 5 m across with a series of cones set out, guiding the participant around the test. Starting from a stationary standing position, participants will be required to; run 10 m, turn around 180^o, run 10 m, turn around 180^o, run around 4 cones evenly spaced in a straight line, turn around 180^o and perform the movement around the cones once more, turn around 180^o, run 10 m, turn around 180^o and run a final 10m. Timing gates (Brower timing systems, Utah, USA) will be set up at the start and finish to measure the time taken for the participant to perform the entire series of movements.

10 m sprint
Timing gates (Brower timing systems, Utah, USA) will be positioned at the start, at 5 m as well as at 10 m to record the time taken to perform the sprint. Participants will start from a stationary position and sprint to cover the 10 m as quickly as possible. Two trials will be performed with 5 min of passive recovery between trials. Performance will be measured to the nearest 0.01 s, with the fastest time for each participant used for analysis.

Participants will be asked to refrain from exercise and caffeine the morning prior to testing. Food consumption will also be controlled with no food or fluid consumption other than water 2h prior to saliva samples.

6.5 DATA ANALYSIS TECHNIQUES

The data will be analysed to identify any significant differences in physiological markers following the netball matches, to identify any significant correlations between physical attributes and match performance, and descriptive statistics used to characterise demands of netball matches. All data will be presented as the mean ± standard deviation unless otherwise indicated. Before carrying out analysis the data will be screened for errors and parametric suitability. Test of assumptions will be carried out to check for normality and homogeneity of variance. Analysis of blood markers, saliva markers and CMJ will be carried out using repeated measures ANOVA. Post hoc comparisons will be made where appropriate. All statistical analysis will be carried out using SPSS (SPSS Chicago, IL) with significance being accepted at the 95% confidence limit.

6.6 STORAGE AND DISPOSAL OF DATA AND SAMPLES

Biological samples (blood and saliva samples) and participant information will be stored and disposed of according to the Swansea University exercise physiology laboratory guidelines, which complies with the Human Tissue Act (2004). All samples will be disposed of once analysed and all samples will only be measured for what is stated in the ethics form. All data will be stored on a password-protected computer. Data relating to participants will be kept in digital format to avoid identification of participants; i.e. participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. Access to data generated during the study will be limited to the research team as stated in section 3 and Welsh netball coaching staff. The data will be retained until award of degree. Hard copies of the consent forms will be stored securely in a locked cupboard in Prof. Liam Kilduff's office and will be responsible for the deletion of all data.

6.7 HOW DO YOU PROPOSE TO ENSURE PARTICIPANT CONFIDENTIALITY AND ANONYMITY?

All data will be stored on a password-protected computer; this will include the original and only copy-aligning name and ID of participants. All further data relating to participants will be kept in digital format to avoid identification of subjects; i.e. all participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. All information will be kept anonymous and not shared outside the Welsh netball coaching team. Private information will not be shared, whilst performance related information will be shared with the Welsh netball coaching team for coaching purposes, however will not influence team selection.

7. LOCATION OF THE PREMISES WHERE THE RESEARCH WILL BE CONDUCTED

Data collection will be completed at Sport Wales National Centre and Northumbria University, with data analysis performed at Swansea University exercise physiology laboratory. A trained first aider (Laurence Birdsey) will be present at all sessions.

8. POTENTIAL PARTICIPANT RISKS AND DISCOMFORTS

There are potential risks of the study. Blood samples will be taken from the participants; procedures of how blood will be taken will be explained to participants prior to taking the samples and will have the right to withdraw at any time. Participants will also be asked of any phobias of needles or blood. A first aider (Laurence Birdsey) will always be supervising the study due to potential health risks and all researchers will wear gloves when conducting the tests and any items that have blood on will be disposed of according to section 6.6. Likewise any sharp items will be disposed of appropriately.

Participants will be asked to provide a sample of saliva into a sterile container, this may cause discomfort and therefore participants will be given the option not to participate if they are uncomfortable.

Participants are required to complete maximal effort during fitness tests and the netball matches. Strenuous exercise could be a risk if there are any underlying health issues present. All participants will fill in a consent form and ACA/ACSM health screening questionnaire to identify any health risks associated with maximal exercise before any testing begins.

Participants will be asked to wear a heart rate monitor and GPS unit during the matches. Opportunities to familiarise with this equipment will be provided to minimise discomfort experienced during the matches and participants will be given the option to not wear this if it is uncomfortable.

9.1 HOW WILL INFORMED CONSENT BE SOUGHT?

Informed consent will be obtained from each participant, participants will be asked to sign a consent form prior to the start of the study if they agree and are comfortable to participate.

9.2 INFORMATION SHEETS AND CONSENT/ASSENT FORMS

• Have you included a Participant Information Sheet for the participants of the study?	YES
• Have you included a Parental/Guardian Information Sheet for the parents/guardians of the study?	NO
• Have you included a Participant Consent (or Assent) Form for the participants of the study?	YES
• Have you included a Parental/guardian Consent Form for the participants of the study?	NO

10. IF YOUR PROPOSED RESEARCH IS WITH VULNERABLE POPULATIONS (E.G. CHILDREN, PEOPLE WITH A DISABILITY), HAS AN UP-TO-DATE DISCLOSURE AND BARRING SERVICE (DBS) CEHCK (PREVIOUSLY CRB) IF UK, OR EQUIVALENT NON-UK, CLEARANCE BEEN REQUESTED AND/OR OBTAINED FOR ALL RESEARCHERS? EVIDENCE OF THIS WILL BE REQUIRED.

11. STUDENT DECLARATION

Please read the following declarations carefully and provide details below of any ways in which your project deviates from these. Having done this, each student listed in section 2 is required to sign where indicated.

- ***"I have ensured that there will be no active deception of participants.***
- ***I have ensured that no data will be personally identifiable.***
- ***I have ensured that no participant should suffer any undue physical or psychological discomfort (unless specified and justified in methodology).***
- ***I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.***
- ***I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.***
- ***I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.***
- ***I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.***
- ***I certify that the above statements are true with the following exception(s):"***

Student/Researcher signature: [redacted]

Date: 24/03/16

12. SUPERVISOR'S APPROVAL

Supervisor's signature:

Date:

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARTICIPANT INFORMATION SHEET
(Version 1.1, Date: xx/xx/20xx)

Project Title:

The relationship between physical characteristics and match demands of international Netball.

Contact Details:

Laurence Birdsey; [redacted]

1. Invitation Paragraph

We would like to invite you to volunteer for this study that aims to identify the relationship between physical characteristics and match demands of international netball. The study will be beneficial to you, aiming to inform your fitness profile, how this relates to match performance, areas which show room for improvement as well as informing recovery strategies. We would like to thank you for taking the time to read this information sheet and very much hope you decide to take part.

2. What is the purpose of the study?

The purpose of the study is to characterise the match demands of international netball, identify the relationship between physical characteristics (such as speed and power) with key match performance indicators and identify the fatigue and recovery responses to a series of matches.

3. Why have I been chosen?

You have been chosen to complete this study as a member of the Welsh netball squad for Netball Europe 2016. You will have the right to withdraw from the study at any time, without having to provide reasoning and this will not affect team selection. Performance related information will be shared only with the Welsh netball coaching team and kept anonymous to those outside, however private information will be kept confidential to all.

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

You will be required to take part in a fitness testing session prior to Netball Europe as part of the regular fitness battery, provide measurements each morning and evening whilst there including saliva and capillary blood samples and wear monitoring devices during matches. The monitoring devices will collect information during the matches using an accelerometer and indoor GPS system to provide movement and acceleration data around the court. You will also be required to wear a heart rate monitor throughout the matches for measurement of heart rate. You will be provided with this equipment during training sessions prior to the competition to familiarise yourself with wearing this. Below provides further information regarding specific procedures to be used during the measurements.

Morning measurements

Capillary blood sample - Prior to any sample being taken you will be asked to be seated, the procedure will be explained to you and confirm you are happy to proceed. The area of the finger will be cleaned with an alcohol wipe before a small capillary blood sample is taken from your finger. A lancet will be used to puncture the tip of the finger in which a small blood sample will be collected from.

Saliva sample - You will be asked to provide a sample of saliva for a period of 2-3 minutes into a sterile container each morning and evening at the same time as the blood samples. This method is not invasive but the procedure will be explained to you to make sure you are happy prior to providing a saliva sample.
Countermovement jump – You will be asked to complete a countermovement jump, which will involve standing on a force platform, hands on your hips, before dipping to a self-selected depth and then exploding upwards to jump as high as possible. You will be required to complete 3 maximum jumps with 1.5 min rest between efforts. This is a normal part of your training so you should be familiar with this.
Questionnaire – You will be asked a number of questions such as how well you slept, how fatigued you are and how sore your muscles are as well as several questions regarding current menstrual cycle phase and hormonal contraceptive use.

Fitness testing

This will include a series of tests designed to assess various components of fitness, which relate to netball performance as well as specific netball tests that make up your normal fitness testing.
Isometric mid-thigh pull – you will be asked to position yourself with a straight flat back and slight bend of the knees with arms extended down holding a bar directly beneath you. The bar height will be adjusted to allow you to reach this position, and once established, you will be instructed to pull as hard and as fast as possible on the bar for a period of approximately 5 seconds. The bar will be fixed so will not move.
Countermovement jump – as described above.
Broad jump – starting in a standing position you will dip, swing your arms and jump as far as possible in a horizontal direction. You must land with both feet still, without losing balance and touching the floor with your hands.
Drop jump – you will start with hands on your hips, stood on a 30 cm box. You will then be required to step down on to a force platform, land with both feet, and upon landing as quickly as possible jump as high as possible, before landing on the force platform. Hands must stay on hips throughout the whole movement. This will also be performed using a single leg only from a height of 20 cm.
10 m sprint – you will start from a stationary position and once ready sprint to cover 10 m as quickly as possible.
Yo Yo – this involves performing a 40 m shuttle (20 m there and back) at progressively faster speeds with a short rest between each effort. The aim is to complete as many stages as possible and as such reach the highest speed you are able to.
505 – starting from a standing position you first perform a 15 m sprint, turn 180^{o}, and a final 5 m as quickly as possible. The aim is to complete to 5 m in to the turn and out of the turn as quickly as possible.
Illinois agility – this involves performing a series of shuttles including 180^{o} turns and running between cones as quickly as possible in order to measure your agility and speed over short distances.
Wall pass – standing 3 m away from a wall you will be asked to pass the ball against the wall and catch it on the rebound as many times as possible. The ball must be caught in both hands for it to be a successful pass.

Participants will be asked to refrain from caffeine, fluid and food each morning prior to testing at Netball Europe and exercise the morning prior to fitness testing.

5. What are the possible disadvantages of taking part?

There are possible risks of the study. Firstly, blood samples and saliva will be collected. Procedures of how both will be collected will be explained to you prior to taking the blood and saliva and you will have the right to withdraw at any stage. During the matches, you will be required to wear a heart rate monitor and accelerometer, which may cause discomfort. Time will be given prior to this to get used to wearing the equipment, however you have the right to withdraw at any stage. You will also be expected to participate in strenuous exercise that may cause some slight discomfort, but should not be any different from your normal training and competition. Although performance related information would be shared with the Welsh netball coaching team this will not influence team selection whether you decide to participate or not, or whether you decide to withdraw from the study at any point.

6. What are the possible benefits of taking part?

As a result of participating you will gain valuable information about your fitness profile, how this can be improved to improve match performance, as well as information regarding suitable recovery strategies.

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

All data will be kept confidential and results will not be accessible to anyone other than the research team and the Welsh netball coaching team. Private information will be kept confidential to all. At the end of the study all data will be disposed of according to set guidelines.

8. What if I have any questions?

If you have any questions throughout the duration of this study, please do not hesitate to ask – contact details for the researcher are provided at the start of this document.

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

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

Project Title:
The relationship between physical characteristics and match demands of international Netball

Contact Details:

Laurence Birdsey; [redacted]

Please initial box

1. I confirm that I have read and understood the information sheet dated ……/……/…… (version number ……………………) 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. ☐
4. I agree to take part in the above study.

Name of Participant	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

Appendix 3: Ethical approval documentation for study two

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with A-STEM and College of Engineering Safety Policy, all research undertaken by staff or students linked with A-STEM must be approved by the A-STEM Ethical Committee.

RESEARCH MAY ONLY COMMENCE ONCE ETHICAL APPROVAL HAS BEEN OBTAINED

The researcher(s) should complete the form in consultation with the project supervisor. After completing and signing the form students should ask their supervisor to sign it. The form should be submitted electronically to Pam Swanborough - [redacted]).

Applicants will be informed of the Committee's decision via email to the project leader/supervisor.

1. TITLE OF PROJECT

The neuromuscular, physiological and endocrine responses to an on court netball session in elite female netball players.

2. DATE OF PROJECT COMMENCEMENT AND PROPOSED DURATION OF THE STUDY

01/12/16 for approximately 6 months.

3. NAMES AND STATUS OF RESEARCH TEAM

State the names of all members of the research group including the supervisor(s). State the current status of the student(s) in the group i.e. Undergraduate, Postgraduate, Staff or Other (please specify).

Laurence Birdsey – PhD student, Swansea University. Trish Wilcox (Celtic Dragons Coach)
Professor Liam Kilduff – Supervisor, Swansea University. Matt Weston – 2nd supervisor (Tees Uni)

4. RATIONALE AND REFERENCES

With reference to appropriate sources of information (using the Harvard system), describe **in no more than 200 words** the background to the proposed project.

Balancing adaptation and recovery is important for coaches, especially when training more than once per day or within a competition season. One study has investigated the responses to an elite level netball match (Wood *et al*., 2013) with reduced CMJ and perceptual well-being markers for 24 h with measures returning to baseline at 36 h post. Following a football match in elite female players, Andersson *et al*. (2008) found it took between 5 h and 3 days for markers of fatigue to return to baseline. Additionally, Twist *et al*. (2011) concluded fatigue experienced following a professional rugby league match was similar between forwards and backs although the mechanism was different and related to demands.

The physiological response to training and performance is therefore important to understand, with markers of fatigue recovering at different rates, and mechanisms of fatigue differing for playing positions, however at present there is a lack of research investigating this area in detail in netball. The aim of this study is therefore to characterise the physiological consequences of performing a regularly performed netball training session, to further understand the balance between adaptation and fatigue in elite netball players to inform the planning of training.

Andersson, H., Raadstad, T., Nilsson, J., Paulsen, G., Garthe I. and Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Medicine and science in sports and exercise*, **40**, 2, 372-380.

Chandler, P.T., Pinder, S.J., Curran, J.D. and Gabbett, T.J. (2014). Physical demands of training and competition in Collegiate netball players. *Journal of strength and conditioning research*, **28**, 10, 2732-2737.

Twist, C., Waldron, M., Highton, J., Burt, D. and Daniels, M. (2012). Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *Journal of sport sciences*, **30**, 4, 359-367.

Wood, A.J., Kelly, V.G. and Gabbett, T.J. (2013). Neuromuscular and perceptual fatigue responses to an elite level netball match. *Journal of Australian strength and conditioning*, **21**, 1, 24-28.

5. OBJECTIVES

State the objectives of the project, i.e. one or more precise statements of what the project is designed to achieve.

- To identify the physiological consequences of performing a netball training session.
- To characterise the recovery profile 2 hours and 24 hours after the training session.
- To provide the coach with detailed information regarding the physiological response to training to inform planning, timing and content of training in the preparation and competition phase of the year.

6.1 STUDY DESIGN

- outline the chosen study design (e.g. cross-section, longitudinal, intervention, RCT, questionnaire etc)

Single group, observational study with no intervention.

6.2 STUDY DESIGN

- state the number and characteristics of study participants
- state the inclusion criteria for participants
- state the exclusion criteria for participants and identify any requirements for health screening
- state whether the study will involve vulnerable populations (i.e. young, elderly, clinical etc.)
- state the requirements/commitments expected of the participants (e.g. time, exertion level etc)

Up to 20 female netball players. All participants will be part of the Celtic Dragons senior netball squad, aged 18 to 35 years, deemed fit by the team physiotherapist and compete as part of the British netball superleague. Participants will perform a training session at the standard time and day of the week as part of the general preparation phase. This will be a 2 hour training session and involve technical / tactical training, as well as high intensity physical exercise. This would be classed as a typical training session, as such players will not be required to perform any training that would not typically be performed at this time of the season.

All participants will read the participant information sheet, provide written consent, and complete a health screening questionnaire prior to testing. Once the above has been completed and it is established there are no reported health risks to participate participants will perform a series of measurements consisting of countermovement jump (CMJ), measures of perceptual well-being, a saliva sample and blood sample (further details in 6.4). Participants will be required to wear a heart rate monitor and accelerometer throughout the training session.

Appendix A provides further details of the training session. Following baseline measurements players will perform a team warm up of approximately 20-mins consisting of a team running exercise, dynamic stretching, ball skills work and specific netball movements. This is then followed by the main session, starting with approximately 20 mins of scenario drills aiming to develop decision making and skills under pressure by use of specific structured exercises. This includes high intensity, small sided games of 4 a side in a reduced space with all players involved in the game at all times. Although there is a strong tactical and technical component, the reduction of playing dimensions and removal of specific positions results in high intensity exercise. Following this the participants will perform scenario game specific match play for approximately 40 mins. The aim of this is to create specific scenarios, for example the team is 2 points behind and a set play is called, to put in to practice what has been worked on during the session thus far. This will be performed with standard court dimensions and player numbers.

Immediately following the training session participants will complete differential RPE to describe the perceived effort of the training sessions and then repeat the measures (CMJ, well-being, saliva, blood). They will then be allowed to shower and get changed, have a standardized meal, and rest. Two hours following the end of the training session participants will perform the measurements for a final time before being allowed to leave. The following day, approximately 24 hours after commencing the training session the day before, participants will perform the same measures again (CMJ, well-being, saliva and blood sample).

6.3 PARTICIPANT RECRUITMENT

How and from where will participants be recruited?

Participants will be members of the Celtic Dragons senior netball team, aged 18-35 years and females only. The team coach has highlighted this as an area she is interested to know more about with her players of the Celtic Dragons. Participants however will not be required to take part if they do not wish to, and only after reading the participant information sheet, providing written consent, and completing a health screening questionnaire will data collection commence. There will be no consequences for participants who do not wish to take part and will be able to train exactly the same with the other participants without taking part in the measurements around training.

6.4 DATA COLLECTION METHODS

- describe all of the data collection/experimental procedures to be undertaken
- state any dietary supplementation that will be given to participants and provide full details in Section 6.5
- state the inclusion of participant information and consent forms (in appendices)
- refer to the use of the ACA/ACSM health screening questionnaire where appropriate (usually for maximal effort exercise)

On arrival participants will complete the ACA/ACSM health-screening questionnaire, consent form and read the participant information sheet (found in appendices).

Blood sample

This will be measured before, immediately post, 2 hours post and 24 hours post the training session. To record blood lactate levels, capillary blood samples will be taken from the finger and will be analysed using an automated lactate analyser for blood lactate (Biosen C-line Sport, EFK – diagnostic GmgH, Barleben, Germany). Davidson et al. (2000) has previously reported that the Biosen Lactate Analyser can provide valid, fast and reliable measure of blood lactate. Additionally, a 600 µL sample will be collected in a capillary tube and immediately centrifuged (Labofuge 400R, Kendro Laboratories, Germany) at 3000 rpm for 10 min for the extraction of plasma, which will be subsequently stored at −20^{o}C. The plasma samples will be left to thaw before 6 µL is used in the analysis of Creatine kinase using a semi- automated analyzer (Daytona Plus; Horiba Medical, UK). Sample testing will be carried out in duplicate. Analysis of other variables such as CRP, TNF alpha and IL-6, IL-10 will be performed as per the manufacturer's instructions.

Saliva sample

Participants will be asked to provide a sample of saliva for a timed period of 2-3 minutes into a sterile container at the same time points as detailed above. Samples will be stored at –20°C until assay. Salivary steroid samples will be taken in this study as they are minimally invasive and have the advantage of reflecting free steroid concentrations, and are reported to be more physiologically relevant than total blood levels. To minimize the possibility of any blood contamination of saliva, which would result in an overestimation of hormone concentrations, the participants will be advised to avoid brushing their teeth, drinking hot or coloured fluids or eating hard foods (e.g. apples) in the 2 h before providing their sample. Saliva samples will be analysed in duplicate for testosterone, cortisol and IGA using commercial enzyme-immunoassay kits as per manufacturer's instructions (Salimetrics Europe Ltd., Suffolk, U.K.).

CMJ
For the measurement of CMJ peak power output (PPO), testing will be complete on a portable force platform (Kistler Instruments Ltd., Farnborough, United Kingdom). To isolate the lower limbs, participants will stand with hands placed on hips throughout the whole movement. After an initial stationary phase of at least 2 s in the upright position, for the determination of body mass, participants will perform a CMJ, dipping to a self-selected depth and then exploding upwards in an attempt to achieve maximum height. Participants will land back on the force platform and keep their arms on hips throughout the movement. Participants will be required to complete 3 maximum jumps with 60 s rest between efforts; PPO will then be calculated as detailed by West *et al*. (2011).

Training demands
Participants will be required to wear a heart rate monitor (Polar Team system 2, Polar electro, Warwick, UK) and accelerometer in a custom made harness placed upon the upper back (Catapult S5, Catapult Innovations, Leeds, UK) throughout the entire training session from the start of the warm up to the end of the cool down. These measurements are minimally invasive, provide accurate information regarding physical exertion and have been previously used to monitor the demands of netball (Cormack *et al*., 2014; Chandler *et al*., 2014).

Perceptual responses
Participants will complete an adapted version of the brief assessment of mood questionnaire (BAM+) which has been previously found to be effective in monitoring recovery in elite athletes (Shearer *et al*., 2016). Using a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc) a series of questions will be asked one at a time with a visual analogue scale ranging from “not at all” to “extremely”. An overall recovery score will be generated by subtracting the mean score of negative related items from the mean score of the positively related questions. BAM+ has been found to be moderately correlated to high intensity match activity, as measured by GPS technology, and is sensitive to physiological responses which occur following competition over 48 hour following performance in elite team sport athletes (Shearer *et al*. 2016).

Differential rating of perceived exertion
After the training session players will record session RPE along with differential session ratings for breathlessness, leg muscle exertion, upper body muscle exertion and cognitive / technical demands. Ratings will be graded using a numerically blinded CR100 scale with verbal anchors, which provides a more sensitive and precise measurement of perceived exertion than the traditional CR10 scale (Fanchini *et al*., 2016), and will be recorded via a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc). Each RPE will then be multiplied by the playing time in minutes to calculate session training loads (Foster *et al*., 2001). Differential RPE has been found to be a more sensitive measure than session RPE for the physiological response to a stimulus (McLaren *et* al., 2015) and provides a detailed quantification for internal load during team sport activities (McLaren *et al*., 2016).

6.5 DATA ANALYSIS TECHNIQUES
- describe the techniques that will be used to analyse the data

The data will be analysed to identify any significant differences in physiological markers at the various time points before and after the training session. Descriptive statistics will be used to characterise physical demands of the training session. All data will be presented as the mean ± standard deviation unless otherwise indicated. Before carrying out analysis the data will be screened for errors and parametric suitability. Test of assumptions will be carried out to check for normality and homogeneity of variance. Analysis of blood markers, saliva markers and CMJ will be carried out using repeated measures ANOVA. Post hoc comparisons will be made where appropriate. All statistical analysis will be carried out using SPSS (SPSS Chicago, IL) with significance being accepted at the 95% confidence limit.

6.6 STORAGE AND DISPOSAL OF DATA AND SAMPLES
- describe the procedures to be undertaken for the storage and disposal of data and samples
- identify the people who will have the responsibility for the storage and disposal of data and samples
- Identify the people who will have access to the data and samples
- state the period for which the data will be retained on study completion (normally 5 years, or end of award)

Biological samples (blood and saliva samples) and participant information will be stored and disposed of according to the Swansea University exercise physiology laboratory guidelines, which complies with the Human Tissue Act (2004). All samples will be disposed of once analysed and all samples will only be measured for what is stated in the ethics form. All data will be stored on a password-protected computer. Data relating to participants will be kept in digital format to avoid identification of participants; i.e. participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. Access to data generated during the study will be limited to the research team as stated in section 3 and Celtic Dragons coaching staff. Data will be provided to the coaching staff regarding the response to the training session as stated in section 5, however all data will be anonymous. The data will be retained until award of degree. Hard copies of the consent forms will be stored securely in a locked cupboard in Prof. Liam Kilduff's office and will be responsible for the deletion of all data.

6.7 HOW DO YOU PROPOSE TO ENSURE PARTICIPANT CONFIDENTIALITY AND ANONYMITY?

All data will be stored on password-protected computer, one belonging to Laurence Birdsey and one located in Prof Kilduff's office and ; this will include the original and only copy-aligning name and ID of participants. All further data relating to participants will be kept in digital format to avoid identification of subjects; i.e. all participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. All information will be kept anonymous and not shared outside the Celtic Dragons coaching team whilst private information will not be shared at all.

6.8 PLEASE PROVIDE DETAILS OF ANY DIETARY SUPPLEMENTATION (DELETE IF NOT APPLICABLE)

7. LOCATION OF THE PREMISES WHERE THE RESEARCH WILL BE CONDUCTED.

- *list the location(s) where the data collection and analysis will be carried out*
- *identify the person who will be present to supervise the research at that location*
- *If a first aider is relevant, please specify the first aider*

Sport Wales National Centre, Cardiff. Laurence Birdsey present to supervise the research. A first aider (Victoria Meah) will be present at all times as per Sport Wales and Celtic Dragons guidelines.

8. POTENTIAL PARTICIPANT RISKS AND DISCOMFORTS

- *identify any potential physical risk or discomfort that participants might experience as a result of participation in the study.*
- *identify any potential psychological risk or discomfort that participants might experience as a result of participation in the study.*
- *Identify the referral process/care pathway if any untoward events occur*

There are potential risks of the study. Blood samples will be taken from the participants; procedures of how blood will be taken will be explained to participants prior to taking the samples and will have the right to withdraw at any time. Participants will also be asked of any phobias of needles or blood. All researchers will wear gloves when conducting the tests and any items that have blood on will be disposed of according to section 6.6. Likewise any sharp items will be disposed of appropriately.

Participants will be asked to provide a sample of saliva into a sterile container, this may cause discomfort and therefore participants will be given the option not to participate if they are uncomfortable. Opportunities to practice will be provided to those unfamiliar with this procedure.

Participants will be required to take part in a strenuous training session. Strenuous exercise could be a risk if there are any underlying health issues present. All participants will fill in a consent form and ACA/ACSM health screening questionnaire to identify any health risks associated with maximal exercise before any testing begins.
Participants will be asked to wear a heart rate monitor and GPS unit during the matches. Opportunities to familiarise with this equipment will be provided to minimise discomfort experienced during the matches and participants will be given the option to not wear this if it is uncomfortable.

9.1 HOW WILL INFORMED CONSENT BE SOUGHT?

Will any organisations be used to access the sample population?

Will parental/coach/teacher consent be required? If so, please specify which and how this will be obtained and recorded?

Informed consent will be obtained from each participant, participants will be asked to sign a consent form prior to the start of the study if they agree and are comfortable to participate. Consent from other parties will not be required. The Celtic Dragons netball team have allowed us access to the players.

9.2 INFORMATION SHEETS AND CONSENT/ASSENT FORMS

- Have you included a Participant Information Sheet for the participants of the study?

  YES

- Have you included a Parental/Guardian Information Sheet for the parents/guardians of the study?

  NO

- Have you included a Participant Consent (or Assent) Form for the participants of the study?

  YES

- Have you included a Parental/guardian Consent Form for the participants of the study?

  NO

10. IF YOUR PROPOSED RESEARCH IS WITH VULNERABLE POPULATIONS (E.G. CHILDREN, PEOPLE WITH A DISABILITY), HAS AN UP-TO-DATE DISCLOSURE AND BARRING SERVICE (DBS) CEHCK (PREVIOUSLY CRB) IF UK, OR EQUIVALENT NON-UK, CLEARANCE BEEN REQUESTED AND/OR OBTAINED FOR ALL RESEARCHERS? EVIDENCE OF THIS WILL BE REQUIRED.

N/A

11. STUDENT DECLARATION

Please read the following declarations carefully and provide details below of any ways in which your project deviates from these. Having done this, each student listed in section 2 is required to sign where indicated.

- ***"I have ensured that there will be no active deception of participants.***
- ***I have ensured that no data will be personally identifiable.***
- ***I have ensured that no participant should suffer any undue physical or psychological discomfort (unless specified and justified in methodology).***
- ***I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.***
- ***I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.***
- ***I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.***
- ***I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.***
- ***I certify that the above statements are true with the following exception(s):"***

Student/Researcher signature: [redacted] (include a signature for each student in research team)

Date: 22/11/16

12. SUPERVISOR'S APPROVAL

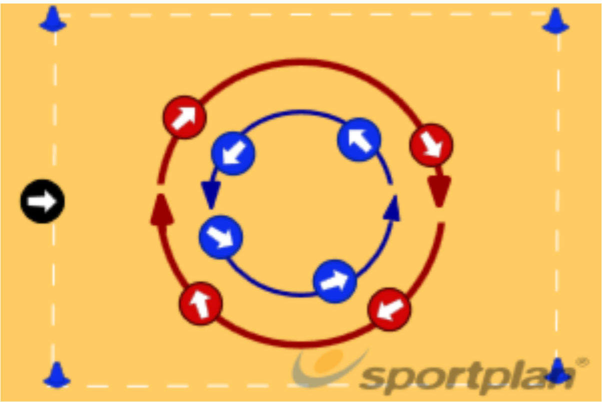
Supervisor's signature:

Date:

APPENDIX A – Netball session to be performed

Warm up **20 mins**

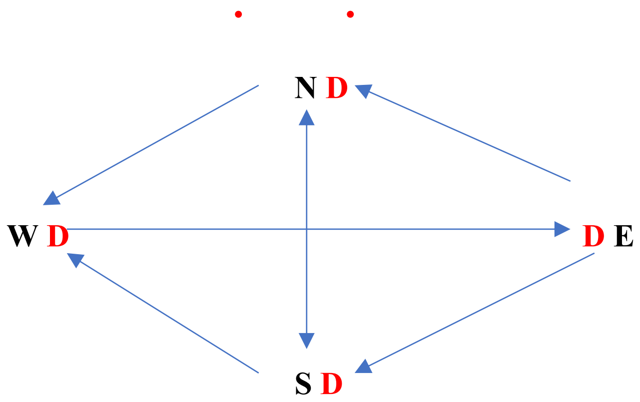
Jail Break



- One team runs clockwise round the inside of the circle with the other team running anti-clockwise around the outside of the circle. In this example the defenders are red, and the attackers are blue.
- When the coach shouts 'Jailbreak' the players inside the inner circle try to 'escape' to outside the 10m x 10m square (yellow cones).
- The inside team scores a point for each 'jailbreaker' - swap over. If you have an odd number of players give the defenders the extra man.
-
- Dynamic Stretching in between each round
-
- Ball Work – pairs (keeping 2 circle formations) red player partners with blue and completes the following ball work activities
- 2 balls - red 10 chest to blue shoulder alternate passing to left and right sides -blue one hand shoulder then swap /red 5 chest -blue bounce then swap/both one hand to hand 10, red shoulder height blue low then swap/ anywhere with 2 balls x 10 then swap

- Back to original formation Coach to call different attacking movements as part of warm up – COD, roll, half roll, dodge / defense to mimic angles and execute open and closed defence appropriate to the situation swap x twice 10 mins

The Compass



- Set up 4 feeders in Compass positions (North, South, East, West), with 2 defenders standing in front of W and E. Set up a square area around NS E and W in which they have to receive a pass
- The E feeder begins the drills by passing to either the N or S feeder. (D has hands over) look for E to pass around D .Whichever N or S feeder has the ball then passes to the W feeder and the D here covers front initially when E has the ball then moves to cover W moves to receive pass and can go for the intercept. N,S,E,W all have to execute a pre movement to receive the ball
- If D intercept then roles are reversed and D s become NSEW and are on attack and original NSEW transition quickly onto D
- Progress to Attackers can drive into another box which then introduces switches on defence (not to chase As) Attackers have to balance the compass

COACHING POINTS
This practice develops decision making and passing/catching under pressure.
The defenders should work together, using good communication and directing each other R etc)

On Defence

- If the defenders miss an intercept then they should recover and get back to cover next move / next pass.
- If one defender goes for the intercept too early then the other can pick up the intercept.
- Make sure all intercepts are clean 2 handed intercepts.
- The attackers can fake passes and vary the types of passing to make it more challenging for the defenders.
- Attackers must use definite short sharp movement using hip turns and keeping

(20mins)

Scenario Game specific match play (40 mins)
Cool down / stretch 15 mins

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARTICIPANT INFORMATION SHEET
(Version 1.1, Date: xx/xx/20xx)

Project Title:

The neuromuscular, physiological and endocrine responses to an on court netball session in elite female netball players.

Contact Details:

Laurence Birdsey; [redacted]

1. Invitation Paragraph

We would like to invite you to volunteer for this study that aims to identify physiological response and recovery profile of a netball training session. The study will be beneficial to you and your team, aiming to inform the planning of training in the preparation and competition phase and ensure you get the most out of training and competition. We would like to thank you for taking the time to read this information sheet and very much hope you decide to take part.

2. What is the purpose of the study?

The purpose is to characterise how your body responds to a netball training session, immediately after training, 2 hours after, and the following day. This will show at what point you have recovered or are still fatigued and will help plan training sessions, especially for weekend camps and in the lead up to matches.

3. Why have I been chosen?

You have been chosen to complete this study as a member of the Celtic Dragons. You will have the right to withdraw from the study at any time, without having to provide reasoning and this will not affect training performance or team selection.

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

You will perform a series of measurements before and after your on court training session. These measurements include a small blood sample from your finger tip, a saliva sample and performing a countermovement jump. Training will be a regular training session, however during this you will be required to wear a heart rate monitor and accelerometer device to monitor your physical activity and exertion. Straight after training you will repeat the measures, followed by 2 hours to shower, have dinner and relax, after which you will repeat the measures once more. The following day you will be required to repeat the measures for a final time.

Capillary blood sample - Prior to any sample being taken you will be asked to be seated, the procedure will be explained to you and confirm you are happy to proceed. The area of the finger will be cleaned with an alcohol wipe before a small capillary blood sample is taken from your finger. A lancet will be used to puncture the tip of the finger in which a small blood sample will be collected from.

Saliva sample - You will be asked to provide a sample of saliva for a period of 2-3 minutes into a sterile container. This method is not invasive but the procedure will be explained to you to make sure you are happy prior to providing a saliva sample.

Countermovement jump – You will be asked to complete a countermovement jump, which will involve standing on a force platform, hands on your hips, before dipping to a self-selected depth and then exploding upwards to jump as high as possible. You will be required to complete 3 maximum jumps with 1 min rest between efforts. This is a normal part of your training so you should be familiar with this.

Well-being - using a tablet device you will be asked 10 questions about your well-being (such as quality of sleep, muscle soreness, fatigue) and using a slider scale you will choose your response.

Rating of perceived exertion – after training you will be asked to rate how hard the training was using a tablet device. This will include how hard the session was overall, how breathless it made you, how hard it was for the upper body, lower body, and technically.

You will be required to avoid brushing your teeth, eating hard food like apples, or drinking hot or coloured fluids 2 hours before attending. This is to avoid your saliva sample being contaminated with any blood.

5. What are the possible disadvantages of taking part?

There are possible risks of the study. Firstly, blood samples and saliva will be collected. Procedures of how both will be collected will be explained to you prior to taking the blood and saliva and you will have the right to withdraw at any stage. During training, you will be required to wear a heart rate monitor and accelerometer, which may cause discomfort. Time will be given prior to this to get used to wearing the equipment, however you have the right to withdraw at any stage. You will also be expected to participate in strenuous exercise that may cause some slight discomfort, but should not be any different from your normal training and competition. Although performance related information would be shared with the Celtic Dragons coaching team this will not influence team selection whether you decide to participate or not, or whether you decide to withdraw from the study at any point.

6. What are the possible benefits of taking part?

As a result of participating you and your team will gain valuable information about the physiological response to training which will help to inform your coach in order to balance the training response with potential fatigue, particularly in the build up to matches to make sure you are as fit as possible but as fresh as possible to perform.

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

All data will be kept confidential and results will not be accessible to anyone other than the research team and the Celtic Dragons coaching team. Results will be anonymized and private information will be kept confidential to all. At the end of the study all data will be disposed of according to set guidelines.

8. What if I have any questions?

If you have any questions throughout the duration of this study, please do not hesitate to ask – contact details for the researcher are provided at the start of this document.

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

Project Title:

The neuromuscular, physiological and endocrine responses to an on court netball session in elite female netball players.

Contact Details:

Laurence Birdsey; [redacted]

Please initial box

1. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) 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. ☐
4. I agree to take part in the above study.

______________________	____________	__________________
Name of Participant	Date	Signature
______________________	____________	__________________
Name of Person taking consent	Date	Signature
______________________	____________	__________________
Researcher	Date	Signature

AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire

Assess your health status by marking all *true* statements

History

You have had:
___ a heart attack
___ heart surgery
___ cardiac catheterization
___ coronary angioplasty (PTCA)
___ pacemaker/implantable cardiac
___ defibrillator/rhythm disturbance
___ heart valve disease
___ heart failure
___ heart transplantation
___ congenital heart disease

Symptoms

___ You experience chest discomfort with exertion.
___ You experience unreasonable breathlessness.
___ You experience dizziness, fainting, or blackouts.
___ You take heart medications.

Other health issues

___ You have diabetes.
___ You have asthma or other lung disease.
___ You have burning or cramping sensation in your lower legs when walking short distances.
___ You have musculoskeletal problems that limit your physical activity.
___ You have concerns about the safety of exercise.
___ You take prescription medication(s).
___ You are pregnant.

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a **medically qualified staff.**

Cardiovascular risk factors

___ You are a man older than 45 years.
___ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
___ You smoke, or quit smoking within the previous 6 months.
___ Your blood pressure is >140/90 mm Hg.
___ You do not know your blood pressure.
___ You take blood pressure medication.
___ Your blood cholesterol level is > 200 mg/dL.
___ You do not know your cholesterol level.
___ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
___ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week).
___ You are > 20 pounds overweight.

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a professionally qualified exercise staff to guide your exercise program.

___ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

Appendix 4: Ethical approval documentation for study three

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with A-STEM and College of Engineering Safety Policy, all research undertaken by staff or students linked with A-STEM must be approved by the A-STEM Ethical Committee.

RESEARCH MAY ONLY COMMENCE ONCE ETHICAL APPROVAL HAS BEEN OBTAINED

The researcher(s) should complete the form in consultation with the project supervisor. After completing and signing the form students should ask their supervisor to sign it. The form should be submitted electronically to Pam Swanborough - [redacted]

Applicants will be informed of the Committee's decision via email to the project leader/supervisor.

1. TITLE OF PROJECT

The neuromuscular, endocrine and perceptual responses to netball training in elite standard netball players

2. DATE OF PROJECT COMMENCEMENT AND PROPOSED DURATION OF THE STUDY

01/08/18 for approximately 12 months

3. NAMES AND STATUS OF RESEARCH TEAM

State the names of all members of the research group including the supervisor(s). State the current status of the student(s) in the group i.e. Undergraduate, Postgraduate, Staff or Other (please specify).

Laurence Birdsey – PhD student, Swansea University.
Professor Liam Kilduff – Supervisor, Swansea University. Matthew Weston – 2nd supervisor (Tees Unversityi)

4. RATIONALE AND REFERENCES

With reference to appropriate sources of information (using the Harvard system), describe in no more than 200 words the background to the proposed project.

The role of the sports scientist is to optimise the training response via manipulation of training type, intensity and duration while also accounting for the recovery from prior exercise stimuli (Smith *et al.*, 2003). It is therefore important to understand the responses to netball-specific training as well as other types of conditioning, such as weights and speed training. Neuromuscular and endocrine responses have been reported following speed (Johnston *et al.*, 2015) and strength training (Kraemer *et al.*, 1991), whilst data reporting the responses to a netball training session do not exist. The effect of performing speed and strength training on the same day compared to speed only has been previously reported (Johnston *et al.*, 2016), as well as the order of sessions performed (Johnston *et al.*, 2107), however data of a strength and sport specific training is unavailable.

Understanding the physiological and perceptual responses to different training volumes (by performing a greater number of training sessions in a day or different training intensity), different order and recovery periods is therefore vital to understand to be able to programme effectively to maximise training and performance adaptations. The aim of this study is therefore to investigate the effect of training volume, intensity, training order and recovery duration in elite level netball players.

Johnston, M.J., Cook, C.J., Drake, D., Costley, L., Johnston, J.P. and Kilduff, L.P. (2016). The neuromuscular, biochemical and endocrine responses to a single session versus double session training day in elite athletes. *Journal of strength and conditioning research*, **30**, 11, 3098-3106

Johnston, M., Johnston, J., Cook, C.J., Costley, L., Kilgallon, M. and Kilduff, L.P. (2017). The effect of session order on the physiological, neuromuscular and endocrine responses to maximal speed and weight training sessions over a 24 hour period. *Journal of science and medicine in sport*, **20**, 502-506

Kraemer, W.J., Gordon, S.E., Fleck, S.J., Marchitelli, L.J., Mello, R., Dziados, J.E, Friedl, K., Harman, E., Maresh, C. and 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**, 2, 228-235.

Smith, D. (2003). A framework for understanding the training process leading to elite performance. *Sports medicine*, **33**, 15, 1103-1126.

5. OBJECTIVES

State the objectives of the project, i.e. one or more precise statements of what the project is designed to achieve.

- To characterise the responses to training in elite female athletes
- To provide the coach with detailed information regarding the physiological response to training to inform planning, timing and content of training in the preparation and competition phase of the year.

6.1 STUDY DESIGN

- outline the chosen study design (e.g. cross-section, longitudinal, intervention, RCT, questionnaire etc)

Repeated measures cross over design.

6.2 STUDY DESIGN

- state the number and characteristics of study participants
- state the inclusion criteria for participants
- state the exclusion criteria for participants and identify any requirements for health screening
- state whether the study will involve vulnerable populations (i.e. young, elderly, clinical etc.)
- state the requirements/commitments expected of the participants (e.g. time, exertion level etc)

Up to 25 female netball players. All participants will be part of England netball's Futures or Roses squads, aged 18 to 35 years and deemed fit by the team physiotherapist. Participants will perform training sessions within the usual standard time and days of the week as part of the general preparation phase. These will be 90-120 min training sessions and involve technical / tactical training, high intensity physical exercise and strength and conditioning. These would be classed as typical training sessions, as such players will not be required to perform any training that would not typically be performed at this time of the season.

All participants will read the participant information sheet, provide written consent, and complete a health screening questionnaire prior to testing. Once the above has been completed and it is established there are no reported health risks to participate participants will perform a series of measurements consisting of countermovement jump (CMJ), measures of perceptual well-being, a saliva sample and blood sample (further details in 6.4). Participants will be required to wear a heart rate monitor and accelerometer throughout the training session. Participants will perform several protocols as part of regular training; a single netball training session, netball followed 2 hours later by weights, weights followed 2 hours later by netball and 4 h recovery between training sessions.

Appendix A and B provide further details of the training sessions.

Netball training session: Following baseline measurements participants will perform a team warm up of approximately 30-mins consisting of activation, dynamic stretching, ball skills work, specific netball movements and speed and agility drills. This is then followed by the main session starting with approximately 20 mins focusing on technical aspects to develop skills under pressure by use of specific structured exercises. This is then intensified towards match-paced play (over approx. 20-30 mins), culminating in game-play using only half of the court for the final 30 mins. Although there is a strong tactical and technical component, the reduction of playing dimensions and removal of specific positions results in high intensity exercise. During this game play specific scenarios are created to put in to practice what has been worked on during the session thus far. A cool down lasting 5-10 mins completes the session.

Weight training session: Following baseline measures participants will perform a warm up of approximately 15-mins consisting of energetic exercise (e.g cycling), dynamic stretching and prehabilitation exercises. This is then followed by the main session consisting of 3 main lifts (individualized by the strength and conditioning coach to include a combination of; back squat, front squat, leg press, hamstring curl, bench press, pull up) lasting approx. 30-40 mins. This is followed by a cool down.

Immediately following either training session participants will complete differential RPE to describe the perceived effort of the training sessions and then repeat the baseline measures (CMJ, well-being, saliva, blood). They will then be allowed to shower and get changed, have a standardised meal, and rest. Two or four hours following the end of the training session participants will repeat the baseline measurements before being allowed to leave (for single session only) or commence the alternative training session as detailed above. The following day, approximately 24 hours after commencing the first training session the day before, participants will repeat baseline measures (CMJ, well-being, saliva and blood sample) for a final time.

This will be performed as part of normal netball training, and as such will not require any further time commitments from participants.

6.3 PARTICIPANT RECRUITMENT

How and from where will participants be recruited?

Participants will be members of the Futures (U21) and Roses (World class) England netball squads, aged 18-35 years and females only. The team coach has highlighted the previously discussed as areas she is interested to know more about with her players. Participants however will not be required to take part if they do not wish to, and only after reading the participant information sheet, providing written consent, and completing a health screening questionnaire will data collection commence. There will be no consequences for participants who do not wish to take part and will be able to train exactly the same with the other participants without taking part in the measurements around training.

6.4 DATA COLLECTION METHODS

- *describe all of the data collection/experimental procedures to be undertaken*
- *state any dietary supplementation that will be given to participants and provide full details in Section 6.5*
- *state the inclusion of participant information and consent forms (in appendices)*
- *refer to the use of the ACA/ACSM health screening questionnaire where appropriate (usually for maximal effort exercise)*

On arrival participants will complete the ACA/ACSM health-screening questionnaire, consent form and read the participant information sheet (found in appendices).

Blood sample

This will be measured before, immediately post, 2 or 4 hours post and 24 hours post the training session. To record blood lactate levels, capillary blood samples will be taken from the finger and will be analysed using an automated lactate analyser for blood lactate (Biosen C-line Sport, EFK – diagnostic GmgH, Barleben, Germany). Davidson *et al*. (2000) has previously reported that the Biosen Lactate Analyser can provide valid, fast and reliable measure of blood lactate. Additionally, a 600 µL sample will be collected in a capillary tube and immediately centrifuged (Labofuge 400R, Kendro Laboratories, Germany) at 3000 rpm for 10 min for the extraction of plasma. 6 µL of plasma is used in the analysis of Creatine kinase using a semi-automated analyzer (Daytona Plus; Horiba Medical, UK). Sample testing will be carried out in duplicate. Analysis of other variables such as CRP, TNF alpha and IL-6, IL-10 will be performed as per the manufacturer's instructions.

Saliva sample
Participants will be asked to provide a sample of saliva for a timed period of 2-3 minutes into a sterile container at the same time points as detailed above. Salivary steroid samples will be taken in this study as they are minimally invasive and have the advantage of reflecting free steroid concentrations and are reported to be more physiologically relevant than total blood levels. To minimize the possibility of any blood contamination of saliva, which would result in an overestimation of hormone concentrations, the participants will be advised to avoid brushing their teeth, drinking hot or coloured fluids or eating hard foods (e.g. apples) in the 2 h before providing their sample. Saliva samples will be analysed in duplicate for testosterone, cortisol and IGA using commercial enzyme-immunoassay kits as per manufacturer's instructions (Salimetrics Europe Ltd., Suffolk, U.K.).

CMJ
For the measurement of CMJ peak power output (PPO), testing will be completed on a portable force platform (Kistler Instruments Ltd., Farnborough, United Kingdom). To isolate the lower limbs, participants will stand with hands placed on hips throughout the whole movement. After an initial stationary phase of at least 2 s in the upright position, for the determination of body mass, participants will perform a CMJ, dipping to a self-selected depth and then exploding upwards in an attempt to achieve maximum height. Participants will land back on the force platform and keep their arms on hips throughout the movement. Participants will be required to complete 3 maximum jumps with 60 s rest between efforts; PPO will then be calculated as detailed by West *et al*. (2011).

Training demands
Participants will be required to wear a heart rate monitor (Polar Team system 2, Polar electro, Warwick, UK) and accelerometer in a custom made harness placed upon the upper back (Catapult S5, Catapult Innovations, Leeds, UK) throughout the netball training session from the start of the warm up to the end of the cool down. These measurements are minimally invasive, provide accurate information regarding physical exertion and have been previously used to monitor the demands of netball (Cormack *et al*., 2014; Chandler *et al*., 2014). All players wear this equipment for each training sessions and match as part of regular monitoring.

Perceptual responses
Participants will complete an adapted version of the brief assessment of mood questionnaire (BAM+) which has been previously found to be effective in monitoring recovery in elite athletes (Shearer *et al*., 2017). Using a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc) a series of questions will be asked one at a time with a visual analogue scale ranging from "not at all" to "extremely". An overall recovery score will be generated by subtracting the mean score of negative related items from the mean score of the positively related questions. BAM+ has been found to be moderately correlated to high intensity match activity, as measured by GPS technology, and is sensitive to physiological responses which occur following competition over 48 hour following performance in elite team sport athletes (Shearer *et al*. 2016).

Differential rating of perceived exertion
After the training session players will record session RPE along with differential session ratings for breathlessness, leg muscle exertion, upper body muscle exertion and cognitive / technical demands. Ratings will be graded using a numerically blinded CR100 scale with verbal anchors, which provides a more sensitive and precise measurement of perceived exertion than the traditional CR10 scale (Fanchini *et al*., 2016), and will be recorded via a bespoke application on an Android tablet (Iconia One 7 B1-750, Taipei, Taiwan: Acer inc). Each RPE will then be multiplied by the playing time in minutes to calculate session training loads (Foster *et al*., 2001). Differential RPE has been found to be a more sensitive measure than session RPE for the physiological response to a stimulus (McLaren *et* al., 2015) and provides a detailed quantification for internal load during team sport activities (McLaren *et al*., 2016).

6.5 DATA ANALYSIS TECHNIQUES

- describe the techniques that will be used to analyse the data

The data will be analysed to identify any significant differences in physiological and perceptual markers at the various time points before and after the training session. Descriptive statistics will be used to characterise physical demands of the training sessions. All data will be presented as the mean ± standard deviation unless otherwise indicated. Before carrying out analysis the data will be screened for errors and parametric suitability. Test of assumptions will be carried out to check for normality and homogeneity of variance. Analysis of blood markers, saliva markers and CMJ will be carried out using repeated measures ANOVA. Post hoc comparisons will be made where appropriate. All statistical analysis will be carried out using SPSS (SPSS Chicago, IL) with significance being accepted at the 95% confidence limit.

6.6 STORAGE AND DISPOSAL OF DATA AND SAMPLES

- *describe the procedures to be undertaken for the storage and disposal of data and samples*
- *identify the people who will have the responsibility for the storage and disposal of data and samples*
- *Identify the people who will have access to the data and samples*
- *state the period for which the data will be retained on study completion (normally 5 years, or end of award)*

All biological samples will be disposed of once analysed and all samples will only be measured for what is stated in the ethics form. All data will be stored on a password-protected computer. Data relating to participants will be kept in digital format to avoid identification of participants; i.e. participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. Access to data generated during the study will be limited to the research team as stated in section 3 and England netball coaching staff. Data will be provided to the coaching staff regarding the response to the training session as stated in section 5, however all data will be anonymous. The data will be retained until award of degree. Hard copies of the consent forms will be stored securely in a locked cupboard in Prof. Liam Kilduff's office and will be responsible for the deletion of all data.

6.7 HOW DO YOU PROPOSE TO ENSURE PARTICIPANT CONFIDENTIALITY AND ANONYMITY?

All data will be stored on password-protected computers, one belonging to Laurence Birdsey and one located in Prof Kilduff's office; this will include the original and only copy-aligning name and ID of participants. All further data relating to participants will be kept in digital format to avoid identification of subjects; i.e. all participants will be assigned a number and all data will be displayed as athlete 1, 2, 3 etc. removing any risk of identification of names and personal data. All information will be kept anonymous and not shared outside the England Netball coaching team whilst private information will not be shared at all.

6.8 PLEASE PROVIDE DETAILS OF ANY DIETARY SUPPLEMENTATION (DELETE IF NOT APPLICABLE)

7. LOCATION OF THE PREMISES WHERE THE RESEARCH WILL BE CONDUCTED.

- *list the location(s) where the data collection and analysis will be carried out*
- *identify the person who will be present to supervise the research at that location*
- *If a first aider is relevant, please specify the first aider*

Loughborough University Netball Centre, Loughborough. Laurence Birdsey present to supervise the research. A first aider (Laurence Birdsey) will be present at all times as per England netball guidelines.

8. POTENTIAL PARTICIPANT RISKS AND DISCOMFORTS

- *identify any potential physical risk or discomfort that participants might experience as a result of participation in the study.*
- *identify any potential psychological risk or discomfort that participants might experience as a result of participation in the study.*
- *Identify the referral process/care pathway if any untoward events occur*

There are potential risks of the study. Blood samples will be taken from the participants; procedures of how blood will be taken will be explained to participants prior to taking the samples and will have the right to withdraw at any time. Participants will also be asked of any phobias of needles or blood. All researchers will wear gloves when conducting the tests and any items that have blood on will be disposed of according to section 6.6. Likewise any sharp items will be disposed of appropriately.

Participants will be asked to provide a sample of saliva into a sterile container, this may cause discomfort and therefore participants will be given the option not to participate if they are uncomfortable. Opportunities to practice will be provided to those unfamiliar with this procedure.

Participants will be required to take part in strenuous training session. Strenuous exercise could be a risk if there are any underlying health issues present. All participants will fill in a consent form and ACA/ACSM health screening questionnaire to identify any health risks associated with maximal exercise before any testing begins.

Participants will be asked to wear a heart rate monitor and GPS unit during the netball training session. Players wear this as part of regular training and competition and as such are used to this.

9.1 HOW WILL INFORMED CONSENT BE SOUGHT?

Will any organisations be used to access the sample population?

Will parental/coach/teacher consent be required? If so, please specify which and how this will be obtained and recorded?

Informed consent will be obtained from each participant, participants will be asked to sign a consent form prior to the start of the study if they agree and are comfortable to participate. Consent from other parties will not be required. England netball have allowed us access to the players.

9.2 INFORMATION SHEETS AND CONSENT/ASSENT FORMS

- Have you included a Participant Information Sheet for the participants of the study?

  YES

- Have you included a Parental/Guardian Information Sheet for the parents/guardians of the study?

  NO

- Have you included a Participant Consent (or Assent) Form for the participants of the study?

  YES

- Have you included a Parental/guardian Consent Form for the participants of the study?

  NO

10. IF YOUR PROPOSED RESEARCH IS WITH VULNERABLE POPULATIONS (E.G. CHILDREN, PEOPLE WITH A DISABILITY), HAS AN UP-TO-DATE DISCLOSURE AND BARRING SERVICE (DBS) CEHCK (PREVIOUSLY CRB) IF UK, OR EQUIVALENT NON-UK, CLEARANCE BEEN REQUESTED AND/OR OBTAINED FOR ALL RESEARCHERS? EVIDENCE OF THIS WILL BE REQUIRED.

N/A

11. STUDENT DECLARATION

Please read the following declarations carefully and provide details below of any ways in which your project deviates from these. Having done this, each student listed in section 2 is required to sign where indicated.

- ***"I have ensured that there will be no active deception of participants.***
- ***I have ensured that no data will be personally identifiable.***
- ***I have ensured that no participant should suffer any undue physical or psychological discomfort (unless specified and justified in methodology).***
- ***I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.***
- ***I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.***
- ***I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.***
- ***I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.***
- ***I certify that the above statements are true with the following exception(s):"***

Student/Researcher signature: [redacted] (include a signature for each student in research team)

Date: 30/05/2018

12. SUPERVISOR'S APPROVAL

Supervisor's signature:

Date:

APPENDIX A – NETBALL TRAINING SESSION

Warm up – 30 min
Individual activation (muscle activation included to reduce the risk of injury, perform prehab exercises, and to improve training performance.
Dynamic movements around the court, including forwards, backwards, sidewards and changes of direction as well as dynamic stretching. Towards the end speed and agility drills will also be performed.

Drills – 10-20 min
A series of technical drills designed to address any highlighted areas of technical development. This starts at a low intensity and designed to aid decision making and technical competency, with intensity progressing throughout.

Game-play – 30 min
Over half a court-players perform scenario specific game-play, aiming to put in to practice the technical drills previously performed. As the court is half the size, play remains in one end, meaning all players are involved at all times, increasing intensity compared to full court game-play.

Cool down – 10 min
Players perform light exercise (including walking, shuffling, or static cycling) and individualised stretching exercises provided by the team physiotherapist.

Netball training session: Following baseline measurements participants will perform a team warm up of approximately 30-mins consisting of activation, dynamic stretching, ball skills work, specific netball movements and speed and agility drills. This is then followed by the main session starting with approximately 20 mins focusing on technical aspects to develop skills under pressure by use of specific structured exercises. This is then intensified towards match-paced play (over approx. 20-30 mins), culminating in game-play using only half of the court for the final 30 mins. Although there is a strong tactical and technical component, the reduction of playing dimensions and removal of specific positions results in high intensity exercise. During this game play specific scenarios are created to put in to practice what has been worked on during the session thus far. A cool down lasting 5-10 mins completes the session.

APPENDIX B – WEIGHT TRAINING SESSION

Warm up – 15 min
Individual activation (muscle activation included to reduce the risk of injury, perform prehab exercises, and to improve training performance.
Dynamic stretching and energetic exercise (including static cycling and rowing) to warm the muscles to improve training performance.

Main lifts – 40 min
3 main lifts are performed, individualized for each player by the strength and conditioning coach based upon their physical needs and progress. This includes a combination of; back squat, front squat, leg press, bench press and pull ups.
5-8 reps are performed for 3-5 sets on each exercise (individualized by the strength and conditioning coach).

Cool down – 10 min
Stretching is performed (individualized for each player by the physiotherapist).

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARTICIPANT INFORMATION SHEET
(Version 1.1, Date: xx/xx/20xx)

Project Title:
The neuromuscular, endocrine and perceptual responses to netball training in elite standard netball players

Contact Details:
Laurence Birdsey; [redacted]

1. Invitation Paragraph
We would like to invite you to volunteer for this study that aims to identify physiological and perceptual response and recovery profile when performing netball training. The study will be beneficial to you and your team, aiming to inform the planning of training in the preparation and competition phase and ensure you get the most out of training and competition. We would like to thank you for taking the time to read this information sheet and very much hope you decide to take part.

2. What is the purpose of the study?
The purpose is to characterise how your body responds to a variety of different training combinations, such as the order of training, double compared to single days and recovery duration. This will show at what point you have recovered or are still fatigued, the difference when performing different combinations of training and recovery, and will help plan training sessions.

3. Why have I been chosen?
You have been chosen to complete this study as a member of England netball World Class squads. You will have the right to withdraw from the study at any time, without having to provide reasoning and this will not affect training performance or team selection.

4. What will happen to me if I take part?
You will perform a series of measurements before and after you perform regular training sessions. These measurements include a small blood sample from your finger tip, a saliva sample and performing a countermovement jump. Training will be a regular training session, however during the netball session you will be required to wear a heart rate monitor and accelerometer device to monitor your physical activity and exertion. Straight after training you will repeat the measures, followed by 2 or 4 hours to shower, have lunch and relax, followed by the measures once more. At this point you will either perform a second training session or be free to continue your day. The following day you will be required to repeat the measures for a final time.

Capillary blood sample - Prior to any sample being taken you will be asked to be seated, the procedure will be explained to you and confirm you are happy to proceed. The area of the finger will be cleaned with an alcohol wipe before a small capillary blood sample is taken from your finger. A lancet will be used to puncture the tip of the finger in which a small blood sample will be collected from.

Saliva sample - You will be asked to provide a sample of saliva for a period of 2-3 minutes into a sterile container. This method is not invasive but the procedure will be explained to you to make sure you are happy prior to providing a saliva sample.

Countermovement jump – You will be asked to complete a countermovement jump, which will involve standing on a force platform, hands on your hips, before dipping to a self-selected depth and then exploding upwards to jump as high as possible. You will be required to complete 3 maximum jumps with 1 min rest between efforts. This is a normal part of your monitoring so you should be familiar with this.

Well-being - using a tablet device you will be asked 10 questions about your well-being (such as quality of sleep, muscle soreness, fatigue) and using a slider scale you will choose your response.

Rating of perceived exertion – after training you will be asked to rate how hard the training was using a tablet device. This will include how hard the session was overall, how breathless it made you, how hard it was for the upper body, lower body, and technically.

You will be required to avoid brushing your teeth, eating hard food like apples, or drinking hot or coloured fluids 1 hour before attending. This is to avoid your saliva sample being contaminated with any blood.

5. What are the possible disadvantages of taking part?

There are possible risks of the study. Firstly, blood samples and saliva will be collected. Procedures of how both will be collected will be explained to you prior to taking the blood and saliva and you will have the right to withdraw at any stage. During netball training, you will be required to wear a heart rate monitor and accelerometer, which may cause discomfort. Time will be given prior to this to get used to wearing the equipment, however you have the right to withdraw at any stage. You will also be expected to participate in strenuous exercise that may cause some slight discomfort, but should not be any different from your normal training and competition. Although performance related information would be shared with the England netball coaching team this will not influence team selection whether you decide to participate or not, or whether you decide to withdraw from the study at any point.

6. What are the possible benefits of taking part?

As a result of participating you and your team will gain valuable information about the physiological response to training which will help to inform your coach in order to balance the training response with potential fatigue, particularly in the build up to matches to make sure you are as fit as possible but as fresh as possible to perform.

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

All data will be kept confidential and results will not be accessible to anyone other than the research team and the England netball coaching team. Results will be anonymised and private information will be kept confidential to all. At the end of the study all data will be disposed of according to set guidelines.

8. What if I have any questions?

If you have any questions throughout the duration of this study, please do not hesitate to ask – contact details for the researcher are provided at the start of this document.

Swansea University
Prifysgol Abertawe

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

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

Project Title:

The neuromuscular, endocrine and perceptual responses to netball training in elite standard netball players

Contact Details:

Laurence Birdsey; [redacted]

Please initial box

5. I confirm that I have read and understood the information sheet dated ....../....../...... (version number ....) for the above study and have had the opportunity to ask questions. ☐

6. 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. ☐

7. 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. ☐

8. I agree to take part in the above study.

______________________	____________	____________________
Name of Participant	Date	Signature
______________________	____________	____________________
Name of Person taking consent	Date	Signature
______________________	____________	____________________
Researcher	Date	Signature

AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire

Assess your health status by marking all *true* statements

History

You have had:

___ a heart attack
___ heart surgery
___ cardiac catheterization
___ coronary angioplasty (PTCA)
___ pacemaker/implantable cardiac
___ defibrillator/rhythm disturbance
___ heart valve disease
___ heart failure
___ heart transplantation
___ congenital heart disease

Symptoms

___ You experience chest discomfort with exertion.
___ You experience unreasonable breathlessness.
___ You experience dizziness, fainting, or blackouts.
___ You take heart medications.

Other health issues

___ You have diabetes.
___ You have asthma or other lung disease.
___ You have burning or cramping sensation in your lower legs when walking short distances.
___ You have musculoskeletal problems that limit your physical activity.
___ You have concerns about the safety of exercise.
___ You take prescription medication(s).
___ You are pregnant.

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a **medically qualified staff.**

Cardiovascular risk factors

___ You are a man older than 45 years.
___ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
___ You smoke, or quit smoking within the previous 6 months.
___ Your blood pressure is >140/90 mm Hg.
___ You do not know your blood pressure.
___ You take blood pressure medication.
___ Your blood cholesterol level is > 200 mg/dL.
___ You do not know your cholesterol level.
___ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
___ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week).
___ You are > 20 pounds overweight.

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a professionally qualified exercise staff to guide your exercise program.

___ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

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