Monitoring Strategies for Predicting Position-Specific Match Performance in State-Level Netball Athletes

Scott Phillip Graham

s3847768

This thesis is submitted to fulfill the requirements for the degree of

Doctor of Philosophy

College of Sport and Exercise Science

Institute for Health and Sport

Victoria University, Melbourne, Australia

Supervisor – Dr James Zois

Co-supervisor – Dr Grant Duthie

Co-supervisor – Professor Robert Aughey

Date: May 2019

Table of Contents

Publications

The following publications have been accepted by, or in production for publication in international peer-reviewed scientific journals as a direct result of the current thesis.

Graham, S., Duthie, G., Aughey, R., and Zois, J. (2019). Comparison of physical profiles of state-level netball players by position. *Journal of Strength and Conditioning Research*. Published ahead of print.

Graham, S., Zois, J., Aughey, R., and Duthie, G. (Accepted with revisions). The peak Player Load^{TM} of state-level netball matches. *Journal of Science and Medicine in Sport*.

Graham, S., Duthie, G., Aughey, R., and Zois, J. (Under review). A brief narrative review assessing player impact following matches in team-sport. *Medicine and Science in Sports and Exercise*.

Graham, S., Duthie, G., Aughey, R., Hopkins, W., and Zois, J. (Under review). Assessing match performance in team-sport athletes with position-specific performance indicators and coach ratings. *International Journal of Sports Physiology and Performance.*

Graham, S., Duthie, G., Aughey, R., and Zois, J. (In production). A narrative review to prepare netball athletes for competition – Part one: Activity profiles, anthropometric characteristics and physical capacities of the sport. *Journal of Strength and Conditioning Research*.

Graham, S., Duthie, G., Aughey, R., and Zois, J. (In production). A brief narrative review to prepare netball athletes for competition – Part two: Guiding athletes towards feeling and performing well. *Journal of Strength and Conditioning Research*.

Graham, S., Duthie, G., Aughey, R., and Zois, J. (In production). Reliability of Player Load^{TM} for quantifying the short and sharp changes in direction and velocity experienced in court-based sports. *International Journal of Sports Physiology and Performance.*

Graham, S., Duthie, G., Aughey, R., Hopkins, W., and Zois, J. (In production). Utilising monitoring practices to predict match performance in state-level netball athletes. *Journal of Strength and Conditioning Research*.

Figures

Figure 1.1. Positional movement restrictions for netball matches. Each position listed in the five areas of the netball court define the positions allowed with those boundaries. C – Centre; GK – Goalkeeper; GD – Goal defence; WD – Wing Defence; WA – Wing Attack; GA – Goal Attack; GS – Goal Shooter.

Figure 2.1. Network analysis of movement similarities between positions (Sweeting et al. 2017).

Figure 3.1. Standardised differences between positions for common performance tests used in netball populations. * Indicates a meaningful difference >75% likelihood threshold. For Yo-Yo IR1, CMJ, 3SB and 1SB, a negative ES equates to worse performance against the selected group. For 505 COD and 20 m sprint a positive ES equates to worse performance against the selected group. For stature, a negative ES equates to a shorter height against the selected group. Sec; seconds, CM; centimeters, M; meters, R; right leg, L; left leg, 505 COD; 505 change-of-direction test, CMJ; countermovement vertical jump, 1SB; one single-leg bound, 3SB; triple single-leg bound, Yo-Yo IR1; Yo-Yo intermittent recovery test level 1.

Figure 4.1. Relationship between the proximally and distally placed absolute Player Load™ values recorded during netball match simulations (r 0.99). AU; Arbitrary units.

Figure 4.2. Residual plot of difference between the distally placed unit minus the proximally placed unit.

Figure 5.1. The mean peak $PL.min^{-1}$ intensities imposed on the three positional groupings and the predicted peak $PL.min^{-1}$ given by the following power law equation; Predicted peak $PL.min^{-1}$ = intercept x duration$^{(slope)}$ (Delaney et al. 2018).

Figure 5.2. Comparison of peak $PL.min^{-1}$ (PPL) at different timepoints between positional groupings. Grey zone represents trivial differences (-0.2 to 0.2 standardised difference), dotted

vertical lines represent boundaries of ES thresholds of 0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large and >2.0 very large. PPL; Peak player load, *; likely, **; very likely, and ***; almost certainly.

Figure 6.1. Correlations between points differential and the five team-performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Team level: championship (●), division-1 (**x**), 19-&-under (▲). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

Figure 6.2. Correlations between points differential and the five shooter-performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: goal shooter (**x**), goal attack (●). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

Figure 6.3. Correlations between points differential and the five mid-court performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: wing attack (●), centre (**x**), wing defence (▲). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

Figure 6.4. Correlations between points differential and the five defender performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: goal defence (●), goalkeeper (**x**). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

Figure 7.1. Substantial training load doses for all three position groups with harmful or beneficial effects on the five match performance measures. EWPI; equally weighted performance indicators, CWPI; coach weighted performance indicators, CR; coach ratings, CWPI + CR; combined coach weighted performance indicators and coach ratings, EWPI + CR; combined equally weighted performance indicators and coach ratings, Sm; smoothed load; Diff; differential load, ACR; acute to chronic workload ratio, Mon; training monotony.

Figure 7.2. Substantial CMJ for shooters with harmful or beneficial effects on the five match performance measures. EWPI; equally weighted performance indicators, CWPI; coach weighted performance indicators, CR; coach ratings, CWPI + CR; combined coach weighted performance indicators and coach ratings, EWPI + CR; combined equally weighted performance indicators and coach ratings, PP; peak power, P Vel; peak velocity, Vel PP; velocity at peak power, FV; force velocity area under the curve, PF; peak force, MF; mean force, F@0V; force at zero velocity.

Tables

changes in load prescribed in Figure 7.1 to increase the chances of enhanced match performance.

Table 7.2. Mean ± within-subject SD data of wellness measures.

Table 7.3. Mean ± within-subject SD data of CMJ measures. Practitioners can use the SD's in this table to monitor changes in CMJ for shooters from Figure 7.2 to increase the chances of enhanced match performance.

Abstract

Introduction: Monitoring athlete performance in training and competition can assist conditioning professionals and sport scientists to enhance performance outcomes whilst also minimising the risk of injury, illness and non-functional overreaching. Yet the monitoring of athletes to improve position-specific match performance has never been investigated in the team-sport of netball. **Aims:** This thesis aims to examine the extent to which three common forms of athlete monitoring relate to match performance in state-level netball athletes, providing practitioners with guidelines for maximising performance outcomes.

Study 1 - Purpose: To determine any substantial differences in physical capacities between positional groups within the state-level netball cohort of this thesis, to justify an investigation into position-specific monitoring strategies for enhancing match performance. **Methods:** Forty-six state-level netball athletes completed physical capacity assessments in the second week of their preseason, over two-seasons. Tests included stature, 20 m sprint (with 5 m and 10 m splits), 505-change-of-direction, countermovement jump, single-leg bounding and the Yo-Yo Intermittent Recovery Test Level One. **Results:** There were numerous substantial differences between positions with mid-court athletes typically displaying the greatest overall physical capacity followed by defenders then shooters.

Study 2 - Purpose: To investigate the reliability of a tracking metric (Player Load™) within a court-based sport environment, to determine its efficacy for objectively investigating activity profiles within state-level netball matches by position. **Methods:** Eighteen state-level netball athletes' accelerations were tracked with two accelerometers, each housed within an athlete tracking unit (OptimEye S5, Catapult Sports, Australia), taped together with axes aligned during netball match-play. **Results:** The inter-device Player Load™ was reliable with the typical error was 5.9 (90% compatibility limits (CL) 5.2 to 6.7), with the CV 4.8% being well below the SWD of 8.2%.

Study 3 - Purpose: To utilise the Player Load^{TM} metric to determine substantial differences between positions by analysing the peak intensities during state-level netball matches, to further justify an investigation into position-specific monitoring strategies for enhancing match performance. **Methods:** Twenty-eight netball athletes wore an accelerometer (S5 Optimeye, Catapult sports) for all matches, in one season. Peak Player Load^{TM} was quantified over 30-seconds and one to ten-minute time periods. **Results:** Across all time periods post 30-seconds, only one comparison was not meaningfully different i.e., three-thirds v two-thirds at the one-minute timepoint (effect size: 0.27, CL -0.05 to 0.60).

Study 4 - Purpose: Following a strong justification for investigating position-specific monitoring strategies to enhance match performance, this study aimed to determine the extent to which performance indicators, coach ratings and their combination predict match outcome in netball. **Methods:** Two seasons worth (39-40 matches) of performance indicators and coach ratings were collected for players of a state-level netball club with one team in each of three divisions (27 championship, 23 division-one, and 19 19-&-under females). There were five performance measures being coach weighted performance indicators (CWPI) and a novel equal weighting (EWPI); coach ratings of overall performance; multiple linear regression was also used to derive correlations for combinations of coach rating with the CWPI and with the EWPI. **Results:** For team performance the combination of EWPI and coach rating was the strongest predictor of points differential. No measure of position-specific match performance was consistently related to points differential across all three teams.

Study 5 Purpose: The aim of this study was to examine the extent to which three monitoring strategies predict five measures of position-specific match performance. **Methods:** State-level netball athletes (n = 46, age = 20.29 ± 4.15 years) were monitored over a two-year period and were split into three position groups (defenders, mid-courts and shooters). Training load (sessional rate-of-perceived exertion), wellness questionnaires and CMJ were collected. All

five predictor measures from Study 4 were the criterion for position-specific match performance. **Results:** Training load dose was the only monitoring tool related to match performance for all three position groups. There were no substantial relationships between wellness questionnaires and match performance for any group. Only shooters were found to have substantial relationships between CMJ and match performance.

Thesis conclusions: Netball athletes have substantial differences in physical capacities dependent on positions played. The peak intensities reached during match-play is also substantially different for positions. There is no superior approach for match performance assessment in netball for predicting points differential. The monitoring of training load doses provides important information for coaching and conditioning staff to predict future match performance for all position groups. The use of wellness questionnaire data does not provide useful information for predicting an athlete's match performance. Finally, only shooters demonstrated a relationship between CMJ and match performance. The findings of this thesis indicate that to enhance match performance in netball, a position-specific monitoring approach is required.

Declaration

I, Scott Graham, declare that the PhD thesis titled Monitoring Strategies for Predicting Position-Specific Match Performance in State-Level Netball Athletes, is no more than 100,000 words in length including quotes and exclusive of Tables, Figures, appendices, bibliography, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: 22 / 5 / 2019

Acknowledgements

It was mentioned to me early on in my PhD by Rob Aughey that completing this degree will be the hardest thing you ever do. I often wonder what I would've done if I truly understood the magnitude of what he meant, would I have still gone through with it? In many cases ignorance really is bliss! This experience has truly been the most difficult and challenging thing I have undertaken thus far, but upon reflection I wouldn't change a thing. A PhD, if nothing else, will teach you the most valuable life skill of all being resilience. Hitting several roadblocks and even a change of thesis question and population, to going on intermission from May 2016 to February 2017, it has truly been a roller coaster ride!

To James, what an incredible journey since first meeting each other at the reading room café in late 2013 to discuss a possible honors project. The PhD has tested us both in many different ways, from the darkest times when considering whether we should change our supervision arrangements, right through to the highs of submission of this thesis. Thank you for continuing to believe in me when everything was falling apart back in May 2016, professionally you have been, and I hope will continue to be my greatest mentor.

To Grant, your contribution towards this project has been enormous since coming on board back in February 2017. Your enthusiasm for producing quality studies / publications has been just the injection of energy I've needed to make this thesis what it is, a piece of work I am very proud of. Your consistent and timely feedback has made the process of producing this thesis a very smooth process with minimal levels of stress, so thank you for being the calming influence I needed, particularly when James was on long service leave. I look forward to working together in the future.

To Rob, given your incredibly busy schedule I truly appreciate the time you were able to spend helping me out along the way. The little nuggets of information and advice you have been able to provide me with has proven invaluable and I hope to continue working together in some capacity in the future.

To Will, who thought such a simple research question would prove to be such a challenging exercise? Absolutely no way I would have been able to achieve this outcome without your devotion and expertise. I will truly miss our catchup chats at the start of each meeting we had, and I’ll always hold onto the fact that you said I was your most challenging project!

To my Parents, Jess and Chloe, thank you for riding every bump along the way and continuing to believe in me when it was all going so poorly at different stages. Your calming influence and reassurance that it would all be worth it (as much as I didn’t want to hear it at the time), was exactly what I needed to hear.

To Gerard, Sarah and Mel, thank you for the opportunity to conduct my research with Geelong Netball Club. Firstly, to Sarah, my PhD quite literally would not have happened if not for our chance meeting in the Noodle House Café at Vic Uni Footscray Park around September 2016. We were chatting about my studies and the difficulties I was having, then you offered the possibility of getting in touch with Gerard about the possibility of working with Geelong. Your kind gesture has taught me that no matter how small you may think a favor to be, it can dramatically impact someone’s life for the better so thank you. Next to Gerard, I was sitting at my desk with the form to terminate my PhD in November 2016. To then get a text message from yourself when we hadn’t spoken for a good year and a half, with the offer to work in my studies at Geelong, was ultimately the reason why I will now have infinitely greater opportunities in my career than I otherwise would. I hope to work with you for many more years to come. To Mel, thank you for being a consistent sounding board for me to throw ideas at. Your openness to explore different ways of training our athletes has allowed me to develop my skills and coaching ability and I’ll be forever grateful. I can’t wait to work more with you well into the future. Finally to the players, staff and club thank you all for such an amazing experience, I am forever grateful and indebted to you all. Up the Cougs!!!

List of abbreviations

1SB	1 single-leg bound
3SB	Triple single-leg bound
BPr	Bench press
BPu	Bench pull
C	Centre
CL	Compatibility limits
CMJ	Countermovement jump
COD	Change-of-direction
CV	Coefficient of variation
CWPI	Coach weighted performance indicators
ES	Effect size
EWPI	Equally weighted performance indicators
FT:CT	Flight time to contraction time ratio
GA	Goal attack
GD	Goal defence
GK	Goalkeeper
GPS	Global positioning system
GS	Goal shooter
ICC	Intraclass correlation coefficient

Kg	Kilogram
kg.bm	Per kilogram of body mass
L	Left leg
$m.s^{-1}$	Metres per second
$m.s^{-2}$	Metres per second squared
R	Right leg
RAT	Reactive agility test
SD	Standard deviation
Sec	Second
SL	Single leg
SWD	Smallest worthwhile difference
TE	Technical error
WA	Wing attack
WD	Wing defence
Yo-Yo IR1	Yo-Yo intermittent recovery test level one

Chapter 1 - Introduction

Netball is popular throughout most Commonwealth countries with more than 20 million athletes participating (Steele and Chad 1991, Delextrat and Goss-Sampson 2010). Matches are played on a 30.5 m by 15.25 m court divided into equal thirds over 15-minute quarters. There are seven playing positions; goal shooter, goal attack, wing attack, center, wing defence, goal defence and goalkeeper. These positions are typically grouped into shooter (goal-shooter and goal-attack), mid-court (wing-attack, center, wing-defence) and defender (goal-defence and goalkeeper) (Thomas et al. 2017). Substitutions of players may take place during quarter and half-time stoppages or during injury time-out. The objective of the game is to score a goal through a ring that is 3.05 m above the ground. Athletes are restricted to moving no more than one step when in possession of the ball and must make their pass within three seconds. Each position encounters a set of movement restrictions demonstrated in Figure 1.1 (Woolford and Angove 1992, Davidson and Trewartha 2008). These restrictions encourage specific skill-sets, as well as body composition and positional-specific physical capacities (Thomas et al. 2017). For example in a junior academy, mid-courts display higher levels of intermittent endurance, acceleration and change-of-direction ability, whilst defenders jump higher than other positions (Thomas et al. 2017). Shooters and defenders are typically taller than mid-court athletes, likely due to requirements of shooting and defending opposition passes in the shooting / defensive circle (Thomas et al. 2017).

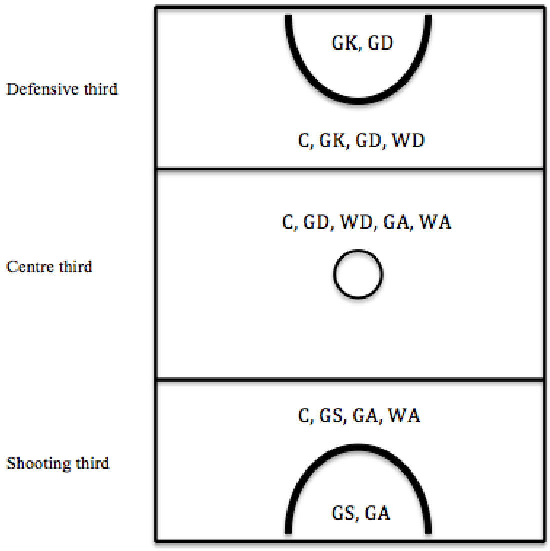

Figure 1.1. Positional movement restrictions for netball matches. Each position listed in the five areas of the netball court define the positions allowed with those boundaries. C – Centre; GK – Goalkeeper; GD – Goal defence; WD – Wing Defence; WA – Wing Attack; GA – Goal Attack; GS – Goal Shooter.

Match performance can be subjective (e.g., coach ratings) and objective (e.g., performance indicators such as turnovers etc.), or a combination of the two resulting in an arbitrary score describing player performance in competition (Felson 1981, Carré et al. 2006, Richmond et al. 2007, Heasman et al. 2008, Plessner et al. 2009, Gastin et al. 2013). Whilst coach ratings and performance indicators have been used routinely in team-sport research as a measure of match performance, no studies have investigated the relationship between these two measures and match outcome in netball. To determine an appropriate measure of match performance for use with netball athletes research must first elucidate the predictive ability of these measures with relation to match outcome.

A combined coach ratings and performance indicator approach has been implemented in Australian football only (Richmond et al. 2007). The benefits of a combined approach to evaluate match performance should be thoroughly investigated as solely utilising coach ratings may be misleading; athletes believe that a coaches assessment can easily be swayed by favouritism of a certain player amongst other potential confounding variables (Gearity and

Murray 2011, Rowe 2011, Norman and French 2013). Performance indicators can also be deceptive (Mooney et al. 2011). For example, an assigned defensive role which results in decreased game stats may indicate minimal match impact. However, the defensive role performed by this athlete may be vital in his / her team winning the game. Therefore, this thesis will investigate a combined approach, utilising performance indicators for each position on the court, and coach ratings. The proposed combined approach may provide a more sensitive evaluation of a player's impact on match outcome (points differential), whilst reflective of strategic objectives set by coaching staff.

Athlete monitoring is an important component of sport science and is readily used in current day practice throughout amateur and professional sports (Halson 2014, Saw et al. 2015). Training load dose, being training volume expressed relative to time (e.g., a rating of perceived exertion multiplied against training time), is one commonly implemented monitoring strategy. Absolute training load dose is the sum of all match and training session load from a particular period of the training plan, across days or weeks (Hulin et al. 2013). Relative training load dose is used to identify changes in load, generally expressed as a percentage from week-to-week or given as a ratio of recent load against a historical average (commonly referred to as the acute: chronic workload ratio) (Hulin et al. 2013, Drew and Finch 2016, Hulin et al. 2016, Hulin et al. 2016). Studies investigating absolute and relative changes in training load have focused on changes to physical capacities, immune system function and likelihoods of injury, yet never in relation to position-specific match performance in netball (Bosquet et al. 2007, Mujika 2009, Mujika 2010, Le Meur et al. 2012, Hulin et al. 2013, Halson 2014, Drew and Finch 2016, Hulin et al. 2016, Hulin et al. 2016). This is an important gap in our current knowledge, as understanding the way in which training load doses interact with match performance would allow a greater likelihood of invoking a beneficial outcome in netball, as well as team-sport athletes in general.

The monitoring of athlete wellbeing is commonly used in high-performance sport (Gastin et al. 2013, McNamara et al. 2013, Wehbe et al. 2015). Athlete wellbeing is typically collected via subjective questionnaires using a 5, 7 or 10-point Likert scale (Gastin et al. 2013, Johnston et al. 2013, McNamara et al. 2013, Gallo et al. 2015, Saw et al. 2015, Wehbe et al. 2015). Questions on wellness reports typically include: mood state, stress levels, energy levels, sleep, diet and areas of muscle soreness (Halson 2014). The corresponding score associated with the athlete's answers is known as their wellness score (Dawson et al. 2014, Gabbett 2016). The wellness score is designed to provide an indication of athlete preparedness for training and competition (Halson 2014). Subjective soreness in professional Australian football players indicates a small inverse relationships with match performance (performance indicators) (r -0.11) (Gastin et al. 2013). Wellness scores have never been related to position-specific match performance in netball, an important question that may influence how coaches prepare netballers for subsequent competition (Halson 2014, Saw et al. 2015).

Countermovement jump (CMJ) testing is a widely implemented monitoring tool for sport scientists to assess neuromuscular function and fatigue with athletes (Gathercole et al. 2015). The use of such testing has provided insight into acute and chronic changes in neuromuscular output (Coutts et al. 2007, Cormack et al. 2008, McLean et al. 2010, McLellan et al. 2011, Cormack et al. 2013, Mooney et al. 2013, Gathercole et al. 2015, Gathercole et al. 2015). Whilst CMJ testing has been implemented in neuromuscular fatigue monitoring for netball, (Wood et al. 2013, McKeown et al. 2016) no study has investigated jump variables which best predict position-specific match performance. By elucidating the best CMJ variable for predicting positional match performance, conditioning professionals can implement a fast and practical measure of "match preparedness" to improve their training program prescription (e.g., training load dose).

1.1 Statement of the problem

Netball athletes are often monitored by coaches through training loads, psychological wellness and physical performance (e.g., CMJ). When determining ways in which match performance can be enhanced within netball populations all of these monitoring strategies should be thoroughly examined to produce greater insights into the preparation of these athletes. As no research has attempted to investigate any relationships between monitoring variables and match performance in netball, findings would assist coaches and sport scientists in applying guidelines for monitoring netball athletes.

Chapter 2 - Review Of The Literature

2.1 Introduction

The purpose of this literature review is to describe the position-specific physical capacity requirements of netball athletes and associated match-play intensities. This review will elucidate the known differences experienced between positions within netball cohorts. A justification can then be made for the development of position-specific monitoring strategies that may maximise the likelihood of improved match performance.

Secondly, this review will focus on match performance assessment in team-sport populations. Two common forms of performance measure; coach ratings and performance indicators will be presented via a benefits / limitations approach of each measure. There is a discussion of a novel form of match performance assessment whereby coach ratings and key performance indicators are combined to provide an alternative performance-based score.

Finally, the review will investigate research pertaining to athlete monitoring tools utilised by strength and conditioning practitioners and how they may predict team-sport athlete match performance. Specifically, the aspects investigated will include training load dose, wellness questionnaires and CMJ performance.

2.2 The physical, physiological and capacity requirements of netball athletes

2.2.1 Introduction

The advancement of athlete monitoring and tracking technology has made it possible to provide valid and reliable measurement of activities in matches and training required for netball. Information provided below will describe the known requirements of training and match-play whilst also providing an evaluation on any substantial differences between positions. The purpose being to lay a fundamental understanding of netball, whilst also developing the justification for an investigation into position-specific monitoring strategies for enhancing match performance, within a state-level netball population.

2.2.2 Activity profile and movement characteristics of netball match-play

Heart rate monitoring can provide insight into the physiological stress of netball competition (Woolford and Angove 1991, van Gogh et al. 2018). In youth level netball, the goal shooter spends the most amount of time working below 75% of maximum heart rate (40.2 ± 15.9%) compared to all other positions, with exception to the goalkeeper (van Gogh et al. 2018). The centre position is exposed to the greatest heart rate stress; spending more time above 85% of maximum heart rate compared to all other positions (62.6 ± 14.9%) (van Gogh et al. 2018). In a senior cohort of national level netballers, almost 50% of match-play was found to be spent between 70 and 85% of maximal heart rate (Woolford and Angove 1991). A limitation of heart rate data for court-sport athletes is the inability to account for magnitudes of acceleration and deceleration, meaning an inability to describe the physical work that an athlete has completed. However, conditioning professionals can use this information to create heart rate targets / training zones, in order to assist their athletes in preparation for competition. With clear differences between positions for heart rate, it may then be justifiable to investigate whether modifying certain monitoring strategies for a player in a certain position has a beneficial effect on match performance scores.

The tracking of athletes provides greater understanding of the activity profiles for the observed sport (Carling et al. 2008, Aughey 2011, Sweeting et al. 2017). Time-motion analysis, a form of notational analysis derived by utilising counts and durations of certain match activities was the first method to elucidate the requirements of netball matches (Allison 1978, Otago 1983, Steele and Chad 1991, Davidson and Trewartha 2008). Two time-motion studies reported differences in percentage of playing time spent in each activity for all positions (Table 2.1). Excluding standing, which was not specifically assessed in one of the investigations, the vast majority of time is spent walking (31 to 52%) for every position (Davidson and Trewartha 2008, Fox et al. 2013). Sprinting, defined as "*running with maximum effort or at maximum speed*", indicated that the goalkeeper position (0.2 - 0.3%) was substantially lower than all other positions, perhaps highlighting a need for a different training emphasis for this position (Davidson and Trewartha 2008, Fox et al. 2013). Further to the goal keeper, whilst there is a relatively low sprinting demand to other positions, 23.3-51.7% of activity is spent in a shuffling movement that should also be considered in training. Although netball is an intermittent high-intensity sport, the movement patterns studied demonstrate that positions with greater movement restrictions (e.g., goal shooter and goalkeeper), demand repeat high-intensity efforts with extended rest periods, while centre positions have less rest and often perform these movements under a fatigued state. These differing positional requirements are further highlighted via analysis of work-to-rest ratios.

Table 2.1. Percent time spent in each activity during competitive matches in the English Super League (Davidson and Trewartha 2008), and Australian international competition (Fox et al. 2013). Data presented as mean ± SD.

		GS	GA	WA	C	WD	GD	GK
Standing	Eng. Super League	44.8 ± 2.4	-	-	12.3 ± 1.8	-	-	35.3 ± 2.8
	Aus. National Team	-	-	-	-	-	-	-
Walking	Eng. Super League	31.1 ± 1.2	-	-	31.8 ± 2.4	-	-	38.7 ± 0.5
	Aus. national team	51.7 ± 6.5	46.3 ± 2.1	46.6 ± 3.6	38.9 ± 2.1	45.4 ± 5.8	40.4 ± 9.1	35.2 ± 8.9
Jogging	Eng. Super League	2.5 ± 0.9	-	-	17.2 ± 2.5	-	-	1.7 ± 0.7
	Aus. National Team	5.0 ± 1.9	15.9 ± 3.6	15.6 ± 3.5	20.5 ± 5.7	10.8 ± 1.8	16.2 ± 1.9	5.2 ± 1.1
Shuffling	Eng. Super League	14.8 ± 2.2	-	-	20.3 ± 2.8	-	-	23.3 ± 2.4
	Aus. National Team	23.6 ± 1.7	20.7 ± 4.0	21.9 ± 3.0	26.1 ± 0.4	31.2 ± 2.8	20.8 ± 5.5	51.7 ± 5.1
Running	Eng. Super League	2.0 ± 0.8	-	-	14.7 ± 2.3	-	-	0.9 ± 0.3
	Aus. National Team	5.4 ± 2.3	6.7 ± 0.9	6.4 ± 1.3	5.5 ± 2.0	5.0 ± 1.6	6.7 ± 1.2	1.7 ± 0.4
Sprinting	Eng. Super League	2.2 ± 0.9	-	-	2.4 ± 1.2	-	-	0.3 ± 0.5
	Aus. National Team	3.4 ± 0.5	3.0 ± 1.8	4.8 ± 2.6	3.0 ± 1.2	3.7 ± 2.1	3.1 ± 2.1	0.2 ± 0.1
W:R	Eng. Super League	1:4.5	-	-	1:1.9	-	-	1:2.9
	Aus. National Team	1:5	1:5	1:5	1:5	1:5	1:5	1:5

GS; goal shooter, GA; goal attack, WA; wing attack, C; centre, WD; wing defence, GD; goal defence, GK; goalkeeper, -; not assessed in the particular cohort, Eng.; English, Aus.; Australian

Time-motion analysis assessing work-to-rest ratios present divergent requirements between positions and different findings across two time-motion studies (Table 2.1) (Davidson and Trewartha 2008, Fox et al. 2013). The goalkeeper, goal defence, goal shooter and goal attack positions required greater work-to-rest ratios. Therefore, in this cohort mid-court players are more continuous in their activity profile (Davidson and Trewartha 2008). In other investigations most frequent work-to-rest ratios were 1:5 followed by a 1:1 for all positions (Fox et al. 2013). These ratios reflect the highly intermittent nature of netball and is similar to those recorded in basketball (1:3.6) (Abdelkrim et al. 2010). The majority of any activity duration in netball lasts approximately four seconds or less (Davidson and Trewartha 2008, Fox et al. 2013). Conditioning professionals can use these observed work-to-rest ratios and general activity durations to guide their training program design. In doing so they may increase their athletes' chances of possessing the capacities necessary to withstand the most intense periods of match-play. These time-motion studies provide the early foundations for understanding the activity profiles of netball, whilst increasing the justification for exploring different monitoring strategies between positions and any corresponding effects on match performance evaluation. Time-motion analysis has provided foundational insights into the activity profiles of netball, however micro-technologies such as radio frequency tracking systems and accelerometers are beginning to provide more objective insights (Young et al. 2016, Sweeting et al. 2017).

Radio frequency is a tracking tool which estimates player position in respect to coordinates of a playing area (Sweeting et al. 2017). Using radio frequency tracking, four of the six most commonly occurring activities involve walking with neutral acceleration for all positions in netball (6.1 to 12.1% of game time) (Sweeting et al. 2017). However, a more pertinent finding from a conditioning perspective are activities of least frequency, which are often more physically exertive and critical to competitive performance (Delaney et al. 2015, Duthie et al.

2018). The six least occurring activities in netball matches all involve sprinting (> 3.9 $m.s^{-1}$) with 90 to 180 degree changes-in-direction (Sweeting et al. 2017). This information becomes important for training drill design; for if the conditioning goal of the drill is to prepare athletes for the most intense periods of play, the training prescription must include sprinting and changes-in-direction ≥ 90 degrees.

When analysing individual positions for similarities between movement frequencies with radio frequency tracking, only the wing attack, goal attack and goal defence positions can be considered similar (Figure 2.1) (Sweeting et al. 2017). It may then be pertinent for conditioning coaches to consider that training, from a volume and intensity perspective, should not differ between these three positions. Findings from this research objectively describe netball as a multidirectional, intermittent high-intensity sport with many aspects that will require specific conditioning. Therefore, it is possible that different monitoring strategies for specific positions may have beneficial effects on match performance scores.

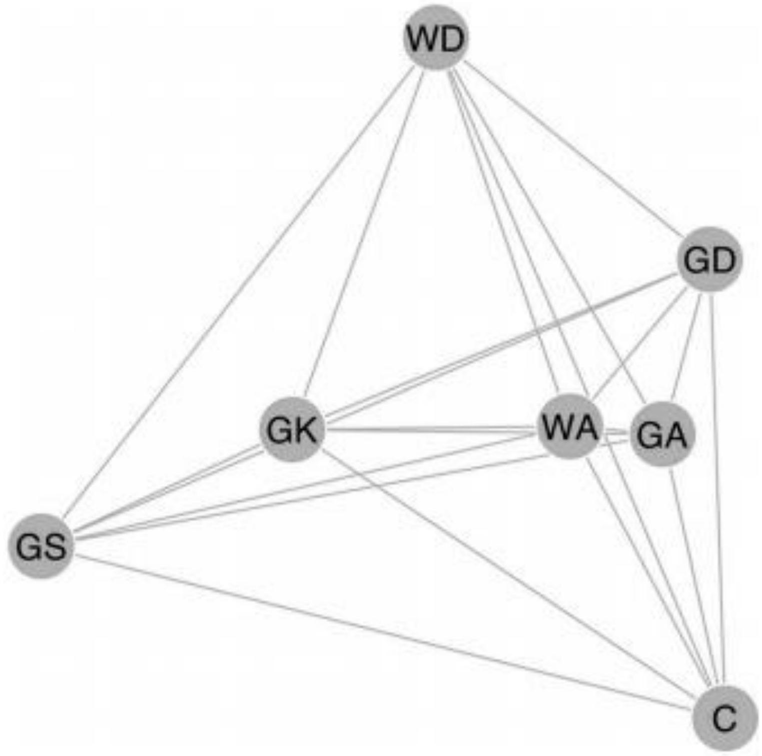

Figure 2.1. Network analysis of movement similarities between positions (Sweeting et al. 2017).

Accelerometers are another tracking device that measure the rate of change in velocity. By combining the total accelerations from all three axis into one vector magnitude (Boyd et al. 2011), sport scientists can quantify total physical work completed. The process of acquiring this vector magnitude is highly reliable (CV < 2%) (Boyd et al. 2011). Early investigations of accelerometer derived load in netball match-play report mid-court athletes (wing defence, centre, and wing attack) on average completing a greater volume of work, at a higher intensity than shooter (goal shooter and goal attack) and defender positions (goalkeeper and goal defence) (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). Victorian state-league athletes complete more work per minute of match-play when compared to recreational B-grade counterparts in the shooter position (effect size (ES) 1.1), mid-court athletes (ES: 2.0) and defenders (ES: 1.7) (Cormack et al. 2014). Mid-court athletes in recreational B-grade competition are more '*likely*' to lower their physical output over the course of a match, where higher standard mid-court netballers will maintain their intensity (Cormack et al. 2014). These early investigations report the average demands of netball competition and provide the foundations for describing match requirements in netball. However, reporting the average demands may provide an inadequate representation for this high-intensity intermittent sport, as reporting average demands across a match will likely include breaks in play such as time-outs and injuries (Delaney et al. 2015, Duthie et al. 2018). It would be more pertinent for conditioning professionals to understand the peak demands of competition to better prepare athletes in training for the most physically exertive periods of play (Delaney et al. 2015, Duthie et al. 2018).

2.2.3 Anthropometry of netball athletes

The anthropometric attributes of netballers have been documented across various age groups and competitive levels (Ferreira and Spamer 2010, Tanner and Gore 2012, Thomas et al. 2017). The mean body mass of British junior academy netball players ranges between 62 to 71 kilograms (kg) (Thomas et al. 2017), with open age semi-professional South African (70 kg) (Ferreira and Spamer 2010), and Australian under 21 (74 kg) and open age national level netballers differing slightly (74 kg) (Tanner and Gore 2012). Only one investigation has analysed differences between positions within stature and mass (Thomas et al. 2017). Shooter position athletes were taller than mid-court athletes (ES 0.7) but shorter than defenders (ES -0.5) where mid-court athletes were much shorter than defenders (ES 1.6) (Thomas et al. 2017). The body mass of shooters were heavier than mid-court athletes (ES 1.1) and lighter than defenders (ES -0.4), whilst mid-court athletes were also lighter than defenders (ES -1.1) (Thomas et al. 2017). Future research should investigate different anthropometrical attributes of netball players in more senior cohorts and investigate different variables such as limb length and body composition. Other team-sports such as basketball (Nikolaidis et al. 2014), and Australian football (Pyne. 2006) have completed such works, aiding the identification of anthropometric attributes required for certain positions. This research in netball is required to assist coaches in choosing appropriately developed athletes for certain netball positions.

2.2.4 Strength capacities of netball athletes

Strength capacity is important for court-based sport athletes as strength underpins power development (Young 2006, Seitz et al. 2014, Suchomel et al. 2016), in turn important for jumping, accelerating, and changing direction that netballers are known to complete (Fox et al. 2013, Sweeting et al. 2017). Only one investigation has performed strength profiling of netball athletes (Tanner and Gore 2012). Comparisons between an Australian national-level and nationally identified under 19 athletes reported that national level athletes were stronger in the three repetition maximum back squat and bench press (ES 0.24 and 0.54 respectively) (Tanner and Gore 2012). When expressing three repetition maximum strength relative to body mass, back squat strength reached 1.02 kg / kg.bm^{-1} and 0.64 kg / kg.bm^{-1} for the bench press (Tanner and Gore 2012). Future research should investigate the strength profiles of these athletes at the highest levels and between positions to provide a deeper understanding / benchmarks for performance within this population.

2.2.5 Jumping and bounding performance in netball

Notational analysis has identified jumping as a consistent requirement of netball athletes in all positions (mean jump count across positions 31 – 67) (Fox et al. 2013). The CMJ is a measure of lower-limb (system) power in the vertical plane (Cormie et al. 2009). The comparison of CMJ data between the two studies in Table 2.2 reported British junior academy athletes achieving a lower jump height than Australian nationally identified athletes (ES -0.42 to -2.63). Maturational status may play a role in differences reported for jump height as an inverse trend appears between differences in jump height vs increasing age (Table 2.2). Whilst jumping is an identified requirement of netball match-play (Fox et al. 2013), no research has attempted to identify differences between positions within a senior cohort for this important physical capacity. Highlighting the positional differences of this physical quality may strengthen the justification for an investigation into whether different position-specific monitoring strategies may enhance match performance outcomes.

Table 2.2. Raw data presented as mean ± SD of physical performance profile data from the three most comprehensive profiles of netball athletes available in the literature, from different countries and levels of competition.

	British junior academy (Thomas et al. 2017)			Australian national (Tanner and Gore 2012)			
	Shooters	Mid	Defenders	U17	U19	U21	Open
5 m sprint (s)	1.18 ± 0.05	1.12 ± 0.06	1.11 ± 0.09	1.25 ± 0.9	1.24 ± 0.08	1.21 ± 0.07	1.22 ± 0.08
10 m sprint (s)	2.00 ± 0.07	1.92 ± 0.06	1.97 ± 0.08	2.07 ± 0.10	2.06 ± 0.09	2.03 ± 0.09	2.03 ± 0.10
20 m sprint (s)	-	-	-	3.52 ± 0.16	3.51 ± 0.14	3.45 ± 0.14	3.46 ± 0.16
505 COD (s)	2.53 ± 0.08	2.43 ± 0.09	2.53 ± 0.10	-	-	-	-
Planned COD (s)	-	-	-	9.05 ± 0.26	-	-	8.92 ± 0.34
RAT (msec)	-	-	-	453 ± 334	454 ± 302	197 ± 218	266 ± 210
CMJ (cm)	38.0 ± 1.0	42.0 ± 4.0	37.0 ± 3.0	43.9 ± 5.0	44.1 ± 5.5	45.8 ± 5.5	46.4 ± 5.4
1 SL bound (m)	1.69 ± 0.2	1.84 ± 0.15	1.75 ± 0.11	-	-	-	-
3 SL bound (m)	-	-	-	-	-	-	-
Yo-yo IR1 (m)	-	-	-	1040 ± 288	1320 ± 384	-	1480 ± 352
30-15$_{IFT}$ (km.h^{-1})	16.9 ± 1.2	18.5 ± 1.3	16.9 ± 1.0	-	-	-	-
3RM squat (kg)	-	-	-	-	71.4 ± 12.6	-	74.2 ± 11.0
3RM BPr (kg)	-	-	-	-	43.5 ± 7.2	-	46.7 ± 5.0
3RM BPu (kg)	-	-	-	-	47.4 ± 6.7	-	-

m; metres, cm; centimetre, kg; kilogram, s; seconds, COD; change-of-direction, msec; milliseconds, Yo-yo IR1; yo-yo intermittent recovery test level one, 30-15$_{IFT}$; 30-15 intermittent fitness test, km.h^{-1}; kilometres per hour, RAT; reactive agility test, CMJ; countermovement jump, SL; single-leg, BPr; bench press, BPu; bench pull.

Single-leg bounding is a measure of horizontal force projection and is a recognised injury-likelihood measure in females (Gustavsson et al. 2006). Positional comparisons of CMJ height and horizontal bounding report mid-court athletes jump higher than shooters (ES 0.80) and defenders (ES 1.40) in British junior academy netballers (Thomas et al. 2017), whilst defenders were only slightly outperformed by shooters in the same junior academy cohort (ES -0.20) (Thomas et al. 2017). Mid-court athletes bound further than shooters and defenders at junior levels (ES 0.85 and 0.75 respectively), with defenders also bounding further than shooters (ES 0.35) (Thomas et al. 2017). The ability to produce vertical and horizontal force appears more integral for those in the mid-court positions within a junior academy cohort (Thomas et al. 2017), and should be trained appropriately. To date, no study has investigated positional differences in CMJ height or horizontal bounding in a senior cohort. Such information would prove valuable for professionals that concern themselves with athlete recruitment and athlete benchmarking. By elucidating the positional differences in jumping performance, justification for an investigation into different monitoring strategies to enhance match performance between positions would be further strengthened.

2.2.6 Acceleration capacities of netball athletes

A high level of acceleration capacity could be considered favourable for enhancing netball performance in training and competition (Sweeting et al. 2017). Junior academy players were faster than Australian nationally identified athletes in all positions over five and 10 m distances (ES range -0.22 to -1.41). Between positions within the same level, shooters are slower than mid-court athletes and defenders over five and 10 m at a junior academy level (ES: 0.9 to 1.0 5m and 0.4 to 1.2 10 m) (Thomas et al. 2017). There is no substantial difference between defenders and mid-court athletes accelerating over five-metres (ES 0.1), though defenders are substantially slower in 10 m sprint performance (ES 0.7) (Thomas et al. 2017). The anthropometry of these populations may shed light on this finding, as the junior academy athlete’s reported less total mass and stature than nationally identified athletes, whilst the mid-court positions were lighter than shooters and defenders in the junior academy cohort (Tanner and Gore 2012, Thomas et al. 2017). A lower body mass and stature could be considered favourable for linear acceleration tasks (Silvestre et al. 2006). Regardless of profiles between levels and positions, acceleration capacities should still be considered important by conditioning professionals working with netball athletes, as this is an important quality required during matches (Davidson and Trewartha 2008, Fox et al. 2013, Sweeting et al. 2017).

2.2.7 Change-of-direction capacities in netball

Changing direction forcefully and rapidly is an important quality identified in netball (Davidson and Trewartha 2008, Fox et al. 2013, Sweeting et al. 2017). The planned change-of-direction test requires five changes in direction ≥ 45 degrees at maximal effort. During the planned change-of-direction task, nationally identified under 17 year old players were slower than their older national level counterparts (ES -0.43) (Tanner and Gore 2012). Given that the national level athletes are typically stronger and more conditioned than junior athletes (Table 2.2), it is possible the senior cohort would be able to maintain their intensity throughout the course more so than the under 17 athletes.

Positional comparisons for the 505 change-of-direction test reported British junior academy mid-court athletes change direction faster than both shooters and defenders (ES range -1.0 to -1.3) (Thomas et al. 2017). There is no substantial difference between shooters and defenders for the 505 change-of-direction test in British junior academy netball players (Thomas et al. 2017). As changing direction forcefully and rapidly is a requirement of all netball positions (Fox et al. 2013, Sweeting et al. 2017), conditioning professionals should invest time towards developing this capacity. Data presented in Table 2.2 can be used to provide benchmarks / guidance for athlete development at all levels of netball.

2.2.8 Intermittent endurance of netball players

High-intensity, intermittent endurance is a requirement in netball due to the nature of the sport, with the most frequent work-to-rest ratio being a 1 work: 5 rest (Fox et al. 2013). Between position comparisons report mid-court athletes outperform shooters and defenders at a junior level in the Yo-Yo Intermittent Recovery Test (ES 1.05 and 1.20) (Thomas et al. 2017), and no substantial difference exists at a junior academy level between defenders and shooters (ES 0.10) (Thomas et al. 2017). These results indicate that mid-court athletes require a higher level of intermittent endurance than shooters and defenders at a junior level. Though differences between positions is limited to one study, conditioning professionals should be mindful of these benchmarks when developing training programs for their netball athletes, though future research should look to investigate positional differences in open age groups to determine whether capacity requirements remain the same.

2.2.9 Summary of physical, physiological and capacity requirements of netball athletes

Netball is an intermittent high-intensity power-based sport, played in 360 degrees of motion (Fox et al. 2013, Sweeting et al. 2017). There are clear differences in the loads accrued over the course of a match between positions (Cormack et al. 2014, Sweeting et al. 2017), which must be accounted for via monitoring practices to better prepare netball athletes for competition. Mid-court athletes possess faster linear accelerations and change-of-direction speed than all other positions (Thomas et al. 2017). Jumping is a consistent requirement in netball matches (Fox et al. 2013), where junior mid-court athletes jump higher compared to other positions (Thomas et al. 2017). There is a higher intermittent endurance requirement for mid-court athletes compared to shooters and defenders (Thomas et al. 2017). The ability to react to a sport-specific stimulus (i.e., reactive agility) is greater in higher level netball athletes compared to their lower level counterparts (Farrow et al. 2005, Farrow et al. 2005, Tanner and Gore 2012), which may be an important training variable for improving match performance. A clear gap exists for position-specific physical capacity investigations utilising a senior netball cohort (Thomas et al. 2017). The clear differences between physical capacity and activity profiles of positions within netball suggests future investigations identifying positional monitoring strategies should be examined.

2.3 The assessment of match performance within team-sport populations

2.3.1 Introduction

Assessing the individual competitive performances of team-sport athletes is of paramount importance for measuring the success of training interventions and player recruitment strategies (Wright et al. 1995, Mooney et al. 2011). More specifically, when assessing the match performance of an individual player the most common forms of assessment include coach ratings and performance indicators, explained in greater detail throughout this section of the review. A relatively new form of match performance assessment includes a combination of coach voting criteria and key performance indicators, resulting in an arbitrary score related to "match impact" (Richmond et al. 2007, Gastin et al. 2013). The aim of this section is to provide a critique of the two most common assessment tools of match performance in team-sport, and where possible the magnitude between the performance variable and match outcome is presented using ES statistics. The purpose of this section is to lay the foundation for an investigation into the relationship between common performance measures and match outcome.

2.3.2 Utilising coach rating as a measure of match performance

Utilising coach expertise in the form of a voting system following a match is a common form of assessment within team-sport literature (Table 2.3). An important consideration for coach ratings of performance is the length of the scale used. Likert scales from a three-point to 20-point method have been implemented to capture coach ratings. A Likert scale is defined as a measure of attitude and provides a range responses to a given question or statement (Cohen et al. 2013). Importantly, for scale selection there is no right or wrong answer in regards to Likert scale range, as there is no way to guarantee that the true distance between 1 = “Definitely disagree” and 2 = “Disagree” is the same as 4 = “No opinion” and 5 = “Moderately agree” (Norman 2010). It is therefore up to the researcher to ensure that these numbers / descriptors are ‘reasonably’ distributed (Norman 2010). The type of statistical approach implemented will not be impacted by the choice of Likert scale, as it will have no bearing on the outcome of analysis (Norman 2010). Researchers and sport science practitioners can choose any length of Likert scale with confidence, being wary however, that the distance between possible responses can be considered ‘reasonable’ (Norman 2010).

Table 2.3. Team-sport research implementing coach ratings with various Likert scales for player performance assessment in individual matches.

Study	Population	Likert scale	Outcome / s
Piggot et al. (2015)	Semi-professional Australian football players	10-point	The only significant relationship ($p < 0.5$) with coach ratings, were a player's number of senior games.
Cormack et al. (2013)	Elite Australian football players	Five-point	No practically important correlation between coach ratings and accelerometer derived workload in any axis of space. Accelerometer derived workloads do not influence coach ratings in Australian football.
Mooney et al. (2011)	Elite Australian football players	Five-point	An individual players Yo-yo Intermittent Recovery Test Level 2 result with mediators being metres per minute and high intensity running metres per minute had no bearing on a coach's rating of performance.
Johnston et al. (2012)	Professional Australian football players	20-point	Player movement demands and match events are objectively related to perceived performance by coaches.
Tangalos et al. (2015)	Junior Australian football players	Six-point	Coach ratings showed the strongest correlations with total number of disposals and effective disposals.
Kinchington et al. (2012)	Amateur Australian football and rugby union players	Not defined	Lower limb discomfort was not correlated with higher ratings of match performance. Usual-high lower limb comfort was correlated with usual-good performance.
Verrall et al. (2006)	Professional Australian football players	10-point	Mean coach rated match performance was significantly reduced for the two games following return to play from hamstring injury (mean prior to injury 6.8 ± 0.6, mean two games post return 5.1 ± 0.9, $p < 0.001$).
Hunkin et al. (2014)	Professional Australian football players	Three-point	Small inverse relationship between pre-match creatine kinase levels and subsequent coach rated match performance (r -0.149, p 0.035).
Cook and Crewther (2012)	Professional rugby union players	Five-point	Watching a video clip of successful skill execution by the player with positive coach feedback, resulted in better coach ratings of performance in both skill execution ($p < 0.05$) and overall performance ($p < 0.003$).
Sullivan et al. (2014)	Professional male Australian football players	10-point	Skill measures in games attributed more to coach ratings of match performance than physical activity profile ($p < 0.05$, p 0.14 respectively).
Curtner-Smith et al. (1999)	Junior female high school basketball players	Five-point	Coach ratings of player performance were positively related with team points differential and winning percentage (r 0.43, p 0.05; r 0.42, p 0.06 respectively).
Fowler et al. (2014)	Professional male soccer players	10-point	Domestic air travel had no significant effect on coach ratings of match performance ($p > 0.05$).
Neave and Wolfson (2003)	Amateur male soccer players	Five-point	Coach ratings of performance did not relate to any testosterone or mood measures taken pre-match.

Coach ratings for evaluating individual performance in team-sports has been considered the '*gold standard*' of performance assessment (Johnston et al. 2012). A players seniority (Piggot et al. 2015), skill level in the match (Sullivan et al. 2014, Tangalos et al. 2015), and pre-match watching of positive video footage (Cook and Crewther 2012), all present beneficial relations with coach perceptions of performance in multiple sports (Table 2.3). A player's level of seniority and skill level in a match is likely influenced by factors beyond the control of the sport scientist. However, the implementation of pre-game video footage where a coach can sit with a player for 15-minutes and provide positive responses such as "*you performed that well*" and "*that's how I want you to do that*", may be a strategy that could improve performance outcomes as assessed by coaches.

Detrimental independent variables on coach ratings can consist of subjective lower limb discomfort (Kinchington et al. 2012), where a very large linear relationship exists with poor match performance as assessed by coaching staff (r 0.79). An athlete's pre-match levels of creatine kinase have a small inverse relationships (r -0.162) with coach assessed match performance in Australian football (Hunkin et al. 2014). Finally, an athlete returning from injury in their initial two games following return to play reported lower coach assessed match performance scores compared to the entire season (ES -2.38) (Verrall et al. 2006). The detrimental variables on coach ratings of performance present a theme relating to physical performance. Sport scientists can use this information to emphasise the importance of 'appropriate' recovery and rehabilitation practices.

Certain aspects of performance such as accelerometer derived workloads (Cormack et al. 2013), tracking data (i.e., via GPS) (Mooney et al. 2011), domestic air travel (Fowler et al. 2014), pre-match testosterone and analysis of athlete mood state questionnaires (Neave and Wolfson 2003), have no bearing on coach perceptions of performance. It is evident that improved match performance scores, as provided by coaching staff, are related closer to the technical and tactical aspects of match-play (Cook and Crewther 2012, Sullivan et al. 2014, Tangalos et al. 2015), as well as playing experience (Piggot et al. 2015). Future investigations implementing coach ratings with team-sport athletes should consider how changes in values associated with athlete monitoring strategies across multiple seasons impact on coach perceptions of performance.

2.3.3 Limitations of coach rating as a measure of match performance

Despite coach ratings being regarded as the '*gold standard*' of team-sport match performance assessment, this form of evaluation is subjective and comes with some confounding variables. As described earlier in Australian football, a player's seniority alone can have a linear relationship with coach ratings received for a particular match (Piggot et al. 2015), indicating perhaps a preferential treatment towards senior members of the team. Indeed, the idea of favouritism of athletes by coaches has been identified across multiple sports including netball, baseball, American football and softball (Gearity and Murray 2011, Rowe 2011, Norman and French 2013). It is also possible that if a player is seen to be putting in more effort by watching pre-match video footage, a coach may reward that athlete with better coach ratings to compensate for perceived effort (Cook and Crewther 2012). When assessing team-sport athlete performance utilising coach ratings, practitioners should consider the following:

- The type of Likert scale implemented will have no bearing on statistical outcome.
- The practitioner must consider 'reasonable' spacing between numbers and qualitative descriptors used for rating athlete performances when using Likert scales.
- It is likely that a coach will rate a player higher on their technical and tactical performance more so than activity profile provided by micro-technologies.
- Coach ratings, being a subjective form of assessment has inherent confounding variables such as favouritism, which may negatively skew data collected.

2.3.4 Utilising performance indicators as a measure of match performance

Analysing performance indicators can provide an important outcome measure when inferring match performance in team-sport populations (Table 2.4). A benefit of performance indicators over coach ratings is a purely objective insight into match events. For example, analysis of top-level soccer in multiple countries (Italy, Serie A; England, English Premier League; Spain, La Liga) has reported that more successful teams accrue greater distances (540 m for successful teams to 443 m for less successful) and durations (~10 seconds compared to 8 seconds for successful vs. unsuccessful teams) with the ball whilst completing a greater number performance indicator involvements (44.7 to 34.5) (Jones et al. 2004, Rampinini et al. 2009, Lago-Peñas et al. 2010). Unsurprisingly, more successful teams will also complete more performance indicator involvements related to offense (ES 0.26 to 0.91) (Lago-Peñas et al. 2010). By spending greater periods of time with possession of the ball, it is likely that this allows for more attacking plays and scoring opportunities. A coach may then extrapolate this team-based data when assessing an individual players' impact on match outcome, by simply assessing individual duration with the ball. Similarly in Australian football, a team is more '*likely*' to be successful based on attaining a greater number of skilled involvements against their opposition (Sullivan et al. 2014). In volleyball, less attacks blocked and spikes (ES -0.98) with reduced reception errors (ES -0.78) were the most consistent performance indicators across studies in relation to increasing chances of team success (Eom and Schutz 1992, Patsiaouras et al. 2011, Medeiros et al. 2017). In international male and female rugby union, teams have a substantially greater chance of winning with increased absolute kicks whilst in possession, kicks to touch, tackles made, rucks and kicks in opposition territory (ES 0.30 to 0.74) (Vaz et al. 2010, Hughes et al. 2017). Coaches can use performance indicators data alone to assess match performance, with the knowledge that the performance indicators assessed can infer the impact which a player had on the match outcome.

Table 2.4. Team-sport research involving the implementation of performance indicators for player performance assessment in individual matches.

Study	Population	PI used	Outcome
Gastin et al. (2013)	Professional Australian football players	Impact rating system (CD)	Only 3.2% of variance (r^2) in match performance is explained by changes in training load.
Eom and Schutz (1992)	Male international volleyball championship	Eight KPI's	The block and the spike are most important for determining team success.
Di Salvo et al. (2009)	English premier league soccer	High-speed running distance in possession	There was no statistically meaningful difference between successful and less successful teams in high-speed running distance in possession.
Rampinini et al. (2009)	Italian Serie A league	Physical activity with the ball Twelve player KPI's	More successful teams spend more distance with the ball (+16%). Involvements with the ball were greater in more successful teams (passes, tackles, dribbles and shots).
Jones et al. (2004)	English premier league	Counts of ball involvements	More successful teams had significantly ($p < 0.05$) longer durations in possession irrespective of match outcome (win, loss, draw).
Vaz et al. (2010)	International rugby union matches, and Super 12 rugby union matches	18 game related KPI's	No significant differences in KPI's between winners and losers in close (<15 points difference) international matches. More successful teams in close matches (<11 points) of super 12 rugby had ↑ possession kicked, kicks to touch, tackles made and ↓ rucks and passes, mauls won, turnovers won, passes completed, and errors made ($p < 0.05$).
Lago-Peñas et al. (2010)	La Liga, professional Spanish soccer league	13 game related KPI's	More successful teams had ↑ total shots, shots on goal, effectiveness, assists, offsides committed and crosses against ($p < 0.01$).
Patsiaouras et al. (2011)	Male Olympic volleyball matches	10 game related KPI's	↑ service points won and attacks blocked with ↓ reception errors were significantly related to winning at the Beijing Olympic games.
Hughes et al. (2017)	International male and female rugby union	14 game related KPI's	For men ↑ tries, rucks in opp. 22-50, more kicks in opp. 22-50, win more opp. lineouts ↓ pick and go carries, penalties conceded in own 22, resulted in winning more often. For women ↑ tries, line breaks, tackle completion, win more opp lineouts↓ pick and go carries, rucks in opp. 22-50, kicks in opp. 22-50, penalties conceded in own 22, resulted in winning more often.
Medeiros et al. (2017)	Male U19, U21 and opens international volleyball	17 game related KPI's	↑ points won on serve, attack and by block resulted in greater chances of winning.

PI = Performance indicators, CD = Match impact score provided by Champion Data (Victoria, Australia: http://www.championdata.com.au/), PERF = Performance, SHOT% = field goal and foul shot percentage combined, PTS = points per game, REB = offensive + defensive rebounds, AS = assists per game, ST = steals per game, TO = turnovers per game, 10 = a constant to ensure positive scores, ↑ = greater, ↓ = fewer, opp. = opposition.

2.3.5 Limitations of performance indicators as a measure of match performance

Limitations exist in performance indicator data that has predominantly focused on the analysis of team performance rather than individual player impact on match outcome (i.e., wins / losses, or points differential). Further research is required in team-sport literature to elucidate positional, or individual player impact on likelihoods of team-success. There is the possibly an inability of performance indicators to account for a change in match tactics either prior to, or, during a game as directed by the coach. In many team-sports the defensive actions and movements are important for all players to perform. As performance indicators are typically related to direct ball involvements, key aspects of defence may not be accounted for, ultimately resulting in an inadequate measure of individual performance (Hiscock et al. 2012). When utilising performance indicators data for assessing an individual player's match performance coaching staff should consider the following:

- Most of the research has investigated performance indicators on a team rather than individual level. Though certain performance indicators may not be suitable for specific positions, e.g., a goal shooter in netball may play an entire match without a single interception as their primary function is to score goals.
- Utilising performance indicator data in team-sports to assess performance will likely have some relation to the outcome of the match i.e., win / loss or points differential.
- Performance indicator data may not provide a true reflection of an individual's impact on match outcome, in instances where a specific defensive role has been asked of that player.
- The quality of the performance indicator (e.g. disposal efficiency) should be considered rather than just the absolute count of a performance indicator for a match.

2.3.6 Combining coach rating and performance indicators to obtain a match performance score

A novel approach to team-sport athlete assessment of match performance is a formula to combine both coach ratings and performance indicator data. A combined coach rating and performance indicator approach has been implemented in Australian football (Richmond et al. 2007), but is yet to be applied in other team-sports. Currently, the implementation of such a tool is lacking in scientific rigor as the formula to combine the two was reported as a "*confidential coach formula*" resulting in the inability for scientific scrutiny (Richmond et al. 2007). Nevertheless, the combined approach may provide more logical and specific assessment of player impact accounting for the limitations of both methods. Further research combining these methods with a statistically 'appropriate' weighting may create a new 'gold standard' of match performance assessment and enhance the ability to evaluate the success of training interventions and team list strategies.

2.3.7 Summary of assessing match performance in team-sport athletes

Using coach ratings as a measure of a team-sport athletes match performance potentially explains more about a players technical and tactical performance than performance indicators, but may be subject to bias such as athlete favouritism (Gearity and Murray 2011, Rowe 2011, Norman and French 2013). Implementing performance indicators provides an unbiased quantification of what the athlete did during the match, though may not indicate the tactical role of a given individual (e.g., defensive roles resulting in lower performance indicators) (Hiscock et al. 2012). Utilising an intricate statistical approach to combine both coach ratings and performance indicators into an arbitrary performance score may prove to be the most rigorous form of assessment, accounting for what the athlete did but also the technical and tactical aspects of match-play. Future research should investigate all of these measures in one study to ascertain their ability to predict match outcome in a team-sport setting.

2.4 Predicting match performance in team-sport populations

2.4.1 Introduction

Sport science practitioners will often monitor the performance in training and competition of athletes, with the goal of procuring data to help inform future training, to enhance competitive performance outcomes. Common monitoring practices include ‘recent’ training loads with one to 28 days / four-weeks typically considered as the relevant time-course for ‘fatigue’ to negatively impact performance (Halson 2014, Thorpe et al. 2015, Gabbett 2016, Lazarus et al. 2017, Rowell et al. 2018). Questionnaires that procure an evaluation of psychological wellness (e.g., how ‘well’ an athlete feels) may also prove beneficial for predicting match performance (Saw et al. 2015). Another commonly implemented monitoring strategy is CMJ performance (Cormack et al. 2008, Cormie et al. 2009, Cormack et al. 2013), where enhanced scores of a given jump variable (e.g., rate-of-force development) is considered favourable for match preparedness and subsequent performance. The purpose of this section is to describe three common monitoring aspects (training load, psychological wellness scores and CMJ performance) used in high-performance sport and how they may aid in match performance prediction in netball athletes.

2.4.2 Training load dose to predict match performance

Training load in athletic populations can be identified as the quantification of the volume of physical work completed (Halson 2014). Training load dose then describes a training volume measure relative to time, for example the absolute training completed over a seven-day period. Using training load dose for predicting competition performance has been routinely investigated within individual sports (Bosquet et al. 2007). A meta analytical review for swimming, running and cycling reported the most likely beneficial training load dose for enhancing performance was a decrease in volume of 41-60% (ES: 0.72, CL: 0.36 to 1.09), of two-weeks duration (0.59, 0.26 to 0.92), whilst maintaining training intensity (-0.02, -0.37 to

0.33) (Bosquet et al. 2007). This analysis provides practical guidelines for coaches maximising the likelihood of enhanced performance during phases of competition for these sports. However, for team-sport populations performing a similar investigation becomes far more complex due to the numerous confounding variables such as the opposition team and travel between training and match venues, which can all impact the performance of team-sport athletes (Fowler et al. 2014, Robertson and Joyce 2015, Fullagar et al. 2016). Nevertheless, current team-sport studies are elucidating how different training load doses can impact certain measures of match performance.

As research into beneficial or harmful training load doses on match performance in netball is non-existent, examples from other team-sports are required. Soccer is a team-sport where attempts have been made to identify any beneficial of harmful effects of training load dose manipulation on performance in games (Fessi et al. 2016, Krespi et al. 2018). Nineteen professional soccer players from the Qatar Stars League (age 25.7 ± 2.6 years) reported training load reductions of 25.5% during a pre-defined phase of the competitive season (Fessi et al. 2016). As a result, the athletes reported an increase in intense and high-intensity running, as well as the number of sprints completed in matches (15.1%, 15.7% and 17.8% respectively) (Fessi et al. 2016). Similar findings are noted with 158 junior soccer players, where training was reduced in two groups utilising either a linear or exponential decay over a four-week period. Increased distance covered in five velocity bands (0.4-3.0 kph to >18 kph) in both groups was noted (ES: 0.26 to 0.72), though slightly favouring an exponential taper from competitive matches ($p < 0.05$) (Krespi et al. 2018). Interpreting these findings can be problematic as it’s likely that the technical and tactical execution of players and coaching staff have greater bearing on match outcome compared to physical activity profiles (Carling 2013). Indeed, the notion of technical and tactical execution was mentioned as part of the Qatar Stars League study “*it needs to be determined whether tapering or tactical and technical aspects led* *to the changes in match activity*” (Fessi et al. 2016). Further, it was assumed that a reduction in training may be best for a soccer population, whilst no attempts were made to investigate whether certain positions may require different training load doses (e.g., an increase in load). Utilising tactical / technical match performance measures whilst accounting for opposition quality and training load would be of high relevance to sport science community.

Recent team-sport publications have identified the impact of training load dose on technical and tactical measures of performance (coach ratings and performance indicators), but importantly have also split their analysis by playing position. Australian male professional soccer players (*n* = 23, age 23.3 ± 4.1 years) training load and match performance (coach ratings on a five-point scale, 1 = poor to 5 = excellent) were monitored for an entire competitive season (Rowell et al. 2018). This study reported centre and wide defenders attained lower coach ratings when experiencing increased training load (mean change -0.32 to 0.11) (Rowell et al. 2018). This is in line with current recommendations suggesting reduced training volume will increase performance (Bosquet et al. 2007, Mujika 2009). However, wide midfielders and strikers presented beneficial effects with coach rating measures when training +1 standard deviation (SD) above the training load mean (mean change -0.05 to 0.29) (Rowell et al. 2018). The results of this study highlight that a reduction in training volume to enhance match performance of team-sport athletes may be a false assumption. Unfortunately, this study did not attempt to account for opposition quality in the statistical analysis which represents a limitation of the research findings.

The effect of training load dose on technical and tactical measures of match performance (performance indicators) has been implemented within an Australian football population. Thirty-six male professional Australian football players (age 23.3 ± 3.2 years) from the same team reported their training load and match performance for an entire season (Lazarus et al. 2017). For all four position assessed (forwards, midfielders, backs and rucks), substantial findings mostly favoured a reduction in training load for enhancing performance indicator-based measures of match performance (Lazarus et al. 2017). However, analysis reported possible beneficial effects following increases in training load that may prove more favourable for enhancing performance in games for both forwards and defenders (Lazarus et al. 2017). In accordance with Rowell et al. (2018), no attempt was made to account for opposition quality in the statistical design which may have influenced the results.

In summary, utilising activity profile as a measure of match performance may be an ill-advised process for assessing the effectiveness of training load dose manipulation (Carling 2013). Findings from both soccer and Australian football have identified that specific training load dose can be substantially different between positions (Lazarus et al. 2017, Rowell et al. 2018). Thus, a ‘blanket’ approach to training load modification for enhancing match performance is no longer appropriate. To date, no study has attempted to account for opposition quality which may have an impact on the technical and tactical output of team-sport athletes. Investigations are required to assess the effect of training load dose on netball athletes by position, as well as potential for improved match performance.

2.4.3 Psychological wellness to predict match performance

Athlete wellness monitoring can include several aspects designed to gauge how an athlete feels before, during and after exercise (Saw et al. 2015). One frequently implemented monitoring approach in high-performance sport is a brief questionnaire format typically completed pre-exercise to ascertain readiness for training (Saw et al. 2015). Responses to the questionnaire are typically graded via a five, seven or 10-point Likert scale with ‘appropriately’ allocated qualitative descriptors (e.g., for a five-point scale, 1 = very poor through to 5 = excellent) (Gastin et al. 2013, Johnston et al. 2013, McNamara et al. 2013, Gallo et al. 2015, Saw et al. 2015, Wehbe et al. 2015). Reports typically include questions relating to mood, stress, energy levels, sleep, diet and areas of muscle soreness (Halson 2014). The corresponding aggregated score associated with the athlete's answers is known as their wellness score (Dawson et al. 2014, Gabbett 2016).

A beneficial wellness score, as graded by the Likert scale implemented, can be interpreted as an athlete possessing a favourable psychological state. This positive state of mind may aid performance in both training and competition (Saw et al. 2015). For example, subjective ratings of sleep quality and general muscle soreness within netball athletes are positively associated with peak velocity obtained in CMJ (r^2 0.50 and 0.72 respectively) (Wood et al. 2013). The peak velocity of a CMJ may indicate neuromuscular preparedness (Wood et al. 2013), which may in turn indicate the maximal force producing capacity of an athlete for a given session (Wood et al. 2013). By considering subjective sleep quality and muscle soreness, conditioning professionals and netball coaches can establish the likely intensity output expected from their athletes in the upcoming session.

Total wellness score decreases of more than 1SD in Australian footballers corresponds to decrements in total high-speed running distance and Player Load™ in training (-7.8 ± 8.6%, ES -0.25 and -4.9 ± 3.1%, ES -0.45 respectively) (Gallo et al. 2016). Australian junior soccer players reported substantially harmful disturbances in wellness scores during the initial days of a training camp (Buchheit et al. 2013). Self-recorded sleep duration reported substantially beneficial effects on total wellbeing scores, ratings of fatigue, sleep quality and perceived recovery status, in youth team-sports athletes (Sawczuk et al. 2018). Subjective soreness in professional Australian football players has a small inverse relationship with match performance (performance indicators) (r -0.11) (Gastin et al. 2013). General soreness also presented a small inverse relationship to the previous days training load during an intensive pre-season camp in professional Australian footballers (Buchheit et al. 2013). Finally, self-reported fatigue pre-match in professional English soccer players is inversely related to total high-intensity running distance (r -0.51) (Thorpe et al. 2015). No research has investigated wellness scores and its subcategories (e.g., sleep quality, stress, fatigue) impact on various forms of match performance in netball. In summary, the monitoring of wellness scores, self-reported sleep duration, general soreness of muscles, and perceptions of fatigue may prove to be important indicators for athlete preparation in netball and should be investigated relative to their impact on match performance. An analysis of athlete's psychological state may increase the likelihood of a player '*feeling well'*, which in-turn, would likely increase output in training and competition as reported in other sports (Gastin et al. 2013, Gallo et al. 2016).

2.4.4 Countermovement jump to predict match performance

A CMJ is performed via a rapid eccentric dip followed by a rapid concentric phase with either bilateral arm swing or no arm swing (Cormie et al. 2009, Thomas et al. 2017). The use of a CMJ is typically implemented by strength and conditioning coaches / sport scientists as a tool for monitoring physical preparedness via various kinetic / kinematic variables (Cormack et al. 2008, Oliver et al. 2008, Cormie et al. 2009, Williams et al. 2011, Taylor et al. 2012, Castagna and Castellini 2013, Comfort et al. 2014, Gathercole et al. 2015, Gathercole et al. 2015, Malone et al. 2015). Enhanced performance reported on CMJ metrics is referred to as a favourable physical state; increasing the likelihood of optimal training and match performances (Twist and Highton 2013, Watkins et al. 2017). Netball staff have implemented the CMJ test in longitudinal monitoring for kinetic and kinematic changes following training intervention (McKeown et al. 2016). Both power and velocity in loaded and unloaded conditions improved (ES range 0.66 to 1.49) over an 18-week period (McKeown et al. 2016). CMJ performance in netball is yet to be assessed relative to match performance measures, which is an important gap in the literature considering the purported benefits from enhanced CMJ performance (Twist and Highton 2013, Watkins et al. 2017).

Using a CMJ assessment to predict match performance in a team-sport setting has been implemented with male professional Australian football players (Cormack et al. 2008, Cormack et al. 2013, Mooney et al. 2013). The CMJ measure utilised included flight-time-to-contraction-time ratio (FT:CT) which is indicative of changes in movement strategy due to neuromuscular fatigue (Cormack et al. 2008, Rowell et al. 2017). A reduction in pre-match FT:CT of >8% was also linked to lower coach ratings of performance (Cormack et al. 2013, Mooney et al. 2013). Whilst evidence exists in Australian football to indicate that match performance can be somewhat predicted by prior CMJ performance (Cormack et al. 2008, Cormack et al. 2013, Mooney et al. 2013), no investigations exist in the netball literature.

2.4.5 Summary of predicting match performance in team-sport populations

This section was designed to assess the ability of commonly implemented athlete monitoring strategies to predict match performance in team-sport athletes. Training load dose has been reported to predict match performance in professional soccer players; coach ratings being the measure of match performance, and Australian rules footballers; performance indicators as match performance indicators (Lazarus et al. 2017, Rowell et al. 2018). Importantly, the findings from position-specific training load doses of two team-sport studies indicates a blanket approach towards training load modification is not advised (Lazarus et al. 2017, Rowell et al. 2018). Given the guidelines provided by investigations in soccer and Australian football, a similar study should be conducted in netball in order to provide guidelines that inform the practice of conditioning professionals to potentially enhance position-specific match performance in netball.

Wellness scores can provide an indication to coaching staff of an athlete's current readiness for training and competition (Saw et al. 2015). Research has elucidated relationships between pre-exercise questionnaires and physical output in games (Thorpe et al. 2015, Gallo et al. 2016), however it remains to be determined whether technical and tactical aspects of the match (e.g., skill execution or opposition quality) may better explain changes in physical exertion (Fessi et al. 2016). Only one study reported a small inverse relationship between subject general soreness and match performance (performance indicators, r -0.11) (Gastin et al. 2013). Given the prevalence of obtaining subjective, pre-exercise questionnaire information in team-sport settings, it is pertinent to discover whether such information provides any prediction / validity in relation to the match performance of netball athletes.

The use of FT:CT from a CMJ pre-game has demonstrated the potential to predict coach ratings of performance in Australian rules footballers (Cormack et al. 2008, Cormack et al. 2013, Mooney et al. 2013), yet no attempt has been made to predict performance indicator output using multiple CMJ variables in any sport. Given the purported benefits of enhanced CMJ performance in relation to competition / training readiness (Twist and Highton 2013, Watkins et al. 2017), it is pertinent for sports scientists to investigate the relationships between CMJ variables and different measures of match performance in netball.

2.5 Summary of chapter 2

The purpose of this literature review was to describe the various physical / physiological facets of netball, as well as identifying commonly implemented match performance measures within team-sports. This review defines netball as an intermittent high intensity sport, where athletes differ in capacities and match intensity requirements between positions, and how match performance measures such as coach ratings and performance indicators can be predicted via common monitoring practices including training load, wellness questionnaires and CMJ.

There are substantial differences between position groupings regarding physical capacities (Tanner and Gore 2012, Thomas et al. 2017), though capacities have never been examined in a senior state-level cohort. Substantial differences in accelerometer derived load exist between positional groups in games (Cormack et al. 2014, Young et al. 2016), though examining differences in the peak accelerometer derived intensities may provide more pertinent information for the physical preparation of these athletes (Delaney et al. 2016, Duthie et al. 2018).

Assessing match performance of team-sport athletes typically involves coach ratings and performance indicators (see Tables 2.3 and 2.4), though an understanding of how these measures relate to match outcome in netball is not yet understood. A combined coach rating of performance and performance indicators approach may provide improved predictions of match outcome due to each measure possibly accounting for aspects that the other does not (Richmond et al. 2007).

Finally, training load dose (Lazarus et al. 2017, Rowell et al. 2018), wellness questionnaires (Gastin et al. 2013) and CMJ performance (Cormack et al. 2008, Cormack et al. 2013, Mooney et al. 2013) have shown the potential to predict match performance in team-sport literature, yet this approach has not yet been investigated in netball.

2.6 Thesis Aims

The primary aim of this thesis is to derive position-specific monitoring guidelines that best predict beneficial match performance for netball. Secondary aims are to examine differences between positions in physical capacities and peak match intensities in a senior netball cohort; establish the relationships between match performance measures (coach ratings, performance indicators and the combination) and match outcome by position. The following studies were designed with the goal of answering the above primary and secondary aims.

1. Do the state-level netball players of this thesis differ in their physical capacities between positions, thus justifying an investigation into position-specific monitoring strategies?
    a. Do differences noted between tests help guide conditioning coaches in developing more effective programs for these athletes?

2. Is Player Load^{TM} a reliable measure for quantifying external load in a court-based team-sport?
3. Does the netball cohort of this thesis differ in the peak Player Load^{TM} intensities during competitive matches?
    a. Do the differences between positions at certain time-epochs justify the development of drills of position-specific durations (e.g., should the centre position train for longer)?
4. What is the strongest predictor of match outcome for netball by team and position?
    a. Are coach ratings, performance indicators or their combination related to match outcome?
    b. Does each match performance measure relate to match outcome equally across positions and competition level?
5. Position-specific monitoring strategies to enhance match performance in netball athletes
    a. Do certain training load measures provide uniform relationships with match performance across positions?
    b. Over what period of time should training be altered to enhance match performance by position?
    c. Do wellness questionnaires and CMJ scores predict match performance?

Chapter 3 - Study 1 Comparison Of Physical Profiles Of State-Level Netball Players By Position

3.1 Introduction

The high-intensity nature of netball is underpinned by strength, speed, and agility, whilst also requiring intermittent endurance to maintain quality of effort (Tanner and Gore 2012). Analysis of match-play across multiple netball leagues and levels of competition identifies the most prevalent work-to-rest ratios being 1:5 across all positions (Davidson and Trewartha 2008, Fox et al. 2013). Marked differences exist between positions in relation to total work completed as measured by accelerometers in matches (Young et al. 2016). For example goal shooter, goal defence and goalkeeper perform the least amount of work on average compared to other positions in a professional cohort (1.94 arbitrary units to 2.95 respectively) (Young et al. 2016). Differences in work rate can be attributed to the unique movement restrictions defined in the rules of the game, explained elsewhere (Australia 2018). The ability to accelerate, decelerate, jump and land are also prevalent in all positions (Davidson and Trewartha 2008, Fox et al. 2013, Sweeting et al. 2017), and require high levels of strength and power to tolerate / control eccentric and concentric forces produced (Mothersole et al. 2013). Physical preparation of netball athletes requires a multi-faceted approach to reduce the likelihood of injury and increase chances of positive match performances (Thomas et al. 2017). Recognising substantial physical differences between positions will aid conditioning professionals in creating targeted programs to improve position-specific netball performance, as well as aiding in team selections.

Previous works in talent identified of Australian netballers has reported a general trend for greater capacity in linear sprinting, planned agility, reactive agility, jump height, intermittent endurance, upper-body and lower-body strength, as athletes progress along the talent pathway (Tanner and Gore 2012). A comprehensive physical profile involving junior netball academy athletes aged 15.51 ± 1.49 years reported shooters were slower than mid-court athletes and defenders across five and 10 m (ES 0.4, 1.2), while mid-court athletes possessed faster change-of-direction ability and intermittent aerobic capacity, compared to shooters and defenders (ES > 1.0) (Thomas et al. 2017). Mid-court athletes were substantially shorter in stature than defenders and shooters (ES 1.6 and 0.7 respectively) (Thomas et al. 2017). The findings from match-play and physical capacity data may be explained by mid-court players being continually involved in transitions, up and down the court, requiring greater intermittent endurance and acceleration capacities due to greater workloads (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016). Furthermore, stature clearly appears to be an advantage for shooters as this characteristic allows the athlete to be closer to the goal (potentially increasing shooting accuracy) (Tanner and Gore 2012, Thomas et al. 2017). Subsequently coaches need to counteract this by matching up with defenders of similar stature. There are no positional comparisons of physical profiles in open age competition for netball. This information would be useful to provide conditioning professionals with position-specific physical quality standards and training benchmarks in open age competition.

The aim of this project was to determine differences between playing position groups (shooters, mid-court athletes and defenders), utilising a sport-specific testing battery with open age netball athletes. Knowledge garnered from this study would aid the netball community in creation of player rosters and developing talent, whilst providing normative data when assessing physical capacities in this population. Furthermore, this study aims to identify whether differing monitoring strategies should be employed for specific positions in order to maximise match performance. It is hypothesised that there would be practically meaningful differences between athletes based on position, in aspects of: stature, vertical jumping, horizontal bounding, acceleration, change-of-direction and intermittent endurance.

3.2 Methods

3.2.1 Design

A cross-sectional observational design of state-level female netball players in Australia was conducted using a field testing battery specific to the sport (Tanner and Gore 2012). Athletes were assessed on stature, and a range of physical characteristics which included single and triple single-leg hop for horizontal distance, countermovement vertical jump, 5 m, 10 m, 20 m sprint, 505 change-of-direction and the Yo-Yo Intermittent Recovery Test Level 1. A magnitude-based decisions approach was employed to investigate differences between positional groups, providing practically important findings for the sport of netball.

3.2.2 Participants

State-level female netballers gave their consent to participate in this investigation (n = 46, age = 20.29 ± 4.15 years, age range 16 to 32 years). All participants were fully informed of the requirements of the investigation and provided appropriate consent to participate, with consent from the parent or guardian of all players under the age of 18. Ethical approval for this research project was granted by the Victoria University Human Research Ethics Committee (HRE17-138). Players were defined by positional area by the coaching staff, thus allowing comparisons between positional areas. The positions were classified as: mid-court (n = 16; Centre, Wing Attack, Wing Defence), defenders (n = 13; Goalkeeper, Goal Defence) and shooters (n = 17; Goal Attack, Goal Shooter). All participants were required to be free of injury and taking part in full training for the previous month in lead up to the day of testing.

3.2.3 Methodology

This observational research project was conducted during the second week of the pre-season in early January 2017 and 2018 with a 'typical' pre-season lasting between 15-17 weeks. Identical testing procedures were conducted in both testing sessions. Participants were assessed during their regular training times on an indoor sprung wooden floor. All athletes performed a standardised warm-up consisting of dynamic mobility exercises and low-to-moderate intensity running. No static stretching was performed, as these activities can have a detrimental impact on power related activities such as sprinting, jumping and change of direction (McMillian et al. 2006, Pearce et al. 2009, Behm and Chaouachi 2011). All athletes were well accustomed to each test through prior experience in high performance programs. Participants were also allowed one practice attempt prior to data being collected. In all tests, the best result of multiple trials were recorded for further analysis (Thomas et al. 2017). The participants stature was collected, with 20 m sprint, 505 change-of-direction, CMJ and single-leg bounding tests all conducted under direct supervision. All athletes were divided into even groups and rotated through each testing station. The Yo-Yo Intermittent Recovery Test Level 1 was performed at the end of the testing session with all athletes being assessed together. Standing stature was recorded to the nearest centimeter utilising a portable stadiometer (Seca portable height measuring rod, AMA medical products, Western Australia, Australia). Participants were required to remove their footwear and wear their ‘usual’ netball training attire.

3.2.3.1 20 m sprint

The 20 m sprint was implemented to assess acceleration ability. The timing gates (Smartspeed, Fusion sport, Queensland, Australia) were set at the 0 m, 5 m, 10 m, and 20 m points along the linear course. Gates were aligned at approximate hip height for all of the participants, in line with previous recommendations (Yeadon et al. 1999). Participants began with their lead foot and toes placed directly behind the starting line in a two-point staggered start, no rocking back and forth or bouncing immediately prior to starting was allowed. The participants were instructed to sprint through each gate as fast as possible. Athletes were allowed three trials with a two-minute rest period between attempts (Thomas et al. 2017). The 20 m sprint test has previously demonstrated good reliability (ICC = 0.95-0.99) (De Villiers and Venter 2014).

3.2.3.2 505 change-of-direction test

Change-of-direction (COD) speed was assessed using the 505 COD test (ICC = 0.81) (Stewart et al. 2014). The timing gate (Smartspeed, Fusion sport, Queensland, Australia) was placed 15 m ahead of the start line and 5 m in front of the turning line. The gate was aligned at approximate hip height for all of the participants, in line with previous recommendations (Yeadon et al. 1999). Participants were instructed to sprint in a forward direction for 15 m and place either foot on a marked line on the floor, then perform a 180º turn and sprint back 5 m to complete the trial (Thomas et al. 2017). The order for the turning foot was right foot for the first two trials and left foot for the final two trials. If the participants failed to touch the line before turning, or turned off the incorrect foot, the trial was discarded from the recording process and another trial was performed after adequate recovery. Participants started with their lead foot placed directly behind the starting line in a two-point staggered start. Participants were allowed two trials on each foot with a two-minute rest period between attempts (Thomas et al. 2017).

3.2.3.3 Countermovement jump

The CMJ is a measure of lower-limb (system) power in the vertical plane. Maximum height of the CMJ was collected using a Vertec (Swift Performance Equipment, Lismore, New South Wales, Australia). Athletes were instructed to perform a rapid eccentric dip followed by a rapid concentric phase with arm swing of both limbs allowed. Participants were instructed to reach for their maximal height by moving the highest vein possible on the Vertec device, the absolute jump height was then subtracted by the standing reach height in order to achieve the relative jump height for analysis. Three attempts were allowed for each athlete with a one minute rest period between attempts (Thomas et al. 2017). This test has previously been established to have excellent reliability (ICC = 0.98-0.99) (Unick et al. 2005).

3.2.3.4 Horizontal bounding

The horizontal bounding test measures lower-limb (system) power in the horizontal plane. A 1 x single-leg bound (1SB) test was performed to assess horizontal jump distance. Athletes commenced the test by balancing on one leg, with their toes behind the start line. Athletes were then instructed to perform a simultaneous arm swing and crouch to a self-selected depth, then propelling forward off one leg to land on two feet. If an athlete failed to land with proficient balance as adjudicated by the qualified strength and conditioning assessor, the trial was discarded and repeated after a 30-second recovery. Distance was recorded using a ten-meter measuring tape from the most posterior aspect of the participants two feet upon landing to the nearest centimeter. The 3x single-leg bound (3SB) was conducted in the same manner as the 1SB, the only difference being three consecutive bounds on the same leg before a two-footed landing. Three trials were give on each leg for each test with a one minute rest period between attempts (Thomas et al. 2017). Reliability of this test has been reported elsewhere (ICC = 0.93-0.99) (Gustavsson et al. 2006).

3.2.3.5 Yo-Yo intermittent recovery test level one

The Yo-Yo intermittent recovery test level one (Yo-Yo IR1) measured athletes intermittent aerobic endurance capacity. The procedures followed were as previously described (Krustrup et al. 2003, Bangsbo et al. 2008, Tanner and Gore 2012). Briefly, athletes were instructed to complete as many intermittent shuttle runs interspersed with a 10-second active recovery over a 25 m long course (2 x 20 m shuttle length, and 2 x 5 m active recovery shuttles per repetition). The athletes began with their toes behind the start line, and upon the first beep sounded via overhead public address system, athletes began running to the 20 m line. At the sound of the second beep a 180º turn was performed at the 20 m line, and participants ran back to the start line, arriving on the third and final beep completing the repetition. Once the repetition was concluded participants continued to walk through to the 5 m recovery mark, where another

180º turn was completed before they returned to the start line to await the initial tone of the next repetition. For successful completion of each repetition participants were required to place one foot either on or over the start or turn line at the sound of each beep. A warning was given to participants when they did not achieve the line in the first instance. The test ended when a participant failed to reach the start or turn line on two consecutive / non-consecutive beeps. Reliability of this test has been reported elsewhere (ICC = 0.86) (Thomas et al. 2006).

3.2.3.6 Statistical design

All analyses were conducted in *R* Studio statistical software (V 1.0.143, R Studio Inc, Boston, USA). Magnitude based decisions were implemented as it provides a more detailed interpretation of the practically meaningful differences between positions, than traditional statistical approaches (Batterham 2006). Linear mixed effects models were used to determine the difference in physical characteristics between positions and within faster and slower groups for the 505 COD test as per previous research (Mcbride et al. 2005, Spiteri et al. 2013, Spiteri et al. 2015). Participants above the 50th percentile were assigned to the faster group and those below the 50th percentile were assigned to the slower group, similar to previous research (Spiteri et al. 2015). In the model design, fixed effects were physical characteristics, and individual athletes as random effects utilising 90% CL (Liow and Hopkins 2003). This investigation implemented a 90% CL rather than 95% to prevent readers from using the CL to re-interpret the results in terms of "statistical significance". The 90% CL defines the likely range of the "true" ES, and has been used consistently within sport science literature (Batterham 2006). The magnitudes of standardised change scores were assessed by calculating an ES from the observed difference between playing positions, and the coefficient of variation between participants within these specified populations, and expressed using the following qualitative descriptors: trivial (< 0.2), small (0.2-0.59), moderate (0.6-1.19), large (1.2-1.99), or very large (> 2.0) (Hopkins et al. 2009). Substantial differences between positions were established if the likelihood of the difference was greater than the smallest worthwhile difference; >75% (Liow and Hopkins 2003).

3.3 Results

Raw values for each of the capacity tests are provided in Table 3.1. Comparison of capacities between positions indicated several substantial differences (Figure 3.1). Compared to defenders, mid-court athletes were shorter in stature (ES: -2.58, CL: -3.35 to -1.80), displayed faster 505 COD (-0.48, -1.07 to 0.11), displayed better 3SB performance on the right leg (0.77, 0.13 to 1.41) and had slightly inferior CMJ height (-0.56, -1.30 to 0.19). Compared to defenders, shooters were slightly shorter (-0.44; -1.00 to 0.12), had inferior 3SB performance on the left leg (-0.57, -1.14 to 0.00), displayed poorer CMJ heights (-0.61, -1.18 to -0.04) and lower Yo-Yo IR1 performance (-0.56, -1.19 to 0.07). Compared to mid-court athletes, shooters had greater stature (1.26, 0.88 to 1.63), were slightly slower over 5 m, 10 m, and 20 m sprint times (0.43, -0.12 to 0.97, 0.54, -0.01 to 1.09, 0.61, 0.03 to 1.18, respectively), displayed slightly slower 505 COD times (0.55, 0.03 to 1.07), were worse at 1SB for the right leg (-0.48, -0.98 to 0.01), 3SB for the left (-0.78, -1.31 to -0.25) and 3SB for the right leg (-1.01, -1.52 to -0.49) and recorded a shorter distance on the Yo-Yo IR1 test (-0.82, -1.34 to -0.31). All other variables assessed for performance tests and bilateral differences within fast and slow groups were either trivial, or unclear between positions.

Table 3.1. Data presented as mean ± SD of physical profile data of Australian state-level netball athletes separated by position.

	Mid-court Mean ± SD	Defenders Mean ± SD	Shooters Mean ± SD
Stature (cm)	172 ± 4	181 ± 2	178 ± 6
5 m sprint (sec)	1.18 ± 0.10	1.21 ± 0.12	1.22 ± 0.10
10 m sprint (sec)	1.96 ± 0.09	1.99 ± 0.10	2.02 ± 0.11
20 m sprint (sec)	3.41 ± 0.14	3.42 ± 0.15	3.52 ± 0.19
505 COD (sec)	2.49 ± 0.11	2.52 ± 0.11	2.55 ± 0.11
CMJ (cm)	48 ± 4	52 ± 5	47 ± 7
1SB R (cm)	186 ± 15	185 ± 12	175 ± 21
1SB L (cm)	185 ± 15	185 ± 14	180 ± 18
3SB R (cm)	575 ± 44	549 ± 39	532 ± 51
3SB L (cm)	561 ± 59	556 ± 57	518 ± 47
YoYo IR1 (m)	1078 ± 320	984 ± 262	784 ± 241

Sec; seconds, CM; centimetres, M; metres, R; right leg, L; left leg, 505 COD; 505 change-of-direction test, CMJ; countermovement vertical jump, 1SB; one single-leg bound, 3SB; triple single-leg bound, Yo-Yo IR1; Yo-Yo intermittent recovery test level 1.

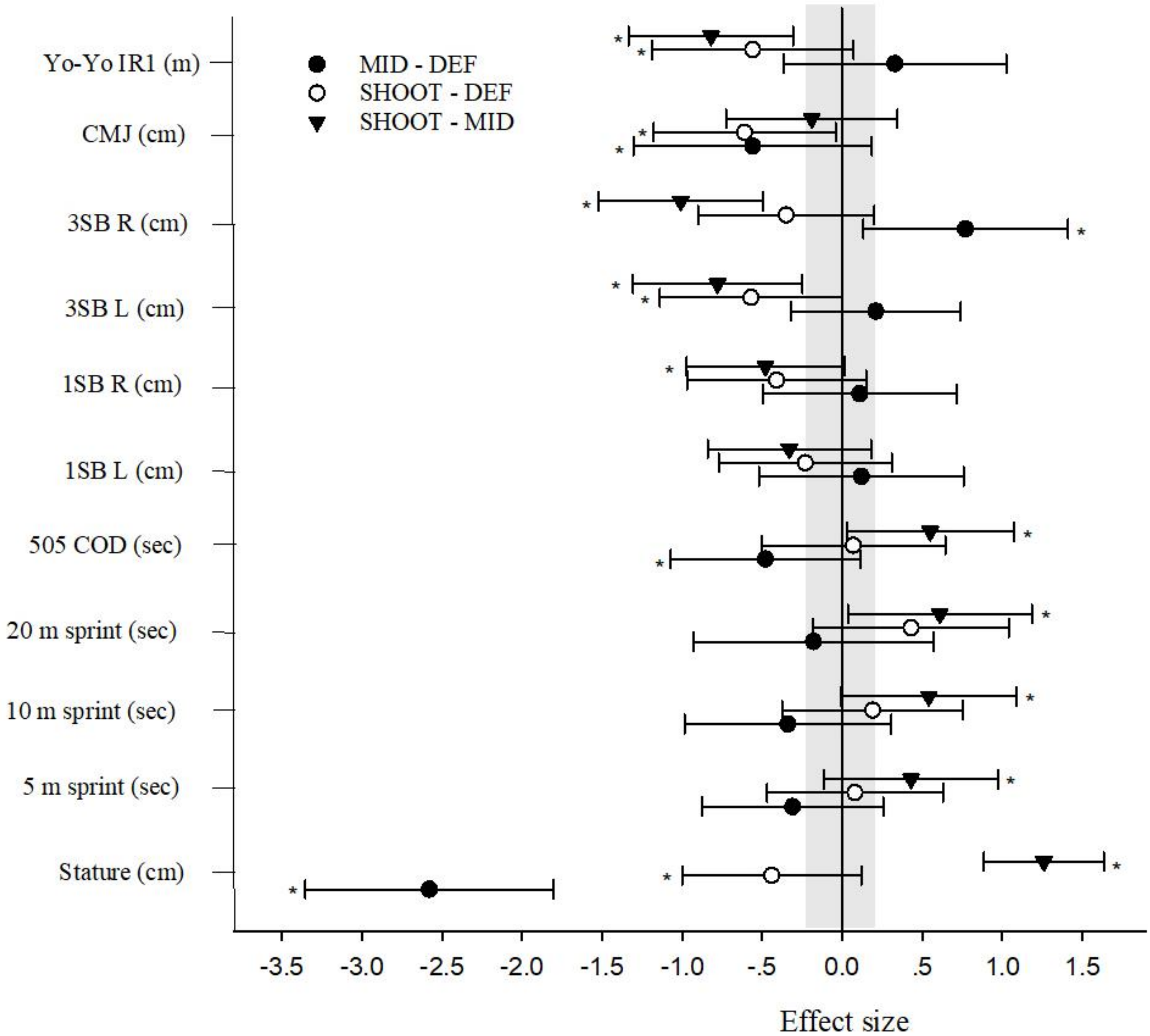

Figure 3.1. Standardised differences between positions for common performance tests used in netball populations. * Indicates a meaningful difference >75% likelihood threshold. For YoYo IR1, CMJ, 3SB and 1SB, a negative ES equates to worse performance against the selected group. For 505 COD and 20 m sprint a positive ES equates to worse performance against the selected group. For stature, a negative ES equates to a shorter height against the selected group. Sec; seconds, CM; centimeters, M; meters, R; right leg, L; left leg, 505 COD; 505 change-of-direction test, CMJ; countermovement vertical jump, 1SB; one single-leg bound, 3SB; triple single-leg bound, Yo-Yo IR1; Yo-Yo intermittent recovery test level 1.

Comparing fast and slow groups within the shooter position for the 505 COD test reported substantial differences in 10 m (-0.94, -2.07 to 0.20) and 20 m (-0.86, -2.01 to 0.29) acceleration times (Table 3.2). Faster shooters in the 505 COD test were also better performers in the 1SB R (1.24, 0.14 to 2.34), 1SB L (0.86, -0.56 to 2.28), and 3SB R (1.34, 0.48 to 2.19). For mid-court athletes, only one variable showed a substantial difference with the fast group outperforming the slow group in the 3SB R (1.84, 0.55 to 3.13). There were no substantial differences between fast and slow groups in the defender position. Within fast and slow groups within positions, there were no substantial differences between right and left legs for any bounding measures. All other comparisons between fast and slow groups were either trivial or unclear.

Table 3.2. Mean ± SD of the raw data displaying comparisons between fast and slow groups of the 505 COD test, with ES and CL's to highlight the magnitude of the difference between groups, as well as the potential of bilateral difference being present.

	505 COD Shooters			505 COD Mid-court			505 COD Defenders		
	Faster	Slower	ES (CL)	Faster	Slower	ES (CL)	Faster	Slower	ES (CL)
505 COD (sec)	2.45 ± 0.08	2.62 ± 0.07	-2.07* (-2.79 to -1.35)	2.43 ± 0.06	2.61 ± 0.05	-3.56* (-4.65 to -2.46)	2.47 ± 0.07	2.63 ± 0.08	-2.48* (-3.35 to -1.60)
Stature (cm)	178.9 ± 6.7	179.4 ± 5.8	-0.17 (-2.41 to 2.07)	172.7 ± 3.9	171.7 ± 4.6	0.52 (-2.87 to 3.91)	181.2 ± 1.9	180.8 ± 4.6	0.04 (-0.49 to 0.58)
5 m (sec)	1.18 ± 0.12	1.25 ± 0.09	-0.74 (-2.76 to 1.28)	1.16 ± 0.08	1.22 ± 0.14	-0.25 (-3.51 to 3.02)	1.18 ± 0.11	1.26 ± 0.14	-0.50 (-4.90 to 3.91)
10 m (sec)	1.96 ± 0.13	2.06 ± 0.08	-0.94* (-2.07 to 0.20)	1.94 ± 0.08	1.99 ± 0.11	-0.35 (-4.95 to 4.26)	1.96 ± 0.10	2.03 ± 0.11	-0.70 (-3.35 to 1.95)
20 m (sec)	3.41 ± 0.20	3.59 ± 0.15	-0.86* (-2.01 to 0.29)	3.37 ± 0.14	3.46 ± 0.14	-0.57 (-6.12 to 4.99)	3.37 ± 0.14	3.50 ± 0.14	-0.84 (-3.91 to 2.23)
CMJ	47.5 ± 6.7	46.8 ± 6.7	0.13 (-1.62 to 1.88)	49.6 ± 4.2	45.9 ± 4.0	-0.17 (-2.48 to 2.13)	52.2 ± 4.1	51.0 ± 7.0	0.20 (-2.44 to 2.83)
1SB R (cm)	187.0 ± 12.8	170.2 ± 22.5	1.24* (0.14 to 2.34)	192.1 ± 14.1	172.4 ± 4.0	1.68 (0.51 to 2.84)	188.4 ± 10.1	185.4 ± 14.7	0.22 (-2.65 to 3.09)
1SB L (cm)	189.1 ± 17.5	176.5 ± 15.4	0.86* (-0.56 to 2.28)	190.3 ± 14.7	175.0 ± 11.2	0.65 (-3.25 to 4.54)	186.8 ± 11.9	187.2 ± 18.4	-0.07 (-1.02 to 0.88)
3SB R (cm)	567.6 ± 40.6	512.7 ± 46.0	1.34* (0.48 to 2.19)	594.3 ± 40.9	537.6 ± 19.5	1.84* (0.55 to 3.13)	558.3 ± 32.0	562.0 ± 38.9	0.01 (-0.17 to 0.20)
3SB L (cm)	545.3 ± 63.6	506.0 ± 22.5	0.76 (-1.88 to 3.39)	578.8 ± 63.4	525.7 ± 29.7	0.51 (-3.69 to 4.71)	574.0 ± 56.7	547.8 ± 56.4	0.25 (-3.03 to 3.52)

Sec; Seconds, CM; centimetres, 1SB; one single-leg bound, 3SB; triple single-leg bound, R; right leg, L; left leg, CMJ; countermovement jump, 505 COD; 505 change-of-direction test, *; meaningful difference >75% likelihood threshold.

3.4 Discussion

The aim for this study was to quantify the differences in commonly utilised performance measures between positions within open age state-level netballers. This study reported differences between positions exist across all measures in the current population. This study provides physical preparation staff important normative data and performance characteristics for each position in a senior (open age) netball cohort (Bailey et al. 2015, Thomas et al. 2017).

This study reports mid-court athletes being shorter than shooters and defenders. This finding is also supported in academy netball athletes (Thomas et al. 2017), however the moderate difference previously observed between mid-court athletes and shooters was of a lower magnitude than in the current study. Differing levels of maturation between cohorts may provide explanation for the differences between studies, as athletes in the youth academy may have been pre-peak height velocity (Lloyd and Oliver 2012, Thomas et al. 2017). Positional differences in stature can be further explained by the demands of the sport, where it is considered an advantage to be tall as a shooter; possibly increasing shooting accuracy (Thomas et al. 2017). Consequently, defenders must be taller to counteract the reach of shooters when making a shot, as well as competing for interceptions of opposition passes towards their opponent. For player selections it is appropriate to suggest coaches may place emphasis (whether consciously or subconsciously) on recruiting tall shooters and defenders with shorter mid-court athletes.

Due to netball being an intermittent sport requiring fluctuations in intensity (Chandler et al. 2014), analysing sprint times over 5 m, 10 m and 20 m distances is warranted (Tanner and Gore 2012). The current study reported differences in acceleration capacities of mid-court athletes and shooters. Trivial and small differences were noted between mid-court and defenders when analysing ES over 5 m, 10 m and 20 m distances (ES: -0.31, -0.34 and -0.18 respectively) however the likelihoods did not cross the 75% threshold required (63%, 64% and 48% respectively) resulting in ‘unclear’ outcomes. A possible explanation for differences between mid-court athletes and shooters could be that on average, mid-court athletes complete more physical work in matches (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016), thus being exposed to more match events requiring acceleration, and consequently are better conditioned for this capacity. To explain the non-substantial differences between mid-courts and defenders, it is likely due to the defensive requirements of both positions. Where shooters are constantly having the ball passed to them or to areas that are more advantageous to gain possession, defenders, and to a lesser extent mid-court players, must possess high acceleration and anticipation to intercept opposing passes. Additionally, at an elite level, players are likely to be undertaking position-specific training. As the defender and mid-court position requires extensive acceleration, via a likely greater exposure in games (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016), specific acceleration training for this position is likely to be undertaken at an elite level.

Despite body mass not being reported in the current investigation, it would be envisaged that the greater stature of the defenders and shooters is likely accompanied by a higher body mass (Thomas et al. 2017). It may be that the smaller stature of the mid court athletes, and thus possible lower body mass, may be advantageous for a greater acceleration ability (Mero 1998, Malina et al. 2004, Mujika et al. 2009). Given the small difference in stature between shooters and defenders (ES -0.44), the difference in body mass would have likely been small also, which may explain why there was no difference in acceleration capacity between these two positional groups. Future research should also consider aspects such as technique and relative strength to body mass when interpreting difference between positional groups within this population. Regardless, for training purposes it seems greater exposure to acceleration training for mid-court athletes is warranted to exploit these demands and a provide a positional edge against competitors. The differences presented are similar to those reported in junior academy netballers, though of a much smaller magnitude which may indicate differences in maturation, training age and competitive level between the current study's participants and the previous investigation (Thomas et al. 2017).

The ability to change-direction forcefully and rapidly is a requirement of all netball positions (Sweeting et al. 2017). The 505 COD test produced a meaningful difference with mid-court athletes being faster than shooters, and defenders. Mid-court positions complete a greater amount of work in games on average (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016), with the relative contribution of work completed in medio-lateral planes being consistent across positions, resulting in a greater volume of COD work completed by mid-court athletes (Cormack et al. 2014). The results of the current study validate these earlier findings that mid-court athletes are more exposed to these lateral movements. The 505 COD positional differences are also consistent within academy level netball players, with differences being of moderate-to-large magnitudes (ES -1.0 to -1.3) (Thomas et al. 2017). Similar to linear sprinting, there may also be an influence of stature and body mass on the player's ability to change direction (decelerate and accelerate). It is suggested that all netball athletes should be exposed to some form of change-of-direction conditioning given the requirements of the sport (Sweeting et al. 2017), with more time devoted to this capacity for mid-court athletes due to a likely greater demand for this area of the court.

Comparing fast and slow groups within positions of a particular test can provide information as to important physical characteristics required to maximise performance in a particular test (Spiteri et al. 2015). Overall, faster participants in the 505 COD had quicker acceleration (ES -0.25 to -0.94) and bounded further than their slower counterparts (ES -0.07 to 1.84). Stature and CMJ performance do not appear to have any bearing on 505 COD performance, though due to statistically unclear results, the researchers cannot rule out sampling variation impacting the findings. Furthermore, there were no substantial differences between right and left legs for bounding within fast and slow groups, indicating no specific limb preferences with positions. To maximise training outcomes for improvement in 505 COD performance, conditioning professionals may implement acceleration and horizontal bounding exercises.

Notational analysis has identified jumping as a consistent requirement of netball athletes in all positions (mean jump count across positions 31 – 67) (Fox et al. 2013)). In the current study, defenders possessed a greater CMJ height compared to mid-court and shooter athletes, possibly indicating a greater physical requirement for this position in the vertical plane. Moreover, as the defenders attempt to provide a barrier for the transition of the ball between the center court and goal circle, it is advantageous for these players to display high levels of jumping ability compared to other positions. The positional averages for the current study were greater than those found in younger academy level netballers (for example defenders 51 cm in the current study versus 37 cm previously) (Thomas et al. 2017)), again highlighting the potential for maturational differences between the two groups, but also a long-term training adaptation. A higher level of competition is also known to result in greater exposure to work completed in the vertical axis (Sweeting et al. 2017), which may also explain the difference in CMJ height between the current state-level participants and academy level netballers. Considering that mean CMJ height is greater than those found in junior academy netballers, conditioning coaches should allocate periods in their training programs for the development of force production in the vertical plane. This will aid the long-term development of netball athletes and provide a potential competitive advantage.

The 1SB testing was implemented to assess horizontal force projection and is a recognised injury likelihood tool in females (Gustavsson et al. 2006). The 1SB on the right foot reported lower bound distances for shooters compared to the mid-court athletes, which may be explained by the shooters required to jump the least in matches (shooters 43 ± 10, mid-court 57 ± 11, and defenders 53 ± 14) (Fox et al. 2013). For the 3SB, shooters reported shorter distances than mid-court athletes and defenders. Given mid-court athletes perform more work than shooters, this finding in part, validates earlier works (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016), reported in academy level netballers (Thomas et al. 2017). However, as defenders will typically perform at the same (Chandler et al. 2014), or even lower intensity (Young et al. 2016) in matches compared to shooters, the difference between these two groups is surprising. It may be a result of shooters only receiving the ball during matches (attacking plays), whilst defenders are consistently lunging and bounding to intercept opposition passes. Future research should analyse the specific type of jumping movements conducted between these two positions. Athletic development programs should aim to condition all positions in single-leg horizontal force projection given the jumping and acceleration requirements of the sport (Fox et al. 2013).

High-intensity, intermittent endurance is a requirement in netball due to the intermittent nature of the sport identified through work to rest ratios, with the most common for all positions being a 1 work:5 rest ratio (Fox et al. 2013). Based on distances achieved in the Yo-Yo IR1, the average level attained by mid-court athletes, defenders and shooters was 15.7, 15.4, and 14.8

respectively. Mid-court athletes possess greater intermittent running endurance than shooters and defenders. Despite small magnitudes, the findings of the current study mirror those of a similar investigation with youth netball athletes, reporting mid-court athletes producing greater intermittent running capacity than shooters (ES 1.20) and defenders (ES 1.40) (Thomas et al. 2017). The more senior competition level of the current study's athletes compared to previous investigations may provide explanation for the decreased contrast between positions. These findings further confirm that mid-court athletes require higher levels of intermittent endurance as they typically complete a greater volume of work when matched for minutes on-court compared to other positions (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016).

It should be acknowledged that only peak values of the performance tests were recorded for analysis. Due to this, no reliability of this cohort's performance can be made, though all performance tests have shown acceptable reliability within similar cohorts (Unick et al. 2005, Gustavsson et al. 2006, Thomas et al. 2006, De Villiers and Venter 2014, Stewart et al. 2014). Training age of the participants was also not quantified within the project design but may have bearing on the outcomes of the performance tests. The age range of participants also presents the possibility of maturational differences within the cohort which needs to be considered by the readers when interpreting findings of this study. Finally, body mass was not measured in the current study, which may have helped explain the differences between positions and should be considered when interpreting the results.

In conclusion, this study achieved its major aim of identifying any substantial differences in the physical capacities between position groups of state-level netball players. Netball coaches may utilise the results of this study for assisting in the creation of player rosters and developing talent, whilst providing normative data when assessing physical capacities in this population. The other aim of this study was also achieved by providing evidence of positional differences existing within the cohort of this thesis, which strengthens the justification for an investigation into position-specific monitoring strategies for enhancing netball match performance.

Chapter 4 - Study 2 Reliability Of Player Load™ For Court-Based Sports

4.1 Introduction

External load is the quantification of physical work completed in training and competition (e.g., total distance covered, or number of efforts above a certain speed threshold) (Halson 2014). Measuring external training and competition load provides conditioning staff with an understanding of the physical requirements imposed on their athletes (Read et al. 2018). Traditionally, the external load monitoring of team-sport athletes have involved tracking metrics such as total distance, average speed (i.e., metres per minute), distance covered at high speed, and peak speed (Coutts et al. 2010, Gabbett and Ullah 2012, Suarrez-Arrones et al. 2012). However, given that 'high velocity' thresholds reached in court-based sports (netball 3.9 $m \cdot s^{-1}$) are relatively small compared to some arbitrary thresholds in field-based sports (Australian rules football 6.0 $m \cdot s^{-1}$) (Coutts et al. 2010, Sweeting et al. 2017), the aforementioned tracking metrics may not provide an adequate reflection of the activity profile for a court sport.

The use of hardware that samples at high frequencies is required to capture possibly more pertinent information than traditional measures such as speed and distance (i.e., accelerations and decelerations of the unit), for conditioning coaches to prepare their athletes for competition. Accelerometers have the capacity to capture acceleration and deceleration information. Often housed within commercially available sport-specific tracking devices, accelerometers sample at 100 Hz compared to the typical 10-20 Hz of commercially available tracking systems (Boyd et al. 2011, Scott et al. 2016). Accelerations measured via accelerometer hardware can be converted into a vector metric for an easier assessment of total work from training and match-play. A metric known as Player Load™ is derived from accelerometers that combines changes in acceleration and deceleration into a vector magnitude from all three axes of space (Boyd et al. 2011). Court sports such as basketball and netball have implemented Player Load^{TM} to determine match activity profile. On average, a basketball game will impose 7.1 ± 1.7 load units per minute (Puente et al. 2017), whilst netball can impose 9.96 ± 2.5 (Cormack et al. 2014). Comparisons between studies is difficult given different vector calculation methods (Cormack et al. 2014, Puente et al. 2017). However, all court based sport studies have assumed the reliability of accelerometers for capturing this information in the court environment, due to previous findings in field-based populations (Boyd et al. 2011).

Intra and inter-unit reliability of Player Load^{TM} has been established in field-based sports (CV < 2%), yet not in court sport environments (Boyd et al. 2011). Differences exist between outdoor field-based and indoor court-based sports for example, field sports such as Australian and association football are typically played on grass where surfaces can become uneven and variable, opposed to netball and basketball typically played on indoor hardwood surfaces. The size of playing area is of important consideration, e.g., an Australian football field, the surface where the original reliability of Player Load^{TM} was conducted (Boyd et al. 2011), can be anywhere from 11,657 m^2 to 22,510 m^2 (League 2017), where a netball or basketball court is 465 m^2 and 436 m^2 respectively (Association 2014, Australia 2018). Further to netball, unique movement restrictions applied to athletes by the rules of the sport, further intensifies the disparities in playing surface area e.g., the goal shooter and goalkeeper positions have an allowable playing surface area of only 155 m^2 (Australia 2018). Indeed, the movement restrictions of netball result in substantially different Player Load^{TM} profiles between positions at different levels of competition and age groups (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). Given the large disparities between field and court-based sports relative to playing surface type, total area and unique rules, an investigation assessing the reliability of Player Load^{TM} within an acceleration reliant court-based environment is warranted.

The aim of this study was to investigate the interunit reliability of Player Load^{TM} within a court-based match-play environment, that would provide justification for use of this tracking metric to assess the activity profile of the netball cohort for this thesis.

4.2 Methods

4.2.1 Design

This prospective / observational study was conducted during the off-season team trials period, where participants were required to play a series of competitive matches for selection in the upcoming 2019 season. All procedures were approved by the Victoria University Human Research Ethics Committee and by the netball club involved (HRE 17-138), with signed informed consent from participants and parents or guardians after a verbal and written explanation of the experimental protocol and its potential risks and benefits. Trial participants were assured they could withdraw without penalty at any time.

4.2.2 Participants

Eighteen state-level netballers who compete in the Victorian Netball League were recruited for this study (age 20.5 ± 3.5 years). In total, the athletes played an average of 4.8 ± 2.4 10-minute quarters each.

4.2.3 Methodology

During match-play, athletes wore the same two tracking units (OptimEye S5, Catapult Sports, Australia) taped together so that axis were aligned, as per previous research (Boyd et al. 2011).

The device placed distally to the body in the current study recorded slightly higher Player Load^{TM} values (10.7%, ES 0.26), which was accounted for by swapping the device position for the second testing session so that each device pairing produced data in both the proximal and distal positions (Boyd et al. 2011). Both units were mounted in a manufacturer designed harness, which placed the unit in centre of the upper back between the scapulae. Accelerometers housed within the player tracking units sampled at 100 Hz in three orthogonal planes with a full-scale output range of ± 2-16 g. The intra-unit reliability of the current study's devices has been investigated elsewhere (mean intra-unit CV % = x axis 0.67, y axis 0.74, and z axis 0.06) (Nicolella et al. 2018).

Player Load^{TM} obtained from matches was cropped (Catapult Openfield v1.11.1) to remove rest breaks (e.g., quarter breaks) so that only data during time on-court was included for analysis. The start and end time points for each playing period were aligned to one-thousandth of a second (0.001s) to ensure that the data obtained from both units included equal epochs (Boyd et al. 2011). The absolute Player Load^{TM} from each device for the corresponding playing periods were compared to assess the difference in accelerometer output between devices.

4.2.3.1 Statistical design

All Player Load^{TM} values were log transformed in an attempt to reduce bias due to nonuniformity of error, then analysed within a customised spreadsheet (Hopkins 2017). Reliability was calculated as the mean difference between the devices across all trials. Reliability was expressed as an absolute typical error (TE) with 90% CL. A CV was also calculated to determine the relative magnitude of difference between devices. Pearson's product-moment correlation coefficient (r) was calculated to express the relationship between devices. As in previous research, the SWD was calculated as 0.2 × between-subject SD from the match simulation data collected (Boyd et al. 2011). For comparisons purposes, the current investigation will also use the term "noise" to represent the technical reliability and "signal" to represent the SWD (Boyd et al. 2011). When noise (CV%) ≤ signal (SWD), the accelerometer was considered capable of detecting differences (Boyd et al. 2011).

4.3 Results

The between-device reliability of accelerometers during simulated netball matches was 4.8% (CV) (Table 4.1). Relationships between data from devices on the same individual ranged r = 0.98–0.99 (Figure 4.1). The measurement noise (CV 4.8%) was smaller than the signal (SWD 8.2%). Analysis of residuals (Figure 4.2) presented a trend for greater differences between the units over time (r = 0.46).

Table 4.1. Inter-device reliability of absolute Player Load^{TM} during netball match simulations.

	Mean	SD	TE	Lower CL 90%	Upper CL 90%	CV%
Match simulation	71.3	24.1	5.9	5.2	6.7	4.8

TE; Typical error, CL; Compatibility limits, CV; coefficient of variation.

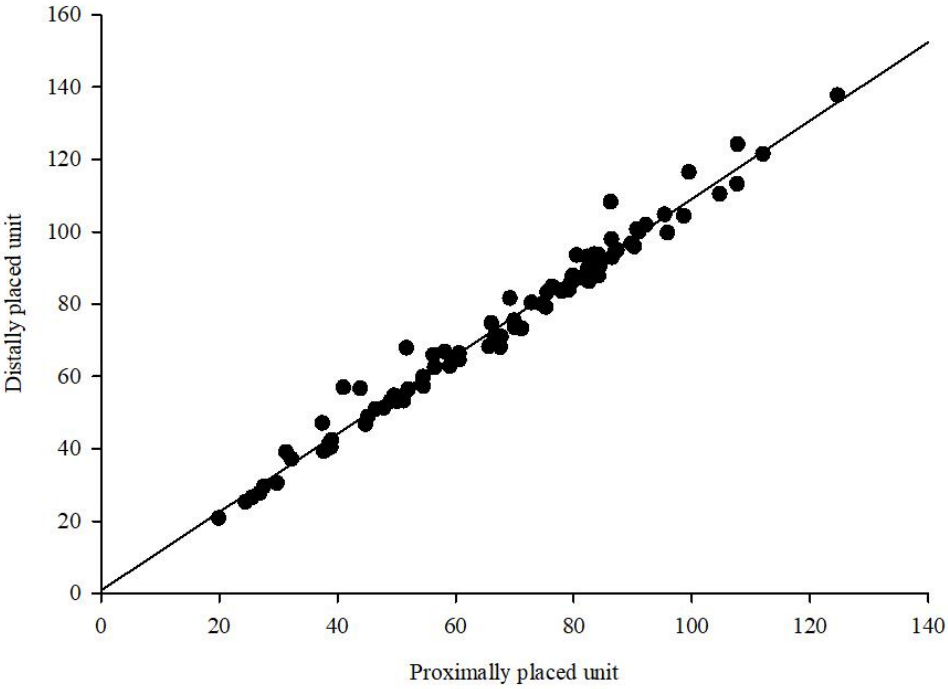

Figure 4.1. Relationship between the proximally and distally placed absolute Player Load^{TM} values recorded during netball match simulations (r = 0.99). AU; Arbitrary units.

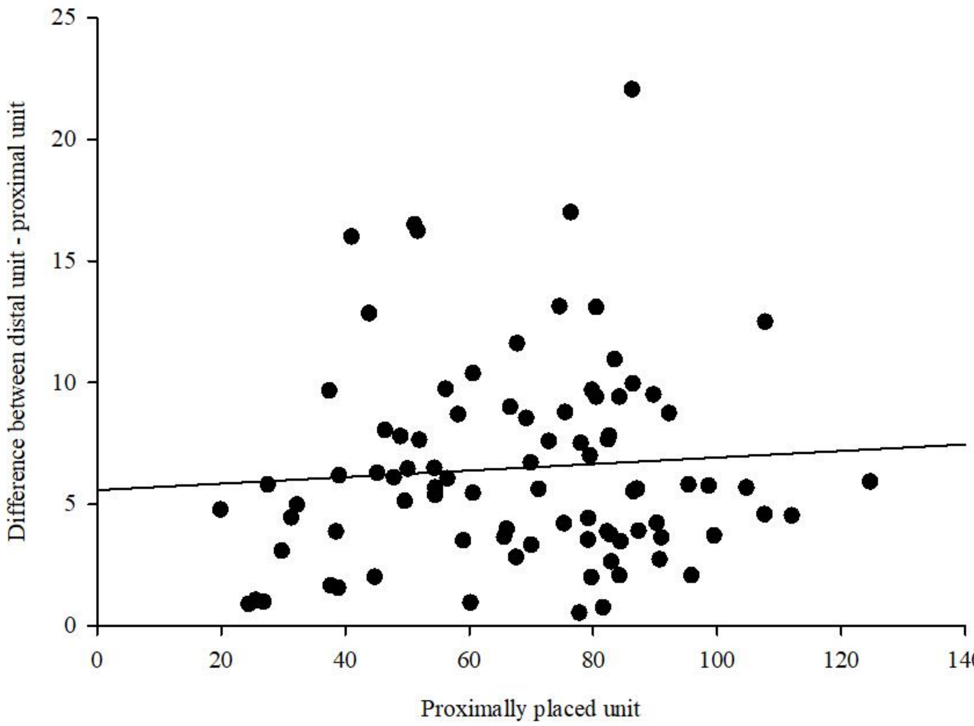

Figure 4.2. Residual plot of difference between the distally placed unit minus the proximally placed unit in absolute Player Load^{TM}.

4.4 Discussion

Inter-device Player Load^{TM} produces acceptable levels of reliability within a court-based, team-sport environment. The CV% for this cohort was 4.8%; well below the signal noise of 8.2%, thus allowing for Player Load^{TM} to detect substantial differences in external load within a court-based sport population. This study also extends on the already proven intra-unit reliability of the same manufactured devices (0.06 to 0.74% CV), by providing ecologically valid results from the reactionary environment of competitive games, rather than a laboratory setting.

In comparison to other Player Load^{TM} reliability research, the noise of the current study was greater (CV 4.8 to 1.9% respectively) (Boyd et al. 2011). One explanation may lie in the differences observed between the units over time (Figure 4.2), potentially imposed by the smaller playing area of netball compared to Australian football. A smaller playing area would typically encourage greater levels of acceleration and decelerations compared to more maximum speed; thus the more constant acceleration and decelerations may explain the greater CV% between the current and previous investigations. Importantly, the noise is within an acceptable range and provides greater reliability than other vector magnitudes reported elsewhere (Powell and Rowlands 2004). The strong relationships between devices ($r = 0.98$-0.99) effectively mirrors that of field-based sport ($r = 0.99$), strengthening the notion that Player Load^{TM} is a reliable metric regardless of the unit used.

Greater variability in the current study compared to field-based populations (CV 4.8% vs. 1.9%) may be due to differences between requirements of court and field-based sports (Boyd et al. 2011). Firstly, the difference in playing surface; netball is played on a hardwood surface and Australian football is played on natural grass. A firmer surface may result in more intense decelerations of the units (Shields and Smith 2009). Further compounding the effects of playing surface would be the unique rule of netball, in which a player most stop as soon as they gather possession of the ball. The consistent decelerations imposed on the unit due to this rule may also explain the increased inter-unit variability reported in this study compared to field-based sports observations.

This study provides evidence to support the reliability of PlayerLoad^{TM} for use in a court-based sport. This tracking is acceptable for use in the quantification of activity profiles by position in the state-level netball cohort of this thesis.

Chapter 5 - Study 3 The Peak Player Load^{TM} Of State-Level Netball Matches

5.1 Introduction

The tracking of athletes in competition provides conditioning professionals with data relating to the physical requirements in matches, from which they can then develop appropriate training programs (Halson 2014). Time-motion analysis is a form of notational examination derived from utilising counts and durations of certain match activities and has been used within netball populations (Allison 1978, Otago 1983, Steele and Chad 1991, Davidson and Trewartha 2008). The two most comprehensive time motion analyses studies were conducted on professional English (Davidson and Trewartha 2008), and Australian netballers (Fox et al. 2013). Excluding standing, which was not specifically assessed in one of the investigations (Fox et al. 2013), the vast majority of time is spent walking (31 to 52%) for every position (Davidson and Trewartha 2008, Fox et al. 2013). For sprinting, the goalkeeper position (0.2 - 0.3%) was substantially lower than all other positions, perhaps highlighting a need for a different training emphasis. This research has enhanced our understanding of the activity profile within netball athletes however time motion analysis is a subjective measure and a more objective approach is required.

Due to the logistics and costs associated with collecting player tracking data indoors, researchers have investigated the intensity that players move by calculating a vector magnitude (from x, y and z coordinates of space), often referred to as Player Load^{TM} (Boyd et al. 2011, Boyd et al. 2013, Cormack et al. 2014). Player Load^{TM} is derived from accelerometers, that measure the rate of change in velocity, and sample at different rates depending on manufacturer hardware. The instantaneous accelerations from all three axes are combined into one vector magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in the three axes, accumulated over time (Howe et al. 2017). The vector magnitude value is then divided by a scaling factor, to reduce the final summed arbitrary figure into a more palatable value for coaches to understand the total physical work completed (Boyd et al. 2011, Howe et al. 2017).

The Player Load™ metric is influenced by both the velocity at which an athlete is running, and the magnitude of their accelerations / decelerations, providing a 'global' measure of intensity (Boyd et al. 2011). Accounting for the changes in velocity, accelerations and decelerations becomes important for sports where playing surface is relatively small and lower velocity-based movements such as shuffling and changing direction are more prevalent (Davidson and Trewartha 2008, Fox et al. 2013, Sweeting et al. 2017). Netball is played on a relatively small area compared to many field-based sports, and requires anywhere from 14.8% ± 2.2 to 51.7% ± 5.1 of game time spent in lateral shuffling movements, with many changes in direction dependent on position (Davidson and Trewartha 2008, Fox et al. 2013, Sweeting et al. 2017). The velocity measures from global positioning or indoor local positioning systems (e.g., maximum speed) often fail to account for these high-intensity short and sharp changes-in-direction and velocity (i.e., shuffling) (Coutts and Duffield 2010, Varley et al. 2012). Accelerometers often sample at higher frequencies than global positioning systems, resulting in a greater potential for quantifying these movements (Boyd et al. 2011, Boyd et al. 2013).

Investigations into activity profiles of netball utilising accelerometer derived workloads have compared positions, positional groupings, and differences of both within and between levels of competition (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). Higher level netball athletes will compete at greater intensities than their lower level counterparts (Cormack et al. 2014). Differences in Player Load™ also exist in games between positions within the same team (Young et al. 2016, van Gogh et al. 2018). These investigations provide evidence of various positional groups requiring unique exposures to match intensities. The intensity of a match is typically derived relative to time spent on the court (i.e., volume of accelerometer load divided by total time on court). This method is problematic, as only the mean physical exertion of match-play is reported which can be considered an insufficient measure of match intensity, particularly as netball is highly intermittent in nature (Fox et al. 2013, van Gogh et al. 2018).

Attaining an understanding of the peak intensities to which athletes are exposed in games will aid conditioning professionals to better prepare their players for competition (Delaney et al. 2015). Using a moving average, the peak running intensity has been established in team-sports such as rugby league and soccer (Delaney et al. 2016, Duthie et al. 2018). Establishing the duration specific running intensities allows coaches to prescribe training intensities specific to the duration of the training drill (Delaney et al. 2016, Duthie et al. 2018). Presently, the peak moving average technique has not been applied in netball for any metric, whilst the peak Player Load^{TM} intensity has not been established for any sport. Investigating peak intensity periods of netball matches utilising multiple timepoints would provide coaching and conditioning staff with intensity benchmarks for the specific design of subsequent training drills. The aim of this study was to investigate the peak Player Load^{TM} per minute (PL.min^{-1}) intensity across multiple time epochs between positional groupings in a state-level netball competition. By doing so, a strong justification for an investigation into position-specific monitoring strategies for enhancing netball match performance would have been procured from the initial three studies of this thesis.

5.2 Methods

5.2.1 Design

A prospective observational study design was used to establish the duration-specific peak PL.min^{-1} intensities of state-level netball match-play. Acceleration data were collected from competitive matches from three teams at the same netball club competing in the Victorian Netball League during the 2018 season. The duration specific peak PL.min^{-1} intensities of specified positions were then quantified and compared.

5.2.2 Participants

Twenty-eight state-level female netballers gave their consent to participate in this investigation (age = 19.3 ± 5.1 years, age range 16 to 30 years, minimum netball training age five-years). All participants were fully informed of the requirements of the investigation and provided appropriate consent to participate, with consent from the parent or guardian of all players under the age of 18. Ethical approval for this research project was granted by the Victoria University Human Research Ethics Committee (HRE17-138). For positional grouping purposes, the researchers created a novel way of combining positions together. Considering the contrasting movement demands of netball, the seven positions were grouped based on the number of thirds that any particular position can travel into. The groupings for this study are one third (goal shooter, goalkeeper), two-thirds (goal attack, wing attack, goal defence, wing defence), and three-thirds (centre). Past investigations in netball have typically grouped the seven positions based on tactical aspects being shooters (goal shooter and goal attack), mid-courts (wing attack, centre and wing defence) and defenders (goal defender and goalkeeper) (Cormack et al. 2014, van Gogh et al. 2018). However, when analysing workloads or intensity of these groupings the tactical shooters group comprises the goal shooter and goal attack positions, where the goal shooter can only travel around the shooting third, whilst the goal attack can venture into the centre third as well as the shooting third. In some instances this can result in five times the amount of accelerometer derived volume between these two positions (van Gogh et al. 2018).

5.2.3 Methodology

Data were collected from one club in one team in each of three divisions for all matches in throughout the season (Championship *n* = 20, Division 1 *n* = 20, and 19-&-under *n* = 19). Participants' accelerometer data was recorded at a sample rate of 100 Hz contained inside a motion-detection unit (OptimEye S5; Catapult Innovations, Scoresby, Victoria, Australia). Units were housed in a manufacturer produced harness that prevented unwanted movement and placed on the middle of the upper back. The raw accelerometer data was exported post-match using manufacturer software (Catapult Openfield, Version 1.17.0). Individual csv files were then imported into R Studio statistical software (V 1.0.143, R Studio Inc, Boston, USA), for PL.min^{-1} quantification and further analysis. From the csv files, the Player Load^{TM} smoothed values were utilised. A moving average analysis was applied to determine the peak PL.min^{-1} at 30 seconds, and one-minute to 10-minute durations. The peak of each duration was then established for each player from each game.

5.2.3.1 Statistical design

All analyses were conducted in *R* Studio statistical software (V 1.0.143, R Studio Inc, Boston, USA). Magnitude based decisions were implemented as it provides a more detailed interpretation of the practically meaningful differences between positions, than traditional statistical approaches (Batterham 2006). Linear mixed effects models were used to determine the difference in peak PL.min^{-1} between positional groups. In the model design, fixed effects were peak PL.min^{-1} at various time points, and individual athletes as random effects utilising

90% CL (Liow and Hopkins 2003). The 90% CL defines the likely range of the “true” ES, and has been implemented consistently within sport science literature (Batterham 2006). The magnitudes of standardised change scores were assessed by calculating an ES from the observed difference between playing positions and the coefficient of variation between participants and expressed using the following qualitative descriptors: trivial (< 0.2), small (0.2-0.59), moderate (0.6-1.19), large (1.2-1.99), or very large (> 2.0) (Hopkins et al. 2009). Substantial differences between positions were established where the likelihood of the difference was greater than the smallest worthwhile difference; >75% (Liow and Hopkins 2003). As per previous analysis (Delaney et al. 2018), the slope and intercept of the relationship between peak PL.min-1 and duration was established based on the power law reporting the decline in peak PL.min-1 as duration increases.

5.3 Results

Within positional groups there were no substantial differences between competitive level for peak Player Load™. The mean ± SD of the peak PL.min^{-1} are presented in Figure 5.1. Comparisons between the positional groupings presented as standardized ES are presented in Figure 5.2. All comparisons at the 30 s time interval were non-substantial. The peak PL.min^{-1} for the one third group was substantially lower than the two third groups at one through to 10-minute time points (ES range 0.36 to 1.17). The three-thirds group reported far higher peak intensities at all time points post 30 s than the one third grouping (0.83 to 2.59). Only post 30 s was not substantially different between three-thirds and two-thirds; at the one-minute duration (ES 0.27, CL -0.05 to 0.60), all other following time points reported small to moderately higher intensities in the three-thirds group compared to the two-thirds grouping (ES range 0.44 to

0.81). Power law assessment produced intercepts and slopes for one third, two-thirds and three thirds groups can be viewed in Table 5.1.

Table 5.1. Intercept and slope values for estimating peak match intensity by duration for netball players.

		One third	Two-thirds	Three-thirds
Peak PL.min^{-1}	Intercept	52.67 ± 6.64	57.63 ± 7.61	60.77 ± 7.63
	Slope	-0.30 ± 0.06	-0.21 ± 0.05	-0.15 ± 0.02

Peak PL.min^{-1}, Peak player load per minute of match-play.

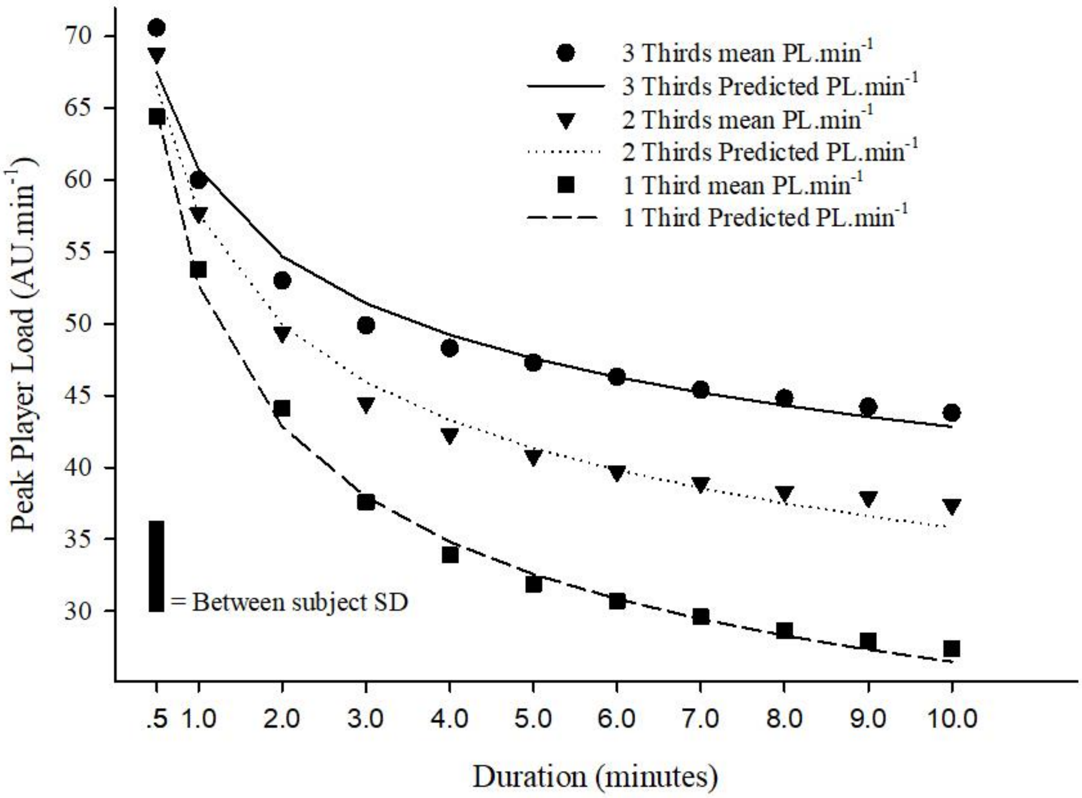

Figure 5.1. The mean peak PL.min^{-1} intensities imposed on the three positional groupings and the predicted peak PL.min^{-1} given by the following power law equation; Predicted peak PL.min^{-1} = intercept x duration$^{(slope)}$ (Delaney et al. 2018).

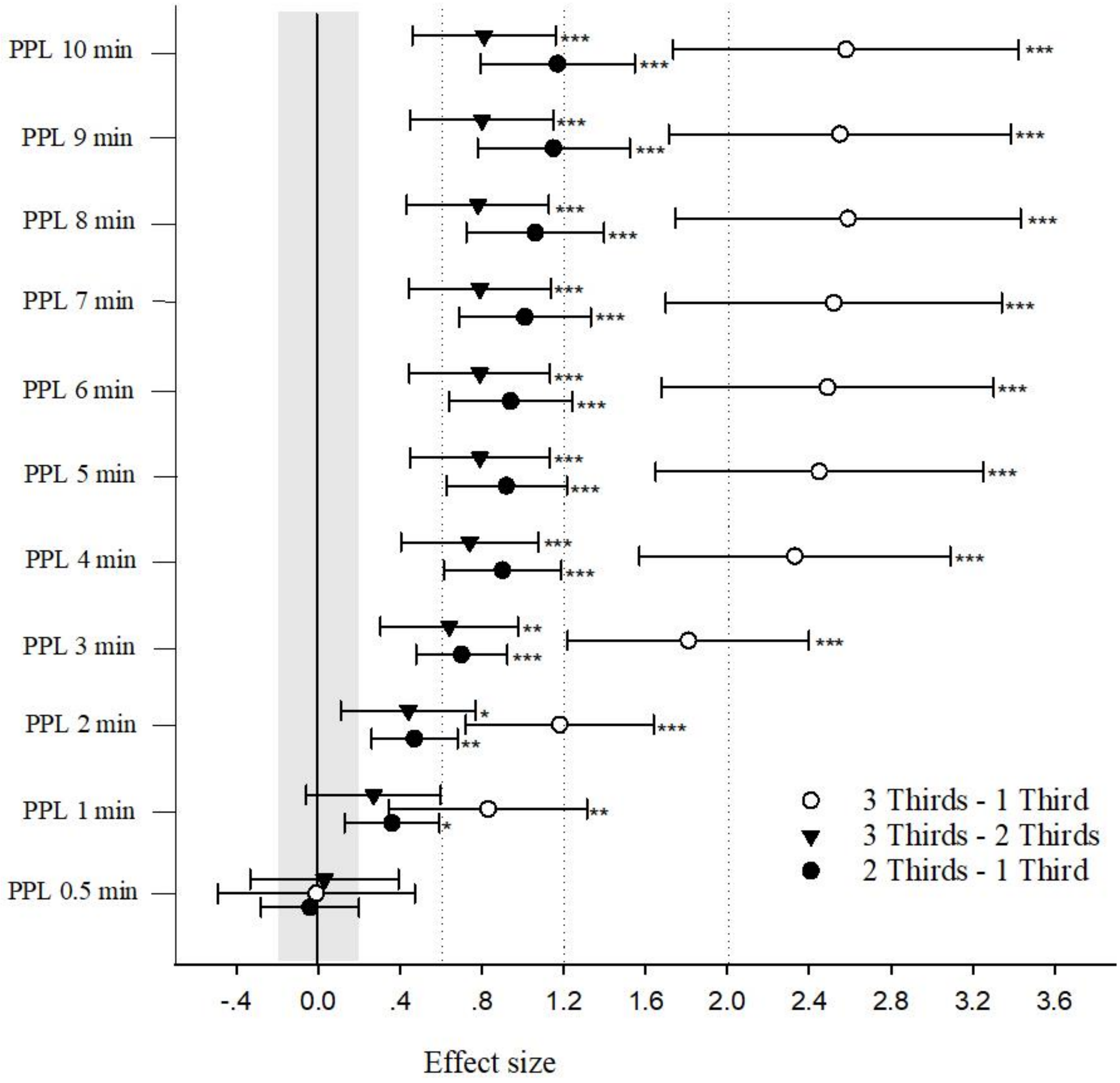

Figure 5.2. Comparison of peak PL.min^{-1} (PPL) at different timepoints between positional groupings. Grey zone represents trivial differences (-0.2 to 0.2 standardised difference), dotted vertical lines represent boundaries of ES thresholds of 0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large and >2.0 very large. PPL; Peak player load, *; likely, **; very likely, and ***; almost certainly.

5.4 Discussion

This is the first study to investigate the peak PL.min^{-1} intensity by epoch in netball. The aim of this study was to investigate whether the peak intensity of netball match-play would differ between positions, with the goal of providing intensity benchmarks for conditioning coaches to better prepare their athletes for competition. Results suggest that post 30-seconds, all but one comparison at a singular time point are substantially different between the novel positional groups used in this study. As such, when prescribing training intensities in netball for drills greater than 30-seconds in duration, it is advised that position-specific intensities are used to guide conditioning practices. Importantly, this study provides a framework for duration specific Player Load™ intensities required in order to expose players to most demanding phases of netball competition.

Comparisons between positional groups for the 30-second epoch yielded non-substantial results. It is well established that differences exist between positions over the course of a match when reporting mean Player Load™ intensity over quarters and games (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018), and indeed this study concurs when reporting the peak intensities. However, reporting the peak intensity of competitive matches provides greater insight into the physical requirements during the most intense passages of play. For example, the average PL.min^{-1} reported in a match from the same competition as the cohort of the current study (Cormack et al. 2014), are in some cases 6x lower than the minimum peak PL.min^{-1} of the current study within a one minute duration. Disparities between peak and average demands are also present within other team-sports such as rugby league and soccer (Delaney et al. 2016, Duthie et al. 2018). During the most intense passages of play in state-level netball matches (i.e., the 30-second epoch), all positions are required to perform at similar intensities between positions. Conditioning professionals and coaches can utilise this data for the development of conditioning activities, as well as motivation for athletes by highlighting / benchmarking the physical demands of competition.

The peak PL.min^{-1} profiles of netball match-play for periods greater than 30-seconds are substantially different between positional groups, most likely because of the movement restrictions imposed on the athletes by the rules of the sport (Woolford and Angove 1992, Davidson and Trewartha 2008). Indeed, it is a common trend in netball that the positions with least movement restrictions will have the highest accelerometer load output (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). The current study also presents similar findings, where three-third athletes post 30-seconds (with exception to one-minute duration compared to the two-thirds grouping) has substantially higher peak PL.min^{-1} throughout a match. A logical sequence follows where the two-thirds grouping requires greater peak intensities in games than the one third groupings. The current findings extend our understanding of what athletes are likely to encounter during the most physically exertive periods of competition. As netball can be considered an intermittent high-intensity power-based sport (Fox et al. 2013), inevitably there will be periods of inactivity due to movement restrictions (Allison 1978, Otago 1983, Steele and Chad 1991, Davidson and Trewartha 2008). Therefore, the reporting of average intensity does not adequately reflect the activity profile of this sport.

Given the low peak speeds reached in netball (Sweeting et al. 2017), accelerations and decelerations will likely provide the majority of physical load imposed on athletes. Global and radio frequency positioning systems do not adequately account for these high-intensity, short and sharp changes-of-direction and velocities (Coutts and Duffield 2010, Varley et al. 2012). Therefore, the use of Player Load^{TM} will likely have greater applicability to court-based sports (e.g., netball, basketball, etc), where the opportunity to achieve even moderate speeds relative to field-based sports (i.e., > $5 m \cdot s^{-1}$) is limited.

The results of this study also justify the use of the novel groupings when comparing the physical attributes of netball athletes. Research involving netball has grouped athletes based on tactical requirements, which may not provide a true reflection of activity profile (Chandler et al. 2014, Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). For example, the goal shooter and goal attack are typically grouped, though given movement restrictions of both positions, the goal attack may perform up to five times the amount of load in games (van Gogh et al. 2018). This new knowledge becomes important for training purposes, as conditioning professionals can now monitor their athletes based on a more reflective activity profile of certain positions. Our findings suggest three-third athletes should complete training drills of longer durations than two and one-third positions. Two-third athletes should also complete drills of greater length in time than one third but not three-thirds athletes.

As presented in other peak intensity literature in team-sports (Delaney et al. 2018), the relationship between peak Player Load™ and time were modelled as a power law relationship. The decrease in peak Player Load™ as time increased displayed a similar relationship to that observed for running speed and acceleration in team sport athletes and also individual running events (Mohr et al. 2005, Bradley and Noakes 2013, Barrett et al. 2016). This analysis provides practitioners with a method for estimating peak 'match Player Load™' for any given duration. This can then be used as a scaling factor to quantify the intensity of training for given durations, ultimately guiding conditioning practitioners towards better physical preparation of their athletes for competition.

A limitation of the current study is the collection of data from one club, where the tactical focus of the coaches is likely to influence the movement of the players. Future research should investigate differences between positional groups on a larger dataset and across multiple clubs.

Such investigations will aid the development of more specific training practices for this population. A further limitation is the absence of positioning data to track the movements of the netball athletes about the court, which would enhance the potential for training drill design.

In conclusion the aim of this study for the current thesis was to further highlight the disparities between positions in relation to their physical and activity profile. The findings of these three initial studies have reported that positions within this cohort are substantially different in many cases. As a result, it is likely that investigating position-specific monitoring strategies for enhancing match performance will provide beneficial guidelines for this sport. However further research is required to determine whether a measure of match performance should be used in preference to others.

Chapter 6 - Study 4 Assessing Match Performance In Netball Athletes With Position-Specific Performance Indicators And Coach Ratings

6.1 Introduction

The final result (win / loss) is typically regarded as the ultimate outcome for assessing team-sport performance. However, producing an objective / subjective assessment of a given match provides context for the outcome of a game. Coach ratings are one measure often considered the '*gold standard*' for team-sport athletes (Johnston et al. 2012) and utilised in professional sporting environments. Coach ratings as a measure of individual performance in team-sport environments have been implemented in Australian football (Verrall et al. 2006, Mooney et al. 2011, Johnston et al. 2012, Kinchington et al. 2012, Cormack et al. 2013, Hunkin et al. 2014, Sullivan et al. 2014, Piggot et al. 2015, Tangalos et al. 2015), rugby union (Cook and Crewther 2012, Kinchington et al. 2012), basketball (Curtner-Smith et al. 1999), and soccer (Neave and Wolfson 2003, Fowler et al. 2014). Yet this form of evaluation is subjective and comes with many confounding variables. For example, in Australian football a player's seniority alone can have a linear relationship with coach ratings received for a particular match (Piggot et al. 2015), indicating perhaps a somewhat preferential treatment towards a certain member of the team. Indeed, the idea of favouritism of athletes by coaches is highlighted in numerous athlete interviews (Gearity and Murray 2011, Rowe 2011, Norman and French 2013). Therefore, a new match performance rating system that reduces the subjectivity inherent in a coach's vote warrants investigation and may inform this thesis by providing a more relevant measure of match performance to be precited by common athlete monitoring practices.

A common form of assessment within team sport populations is the quantification of performance indicators using match statistics such as goals scored, successful passes, or turnovers. This form of analysis has been implemented in Australian football (Gastin et al. 2013), rugby union (Jones et al. 2008, Vaz et al. 2010, Hughes et al. 2017), volleyball (Eom and Schutz 1992, Patsiaouras et al. 2011), basketball (Bray and Whaley 2001) and soccer (Jones et al. 2004, Rampinini et al. 2009). Indeed most of these studies have reported linear relationships between certain performance indicators relevant to their sport and match outcome, though such a study is yet to be completed in netball (Eom and Schutz 1992, Jones et al. 2004, Rampinini et al. 2009, Vaz et al. 2010, Patsiaouras et al. 2011, Hughes et al. 2017). Furthermore, an adjustment of performance indicators has been undertaken within Australian football where subjective weighting factors, based on expert opinion, have been applied to performance indicators (Sullivan et al. 2014). The purpose being to produce an arbitrary score that represents an individual players impact on the match result, though no direct correlation with match outcome was concluded (Sullivan et al. 2014).

The use of performance indicators does not necessarily account for the specific roles that a player may have been requested to complete by the coach (Hiscock et al. 2012, Johnston et al. 2012). For example, Australian Rules football midfielders would typically accrue a high number of ball involvements and thus high match impact score. However, if they were tasked with a defensive role on an opposition player their overall ball involvement would be low, but their actual match impact high (Hiscock et al. 2012, Johnston et al. 2012). Coach rating and performance indicator analysis for team-sport performance presents both criteria having limitations when accounting for certain aspects of performance. Therefore, a combination of the two measures to produce one arbitrary score provides the potential to minimise subjectivity and an inability to account for tactical differences between matches.

The primary aim of this project was to compare the predicative validity of coach ratings, performance indicators and a new combined coach ratings and performance indicator approach, to predict points differential in a netball setting. The secondary aim was to develop a statistical model to inform sport scientists on how to produce a combined score of match performance, through a combination of coach ratings and performance indicator data. This study would then provide an appropriate match performance measure to be modelled against position-specific monitoring strategies for the development practical guidelines for the sport of netball.

6.2 Methods

6.2.1 Design

This prospective observational study was conducted over two netball seasons. All procedures were approved by the Victoria University Human Research Ethics Committee and by the netball club involved (HRE 17-138), with signed informed consent from participants and parents or guardians after a verbal and written explanation of the experimental protocol and its potential risks and benefits. Trial participants were assured they could withdraw without penalty at any time.

6.2.2 Participants

Match performance data was collected on state-level netball athletes from the same club (n = 53, age = 21.6 ± 3.9 years) across two seasons, with athletes playing in multiple teams over a two-year period. Players were placed into their teams by club coaching staff, with teams listed here in descending order relative to competitive level; championship (n = 27, age = 23.7 ± 4.2 years), division one (n = 23, age = 21.9 ± 3.2 years), and 19-&-under (n = 19, age = 18.3 ± 1.1). Over the two seasons the teams finished in the following order (2017, 2018):

championship 3rd and 2nd, division one 1st and 2nd, and 19-&-under 1st and 4th. Players were measured in a number of different positions and their role within the team structure would have changed during the games analysed.

6.2.3 Methodology

A retrospective time motion notational analysis to record performance indicators was conducted for each position on the court. This analysis was completed by using video footage from a freely available website (https://vimeo.com/sportscastaustralia). All notational analysis was completed by one member of the research team and the performance indicators coded are found in Table 6.1. Performance indicators used were those utilised on a freely available website (https://mc.championdata.com/super_netball/index.html) and also those believed to have greatest impact on match outcome by expert coaches at the netball club involved. A coach rating of athlete performance was also collected approximately one-hour post-match completion. Two coaches assessed each player who took part in the game on their overall impact described to the coaches as "what would you rate this athlete's overall performance for the game?" The coach voting system was completed using a 5-point Likert scale (1=very poor through 5=excellent).

Table 6.1. Performance indicators coded, and the criteria required to achieve them.

Performance indicator	Criteria
Positive performance indicators	
Pass success	Any stage where the player being coded successfully passed the ball to their intended target.
Intercepts	Any stage where a player has disrupted a pass from an opposing player. This may include taking possession of the ball, knocking a ball into the possession of their team or opposing team, or knocking a pass out of play.
Centre pass 1st phase involvement	Gaining possession of the ball from the centre pass restart.
Centre pass 2nd phase involvement	Gaining possession of the ball from the second pass following the centre pass restart.
Centre pass 3rd phase involvement	Gaining possession of the ball from the third pass following the centre pass restart.
Free pass for	Any stage where the player has been infringed by the opposition.
Shot success	A successful shot on goal by either the goal attack or goal shooter.
Feed receive success	Where either the goal attack or goal shooter have received a pass from outside the shooting circle, inside the shooting circle.
Feed into circle success	Where a player has successfully passed the ball from outside the shooting circle, to either the goal attack or goal shooter inside the shooting circle.
Offensive rebound	Where the goal attack or goal shooter has gained possession of the ball following a missed shot on goal.
Defensive rebound	Where the goal defence or goalkeeper has gained possession of the ball following a missed shot on goal by the opposition.
Prevent opposition circle entry	When the goal defence or goalkeeper are standing within the defensive circle and prevent an opposition player from gaining possession within the defensive circle from an opposition pass.
Goal assist	The player with the final successful pass that precedes a successful shot on goal for their team.
Negative performance indicators	
Free pass against	Any occurrence where a player has infringed on their opposition, resulting in a free pass / shot on goal for their opposition.
Bad pass	Any stage where a player has passed the ball towards an intended target but not been successful. This includes a turnover to the opposition, a pass being knocked out of play, also a pass that may be knocked into a teammate's possession, but that teammate was not the initial intended target.
Feed receive failure	When a pass is intended for either the goal attack or goal shooter within the shooting circle, but not possession has been taken.
Shot miss	A shot missed by either the goal attack or goal shooter, but possession has been regained by any of member of the team.
Shot miss turnover	A shot missed by either the goal attack or goal shooter, but possession has then been lost to the opposition.

6.2.3.1 Statistical design

The first derived performance indicator was the sum of the square roots of all performance indicators that coaches considered to be associated with better performance minus performance indicators thought to be associated with worse performance. The square root transformation was used to provide equally weighted performance indicators (EWPI) to the respective sum. Each performance indicator is a count, and the square root of a count of independent events has a sampling error of ~0.5, as shown by elementary calculus and by simulation.) The second derived performance indicator consisted of the difference in weighted sums of the performance indicators associated with better and worse performance, where the weights were provided by the coaching staff (CWPI) (Table 6.2).

Table 6.2. Club endorsed weighting of performance indicators by playing position.

	GS	GA	WA	C	WD	GD	GK
Positive performance indicators							
Pass success	1	1	1	1	1	1	1
Intercepts	4	4	4	4	4	4	4
CP 1st phase involvement	-	3	3	-	3	3	-
CP 2nd phase involvement	2	2	2	2	2	2	1
CP 3rd phase involvement	1	1	1	1	1	1	1
Free pass for	2	2	2	2	2	2	2
Shot success	5	5	-	-	-	-	-
Feed receive success	3	3	-	-	-	-	-
Feed into circle success	1	2	3	3	2	2	
Offensive rebound	3	3	-	-	-	-	-
Defensive rebound	-	-	-	-	-	5	5
Prevent opposition circle entry	-	-	-	-	-	3	3
Goal assist	2	3	3	3	2	2	-
Negative performance indicators							
Free pass against	-2	-2	-2	-1	-1	-1	-1
Bad pass	-3	-3	-3	-3	-3	-3	-3
Feed receive failure	-2	-2	-	-	-	-	-
Shot miss	-1	-1	-	-	-	-	-
Shot miss turnover	-3	-3	-	-	-	-	-

GS; goal shooter, GA; goal attack, WA; wing attack, C; centre, WD; wing defence, GD; goal defence, GK; goalkeeper, CP; centre pass, -; particular performance indicator does not occur in that position.

The coach rating used for analysis was the mean of the scores of the players who contributed to that position in the given match (weighted by the time the player was on the court). If a player contributed to multiple positions in a given game the rating was set to missing and subsequently the rating specific to the position was imputed. Ratings were also imputed for substitute players who did not have a rating recorded. The method for imputing the missing ratings was as follows. A value was predicted using separate multiple linear regressions for each playing position. The predictors in the multiple linear regression were better and worse equally weighted performance indicators (Table 6.2), the associated square root of the athlete's time on court, the points difference for the give game and the logarithm of the previous season's ladder position of the current study's team minus that of the opposition team. For players who played multiple positions in a given game the imputation took into account the coaches' original rating for that player by adding the difference between the predicted rating and the mean of the predicted ratings for the multiple positions.

The effects of the derived performance indicators and the coach rating on points difference were interpreted with correlation coefficients produced by simple linear regression for each playing position using Proc Reg in the Statistical Analysis System (version 9.4 in SAS Studio University Edition, SAS Institute, Cary, NC). The points difference was first adjusted to that expected in an even match, by removing the effect of ladder difference on the points difference. This adjustment was achieved by predicting the points difference with the difference in the logarithm of the previous season's ladder position using a simple linear regression with Proc Mixed in SAS; the residuals from this analysis were then the dependent variable in the simple linear regressions. Multiple linear regressions (using Proc Reg) were also performed with the coach rating and each of the derived performance indicators predicting the adjusted points difference, and the resulting multiple correlation was derived as the square root of the adjusted R-squared (to remove small sample bias). The coefficients in the multiple linear regression provided a predicted points difference for the EWPI and the CWPI with coach ratings and these became two additional match performance measures.

Decisions about the magnitude of the correlations of the five match performance measures on points differences were based on the smallest meaningful difference in points scored during close matches from the Victorian Netball League over the 2017 and 2018 seasons. In this context, close matches were defined initially as those where the leading team in the match altered at the completion of the 2nd, 3rd and 4th quarters (16% of observed matches, n = 90). The smallest meaningful difference is given by 0.3 of the typical variation between competitions of an athlete's or team's performance in close competitions, which would increase the athlete’s or team’s chances of winning by 10% (one extra competition or match every 10 matches) (Hopkins et al. 1999, Higham et al. 2014). The points difference was calculated as the standard deviation of the points difference in the close matches (7.1) multiplied by $0.3 / \sqrt{2}$, equal to approximately two points. The square root in the formula accounted for the combined random variation in the performance of the two teams contesting a match. Correlation coefficients were interpreted as follows, <0.13 no relationship, 0.13-0.36 small, 0.37-0.55 moderate, 0.56-0.71 large, 0.72-0.85 very large, ≥0.85 nearly perfect. A decision about the true (very large sample) value of an effect was based on the uncertainty of its magnitude. When the 90% compatibility interval crossed the threshold for both negative and positive values of the smallest meaningful correlation, the effect was deemed unclear (Hopkins et al. 2009). Substantial correlations between positions and points differential were established if the likelihood was greater than the smallest meaningful relationship; >75% (Liow and Hopkins 2003).

6.3 Results

Relationships between match performance measures and points differential are presented in Figures 6.1 to 6.4. The CWPI provided stronger correlations with points differential in nine of 24 comparisons with EWPI. For team performance, the CWPI, coach ratings and a combined CWPI and coach ratings did not result in a substantial relationship with points differential for division-1 (r range 0.11-0.21). All other relationships with points differential were small to very large (r range 0.36-0.72).

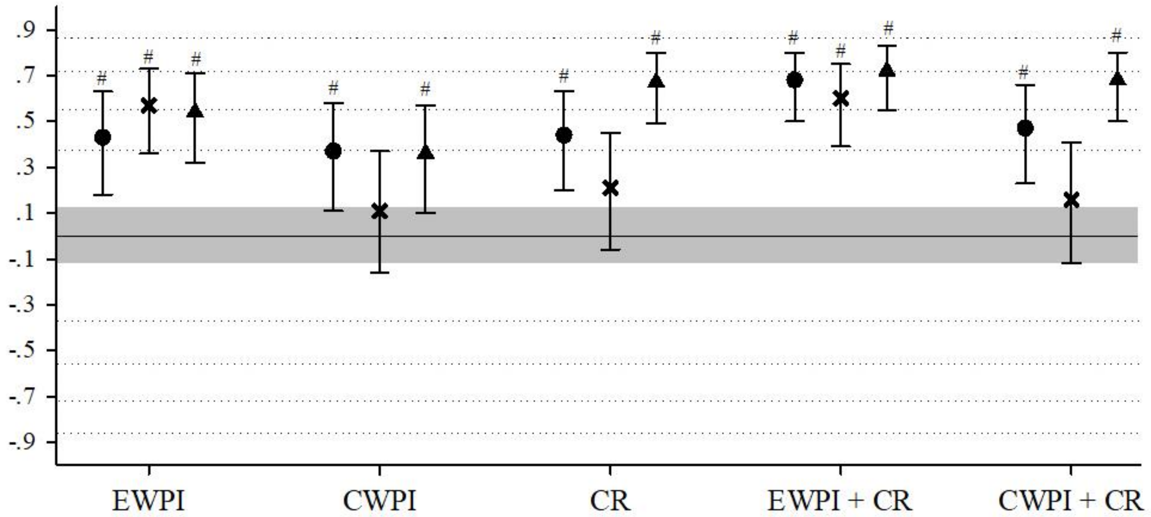

Figure 6.1. Correlations between points differential and the five team-performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Team level: championship (●), division-1 (x), 19-&-under (▲). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

For shooter positions, only two measures were substantially related with points differential for the championship side, being CWPI and the combined EWPI and coach ratings for the goal shooter, with the combined EWPI and coach ratings being substantial for the goal attack position. For the division-1 team, EWPI was substantially related to points differential for the goal shooter and goal attack, all other measures were substantially related to points differential for the goal attack (r range 0.27-0.69). For the 19-&-under team, all measures were substantially related to points differential for the goal shooter and goal attack positions (r range 0.29-0.72). All other assessments for the shooter positions were either trivial or unclear.

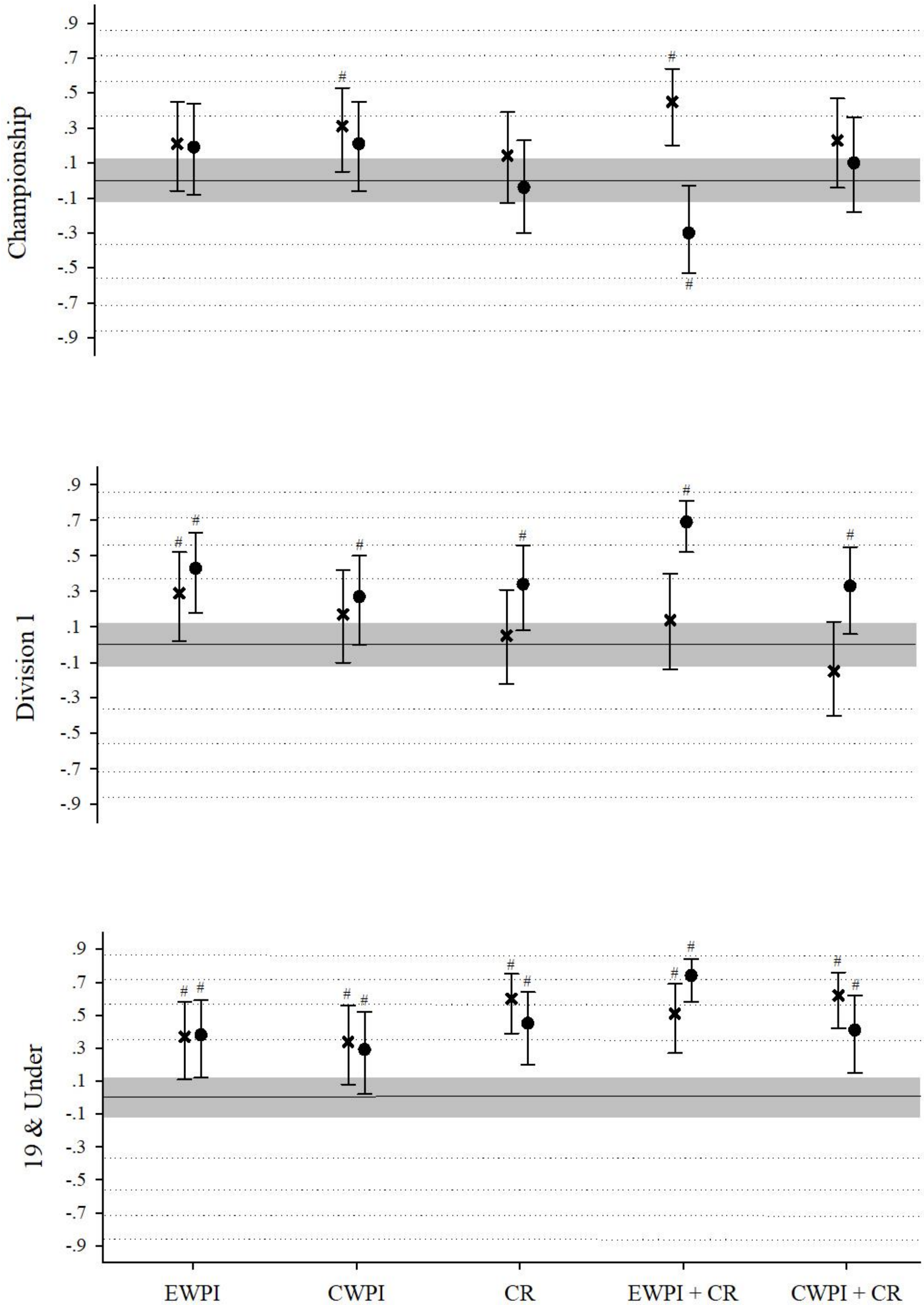

Figure 6.2. Correlations between points differential and the five shooter-performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: goal shooter (**x**), goal attack (●). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

For mid-court positions, CWPI, combined EWPI and coach ratings, and combined CWPI with coach ratings was substantially related to points differential, for the wing defence position in the championship team. All measures, with exception to the EWPI, were substantially related to points differential for the wing attack and centre positions in the championship team (r range 0.46-0.59). For the division-1 team, EWPI (r range 0.24-0.25) and combined EWPI with coach ratings (r range 0.30 to 0.57) were substantially related with points differential for the wing attack and centre positions. The only substantial finding for the wing defence was with a combined EWPI and coach ratings. In the 19-&-under team, EWPI was substantially related to points differential for the centre and wing attack positions (r range 0.27-0.52), with CWPI being substantially related for the centre position only. Coach ratings were substantially related for all positions (r range 0.51-0.64). The combined EWPI and coach ratings was substantially related to points differential for the wing attack and wing defence positions (r range 0.52-0.71), with combined CWPI and coach ratings being substantially related for all positions (r range 0.48-0.65). All other assessments for the mid-court positions were either trivial or unclear.

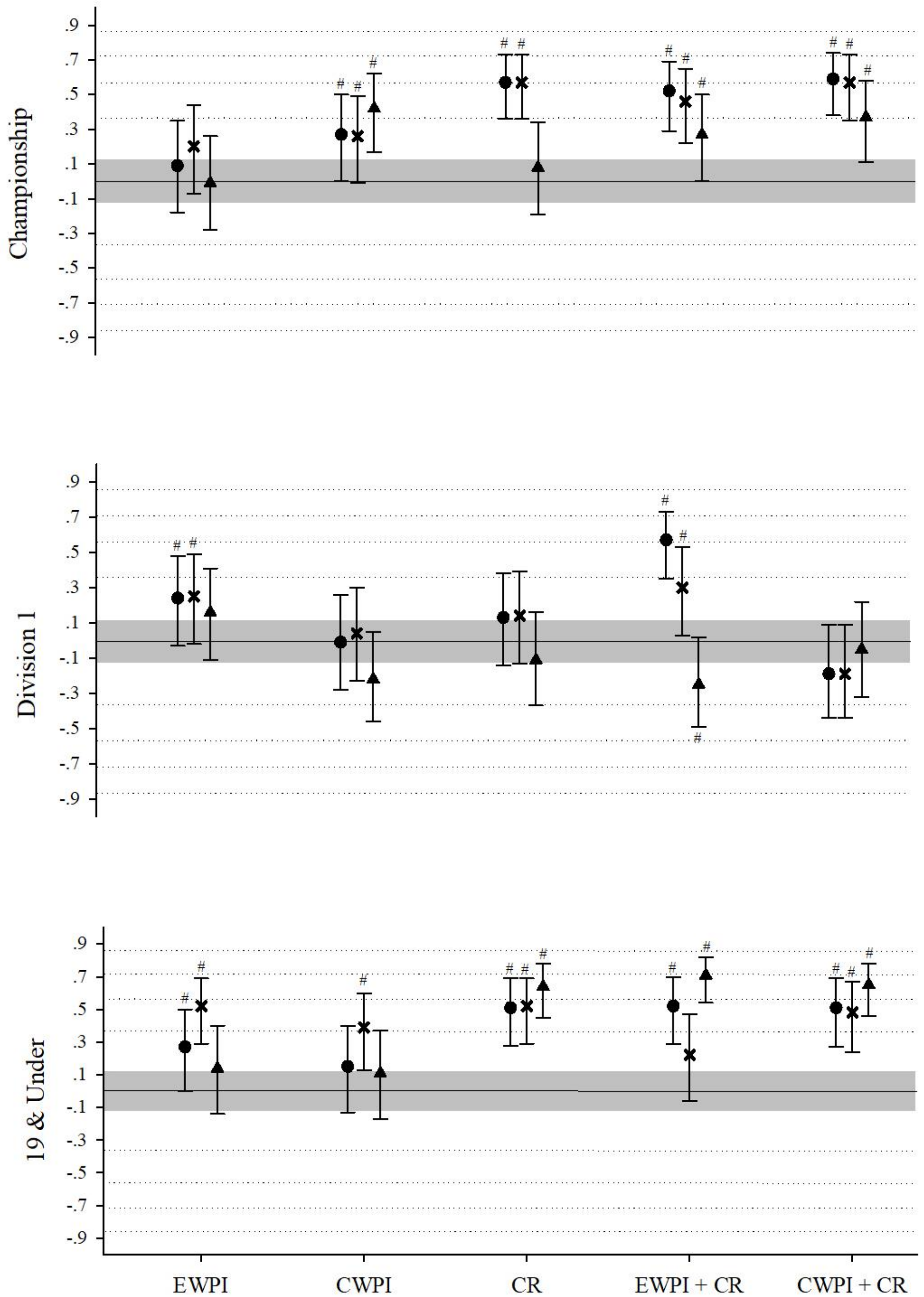

Figure 6.3. Correlations between points differential and the five mid-court performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: wing attack (●), centre (**x**), wing defence (▲). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

For defender positions, only coach ratings were not substantially related to points differential for the goalkeeper position in the championship team, with all other relationships found to be substantial for both positions (r range 0.25-0.60). For the division-1 team, EWPI and combined EWPI with coach ratings were substantially related to points differential for the goalkeeper. A substantial relationship with points differential is reported for combined CWPI with coach ratings, and combined EWPI with coach ratings for the goal defence. For the 19-&-under team, relationships were not substantial for EWPI for both goalkeeper and goal defence positions, as well as CWPI for the goalkeeper, all other comparisons were substantially related to points differential (r range 0.25-0.46). All other assessments for the defender positions were either trivial or unclear.

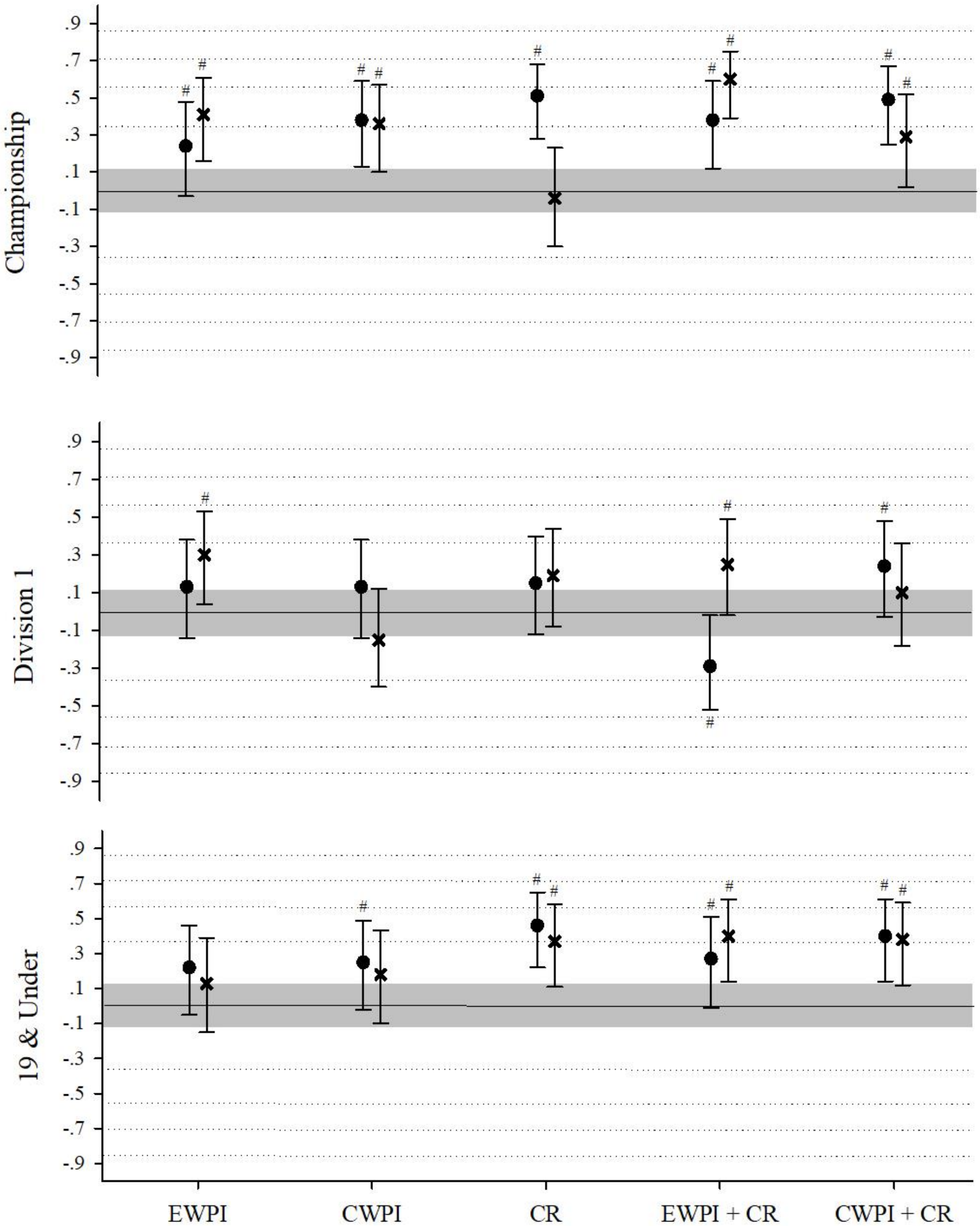

Figure 6.4. Correlations between points differential and the five defender performance measures: equally weighted performance indicators (EWPI), coach-weighted performance indicators (CWPI), coach ratings for match impact (CR), EWPI combined with CR (EWPI+CR), and CWPI combined with CR (CWPI+CR). Position: goal defence (●), goalkeeper (**x**). Grey shading indicates trivial correlations, with dotted lines delimiting small moderate, large, very large and extremely large correlations. # indicates likely substantial correlations (>75% likelihood of at least small).

6.4 Discussion

This is the first study to report the correlation of multiple modes of match performance assessment with points differential in a team-sport setting. Importantly, there is no superior measure of match performance for either a team or position that can't be biased due to sampling variation. There are clear differences in the magnitude of relationships between the measures of match performance in this study and points differential, between levels and positions. This finding provides a clear outcome that coaches should not implement one match performance measure for all positions / teams. This study extends the body of knowledge of match performance assessment in a team-sport setting by providing coaches with an evidence-based approach to infer their athlete's performance, relative to the competitive level and position played.

A novel aspect of this study was the combining of multiple variables to predict points differential. This study was able to demonstrate (Figure 6.1) that when all seven position contributions are summed together, EWPI and coach ratings combined was the strongest predictor of match outcome for all three teams (r range 0.60-0.72). Though highly varied, there were many occasions were a combined performance indicator and coach rating approach yielded stronger relationships with points differential compared to measures in isolation for positions within individual teams. Only one study in Australian football has used a combined match performance assessment measure, though that study implemented a "*confidential formula*" and did not attempt to correlate these measures with match outcome (Richmond et al. 2007). The current study has demonstrated that a combination of coach ratings with either equally weighted or coach-weighted performance indicators has the potential to derive a greater explanation for match outcome over a team and individual positions. Sport scientists and coaches can use the methodology of this study to develop their own combinations of match performance variables providing a greater explanation for wins and losses. Future research could utilise this methodology on individual players to assess the between subject variability which may explain the differences reported between positions in different competitive levels of this study.

Between the championship and 19-&-under teams (Figure 6.1) all measures of match performance were substantially related to a beneficial match outcome. Findings were less consistent for the division-1 level with three out of the five variables not achieving a substantial relationship. These results are surprising as all three teams were consistently strong performing across the two-year period. Given there was a different head coach for each side (but the same head coach for the two seasons) perhaps the variations in relationships can be more closely attributed to differing tactical plans implemented within each team. Indeed, it has been noted that changes in tactics are responsible for alterations in how team-sport athletes will compete in certain playing positions (Bush et al. 2015, Memmert et al. 2017). Based on variations in findings and the magnitude of relationships across levels, team performance should be defined for the individual team based on measures related to desired tactical outcomes.

When analysing positions within teams, only the shooter group for the 19-&-under team reported substantial relationships with points differential for every match performance measure. Furthermore, when analysing individual positions between teams, no measure of match performance was consistently related to match outcome. This may be indicative of different tactics of the assessed teams and the individual athletes. Indeed, the notion of team and athlete variability impacting on how a team performs has been well established (McGarry 2009). Therefore, it can be concluded that when analysing match performance for netball athletes the level of competition and position within that level must be considered with a similar analysis to this study. Future investigations should investigate these performance variables between teams within the same competitive level.

A focus of this study was an investigation of coach-weighted and a novel equally weighted performance indicators and their relationship with points differential. A coach-weighted measure has been applied previously (Sullivan et al. 2014), as expert-derived weighting factors are believed to provide appropriate context-specific levels of importance to particular performance indicators (Sullivan et al. 2014). Surprisingly, the coach-weighted measure in the present study resulted in a stronger relationship with match outcome in only a minority of the comparisons with the novel measure. Given the sampling uncertainty in the correlations, it would be inappropriate to use the difference in the correlations as the basis for deciding between the coach or equal weighting for a given playing position and level. Instead we suggest implementing equally weighting method across all positions and levels, at least in netball. Researchers need to investigate the efficacy of this novel weighting in other sports.

Limitations of the current study may be attributed to the performance indicators used. Investigating such general performance indicators may be too simplistic and not provide enough context as to how a performance indicator occurred at a given point in time during match-play. Future research should examine where on the court, and perhaps the stage of the game various performance indicators occurred, which may also improve the efficacy of the coach-weighted measure. It may also be considered that the use of points differential as the criterion measure for positional performance is inadequate, or not appropriate due to the match result being arguably a team-based outcome. However, as team-sport success is ultimately the product of match outcome, points differential may still be the most appropriate criterion measure currently available.

It would have been interesting and potentially valuable to use multiple linear regression to combine the measures for the seven playing positions into a single team-specific measure. This process would account for the relative contribution of each position to the team's performance and inevitably improve the correlations with points differential. The limited sample size precluded such analysis in the present study, and it would seem to be possible only in sports where the performance indicators for an entire league are available in the public domain.

In conclusion, this study achieved its primary aim be elucidating a high degree of variability in the strength of relationships between performance measures and points differential by positions and competitive levels. This indicates that no match performance measure should be preferred to another that cannot be biased due to sampling variation. As such, all five measures will be used to determine the extent to which they are predicted by common athlete monitoring strategies. This study achieved it's secondary aim by developing a statistical model to derive a performance score using a combined performance indicator and coach rating, which can now be replicated in team-sport research. A strong justification has now been made for a further investigation into the extent to which monitoring strategies can predict position-specific match performance, through having achieved the primary and secondary aims of this study, coupled with the findings of the previous three studies.

Chapter 7 - Study 5 Utilising Athlete Monitoring Practices To Predict Position-Specific Match Performance In Netball

7.1 Introduction

Monitoring athletes in order maximise preparation for training and competition is common place in high performance sport (Halson 2014). Training load in athletic populations is identified as the quantification of the volume of physical work completed, which can then be further analysed into training load dose (Halson 2014). Training load dose describes a training volume measure relative to time. For example, the absolute training completed over a seven-day period. Other measures of training load are relative training volumes that incorporate intensity of training and duration such as the sessional rating of perceived exertion (RPE), where an RPE is multiplied against session duration to produce an arbitrary value of training load (Impellizzeri et al. 2004). Recent investigations have reported Australian footballers were more likely to play better following a reduction of ~1SD in many different forms of acute training load (Lazarus et al. 2017). Similar findings in Australian soccer report centre and wide defenders receiving lower coach rating scores with increases in acute training load (mean change -0.32 to 0.11) (Rowell et al. 2018), in line with current recommendations that reducing acute training volume will increase subsequent acute performance (Bosquet et al. 2007, Mujika 2009). However, wide midfielders and strikers in Australian soccer report beneficial effects with coach ratings when training increased by 1SD (mean change -0.05 to 0.29), which highlights the potential for a position-specific approach to monitoring of athletes (Rowell et al. 2018). The two recent investigations involving Australian football and soccer have provided practical guidelines for practitioners in the field, yet no such investigations exist in netball, and warrants examination.

Athlete wellness monitoring can include several strategies designed to gauge how an athlete feels before, during and after exercise (Saw et al. 2015). One frequently implemented monitoring approach in high-performance sport is a brief questionnaire format typically completed pre-exercise to ascertain readiness for training (Saw et al. 2015). Positive wellness questionnaire responses are interpreted as an athlete being in a favourable psychological state, with a positive state of mind purported to predict better readiness for training and competition (Saw et al. 2015). For example, subjective ratings of sleep quality and general muscle soreness within netball athletes are linearly associated with peak velocity obtained in a countermovement jump (r^2 0.50 and 0.72 respectively) (Wood et al. 2013). Yet wellness questionnaire responses have never been compared to match performance scores in netball populations, which may provide pertinent information for the preparation of netball athletes.

The monitoring of physical performance pre-training and competition to maximise overall preparation for competition is another important area of consideration for conditioning and coaching professionals. The use of a CMJ has been implemented by strength and conditioning coaches / sport scientists as a tool for monitoring physical preparedness via various kinetic / kinematic variables (Cormack et al. 2008, Oliver et al. 2008, Cormie et al. 2009, Williams et al. 2011, Taylor et al. 2012, Castagna and Castellini 2013, Comfort et al. 2014, Gathercole et al. 2015, Gathercole et al. 2015, Malone et al. 2015). Performing a CMJ following a netball match can indicate alterations in neuromuscular output such as reductions in peak velocity (substantial decrease -6.13%), up to 24hrs post-match (Wood et al. 2013). However, no study has investigated the relationship between pre-match CMJ performance and subsequent match performance in netball. Given the purported benefits of enhanced CMJ variables in relation to competition / training readiness (Twist and Highton 2013, Watkins et al. 2017), an investigation to determine the extent of this relationship should be undertaken.

The aim of this project was to ascertain the extent to which three monitoring strategies (training load, subjective wellness and CMJ) predict five measures of match performance (EWPI, CWPI, coach ratings, EWPI + coach ratings and CWPI + coach ratings). This research will aid practitioners in athlete preparation and potentially improve match performance by providing practical guidelines for physical preparation staff to follow when designing training programs.

7.2 Methods

7.2.1 Design

A prospective observational study design was used to identify the changes in three types of monitoring strategy with beneficial and harmful effects on five measures of match performance. Training load and match performance data were collected from three teams at the same netball club competing in the Victorian Netball League during the 2017 and 2018 seasons.

7.2.2 Participants

Across two seasons, state-level netball athletes (*n* = 53, age = 21.6 ± 3.9 years) were recruited for this study, with athletes competing in multiple teams over the two-year period. Players were defined by positional group via coaching staff, thus allowing comparisons between positional areas. The positions were classified as: defenders (*n* = 13; Goalkeeper, Goal Defence), mid-court (*n* = 16; Centre, Wing Attack, Wing Defence) and shooters (*n* = 17; Goal Attack, Goal Shooter). Players were measured in several positions and their role within the team structure would have changed during the games analysed, which is accounted for in the methodology and statistical design. All participants were fully informed of the requirements of the investigation and provided appropriate consent to participate, with consent from the parent or guardian of all players under the age of 18. Ethical approval for this research project was granted by the Victoria University Human Research Ethics Committee (HRE17-138).

7.2.3 Methodology

Methodology for collecting match performance scores was completed as per Chapter 6 (see section 'Methodology 6.2.3'). In brief there are five measures of match performance for each of the three position groups, being equally weighted performance indicators (EWPI); coach weighted performance indicators (CWPI); coach ratings; combined EWPI and coach ratings; combined CWPI and coach ratings.

Training load was quantified via self-reported sessional rate-of-perceived exertion (sRPE) for all training activities and matches for both seasons utilising a smartphone application (Smartabase, Fusion Sport, Queensland, Australia). Participants were asked to log their rating of perceived exertion (10-point modified Borg) and training duration (total minutes), within 30 minutes of completing their session (Uchida et al. 2014, Drew and Finch 2016). The sRPE method for quantifying training load was the RPE provided by the athlete multiplied against training session duration (Impellizzeri et al. 2004).

Cumulative training load was derived via exponentially weighted moving averages (smoothed load). This approach uses a decay factor λ (lambda; value between 0 and 1), accounting for the decaying nature of load by assigning a higher weighting factor to more recent sessions (Hunter 1986). The cumulative load was calculated by λ × (the previous day's training load) + (1 – λ) × (the cumulative training load up to that point). The resulting cumulative load is effectively smoothed with the time constant given by the ratio 1 / λ (λ = 1 over the number of days)

(Lazarus et al. 2017). The smoothed load for this study was generated with λ of 0.14, 0.1, and 0.04 (representing time constants of 7-, 10-, and 28-day; day periods, respectively).

A formula similar to the smoothed load data was used to calculate a predictor variable called differential load, representing the smoothed rate of change in load from one time period to the next. In this case, the previous day's load in the above formula was replaced with the change in load between the current and previous time period. Differential load time constants were the same as those generated for the smoothed cumulative loads.

Training monotony was calculated by dividing the 21-day rolling mean load by the SD of the 21-day of daily load. Training strain was calculated by multiplying the monotony by the 21-day rolling mean (Foster et al. 2001). A ratio of acute: chronic training was calculated by dividing the seven-day load by the 28-day rolling mean (Hulin et al. 2016).

Subjective wellness was completed during the morning of match days. The sub-scales of the wellness monitoring were as follows: general body soreness, total sleep hours (of previous night), sleep quality, fatigue, stress levels, mood, and motivation. Wellness questionnaires were completed using a five-point Likert scale for all questions, except for total sleep hours. A total wellness percentage was calculated for each log by averaging the athlete responses (excluding total sleep hours), dividing by five (i.e., the five-point Likert scale) then multiplying by 100. All sub-scales are in accordance in with previous recommendations (Halson 2014, Saw et al. 2015).

Neuromuscular preparedness was assessed via CMJ performance between 60-90 minutes prior to every match for the duration of the two-year data collection period. Ground reaction force data was collected via force plate (Quattro jump, Kistler, Victoria, Australia) with displacement and velocity quantified via linear position transducer (String pot SG1, Applied Measurement, Victoria, Australia). The linear position transducer was affixed laterally to the force plate to provide consistency of measurement. A wooden broom stick was positioned on the participants back, similar to a back squat. Participants were instructed to limit dowel movement while the force plate and position transducer were zeroed prior to every jump (three jump trials in total). Force and velocity data were quantified manually via excel spreadsheet. The raw csv files were split into different jump phases based on recommendations from the literature (Cormie et al. 2009). The CMJ variables assessed were those utilised elsewhere (Gathercole et al. 2015).

7.2.3.1 Statistical design

Effects of training load data on performance were analysed using a quadratic mixed model in the Statistical Analysis System (version 9.4 in SAS Studio University Edition, SAS Institute, Cary, NC). The quadratic model allowed for a curvilinear effect of training load on the five measures of match performance (EWPI, CWPI, coach ratings, EWPI + coach ratings, and CWPI + coach ratings). Fixed effects in the model were playing position (nominal, 2 / 3 levels), and numeric linear and quadratic terms for the between- and within-player effects of training load. The predictor (training load), and the square of the predictor, which collectively estimated the mean quadratic effect. In initial analysis the random effects were the match identity (nominal, 40 levels, to adjust for the mean difficulty of each game), player identity (to estimate different between-player means across the season), the interaction of player identity with the predictor and its square (to estimate individual differences in the quadratic effect), the interaction of match identity with player identity (to estimate within player variability between matches) and the residual error (within-player variability within matches). Separate analyses were performed for each playing position group. In subsequent analysis individual differences in the linear and quadratic effects were eliminated.

To simplify specification of estimates of effects in the models, the values of training load for the within-player effects were each player’s values re-scaled to a mean of zero, followed by re-scaling all values to a standard deviation of one. Similarly, the values of training load for the between-player effects included each player's means re-scaled to a mean of zero and a standard deviation of one. The effects of changes in playing load within players and differences in training load between players were then estimated for two SD of each measure, in steps of 1 SD: mean minus mean-2SD, mean+1SD minus mean-1SD, and mean+2SD minus mean.

Similar analyses were performed for the effects of wellness and CMJ measures. A preliminary model allowed for numeric linear within- and between effects and individual differences in the linear effect. The within- and between-player effects of the predictors were estimated for 2SD. The magnitudes of relationships between training load, wellness and CMJ measures on the five measures of match performance were assessed by calculating an ES for the three playing positions expressed using the following qualitative descriptors: trivial (< 0.2), small (0.2-0.59), moderate (0.6-1.19), large (1.2-1.99), or very large (> 2.0) (Hopkins et al. 2009). Substantial relationships were established where the likelihood was greater than the smallest worthwhile difference; >75% (Liow and Hopkins 2003).

7.3 Results

In the preliminary analysis the individual differences in the quadratic effects of training were either zero, trivial or unclear; hence the simpler random effects model allowing for only mean differences in each player's mean performance was applied to all dependent variables and training variables.

The mean ± within-subject SD for training loads and match performance scores by position are presented in Table 7.1. Substantial relationships between training load dose and the five measures of match performance for all position groups can be seen in Figure 7.1. For defenders there are eight training loads with substantial effects across three of the five measures of match performance (ES range -0.64 to 0.32). For mid-court athletes there are eight training loads with substantial effects across three of the five measures of match performance (ES range -0.30 to 0.42). For shooters there are 18 training load measures with substantial effects across all five measures of match performance (ES range -0.52 to 0.48). All other comparisons between training load measures and match performance were either trivial or unclear

Table 7.1. Mean ± within-subject SD data of the eight-training load and five match performance measures over two seasons. Practitioners can use the SD's in this table to apply changes in load prescribed in Figure 7.1 to increase the chances of enhanced match performance.

	Defenders		Mid-court			Shooters	
	GK	GD	WD	C	WA	GA	GS
Training load measures							
Smooth 7d	218.3 ± 60.4	233.1 ± 75.0	233.7 ± 84.7	226 ± 62.7	231.5 ± 56.8	207.2 ± 62.8	216.4 ± 59.4
Smooth 10d	219.8 ± 53.7	234.7 ± 64.5	237.6 ± 83.7	231.8 ± 59.0	236.9 ± 50.7	209.3 ± 55.6	217.3 ± 50.4
Smooth 28d	244.5 ± 55.7	257.6 ± 53.5	278.2 ± 93.3	267 ± 72.3	265.7 ± 59.4	235.8 ± 61.7	240.9 ± 50.7
Diff 10d	-13.8 ± 17.0	-14.1 ± 18.9	-14.5 ± 19.6	-17.2 ± 16.6	-18.1 ± 14.5	-14 ± 16.4	-15.0 ± 15.9
Diff 28d	-5.5 ± 6.1	-5.5 ± 6.7	-6.3 ± 7.2	-7.0 ± 6.1	-7.1 ± 5.2	-5.7 ± 5.9	-5.9 ± 5.3
Strain	1301.6 ± 698.5	1508.9 ± 979.6	1406.6 ± 1031.4	1308.9 ± 775.7	1294.0 ± 739.8	1165.3 ± 713.6	1174.9 ± 719.8
Monotony	0.8 ± 0.2	0.8 ± 0.2	0.8 ± 0.3	0.8 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2
ACR 7 to 28d	1.0 ± 0.3	1.1 ± 0.5	1.0 ± 0.4	1.0 ± 0.3	1.0 ± 0.3	1.0 ± 0.3	1.0 ± 0.4
Match performance measures							
EWPI	8.6 ± 2.1	14.1 ± 2.5	10.9 ± 2.1	26.2 ± 2.3	30.4 ± 2.6	31.1 ± 3.4	21.3 ± 3.5
CWPI	10.4 ± 1.3	11.7 ± 1.2	10.3 ± 1.1	19.7 ± 1.2	21.3 ± 1.1	22.4 ± 1.6	20.8 ± 1.8
CR	4 ± 0.6	4.1 ± 0.5	3.8 ± 0.6	4 ± 0.6	3.8 ± 0.7	3.8 ± 0.5	3.9 ± 0.7
CWPI + CR	2.8 ± 3.9	1.4 ± 5.4	0.3 ± 4.5	1.2 ± 7.0	2.4 ± 9.1	0.7 ± 3.2	1.1 ± 4.8
EWPI + CR	-0.4 ± 4.9	-0.1 ± 5.0	-1.2 ± 4.3	-0.2 ± 5.7	-1 ± 8.7	-0.2 ± 3.7	-0.9 ± 4.5

Smooth; Smoothed load, Diff; Differential load, ACR; Acute: Chronic workload ratio 7 to 28d, EWP; Equally weighted performance indicators, CWPI; coach weighted performance indicators, CR; Coach ratings.

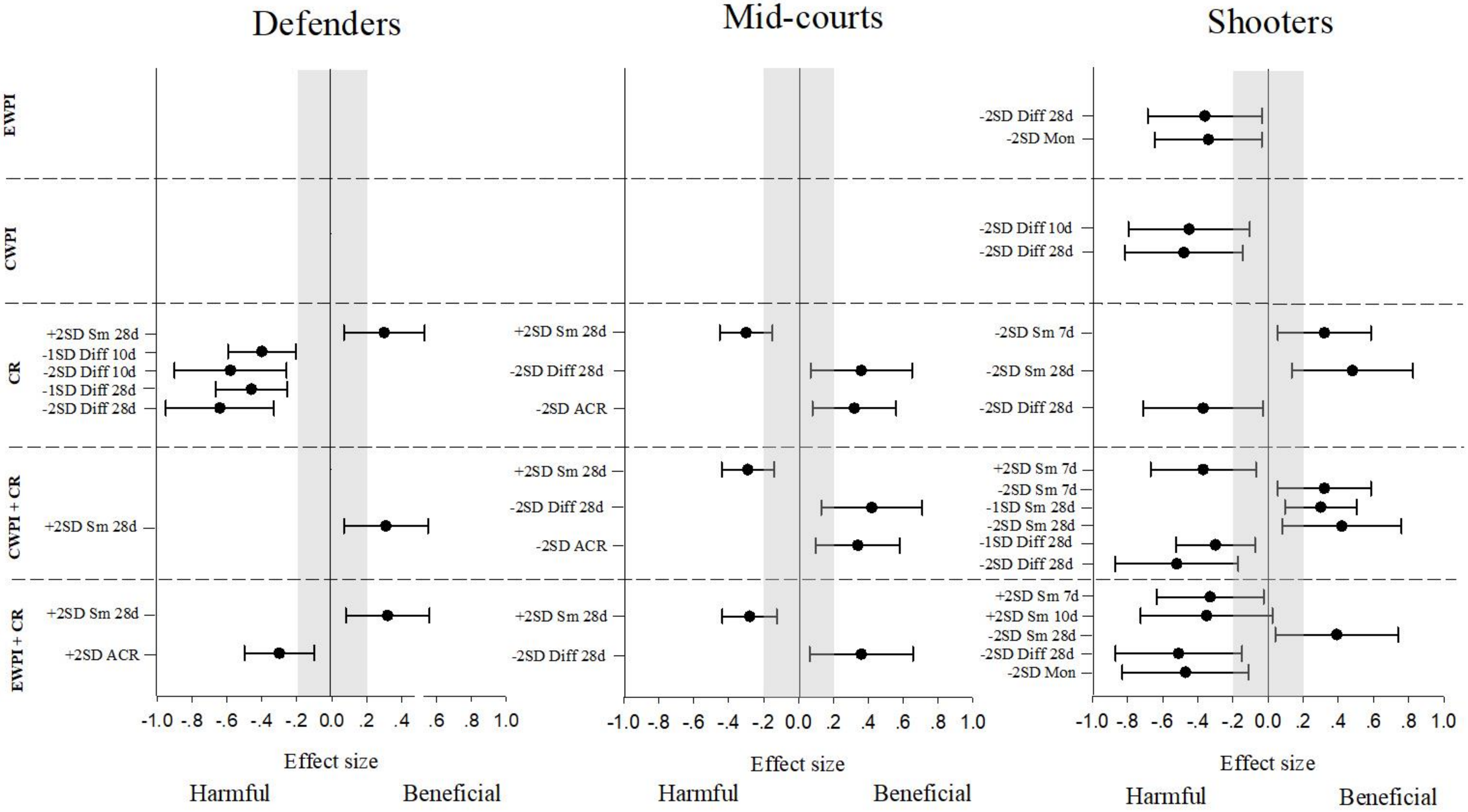

Figure 7.1. Substantial comparisons of training load doses for all three position groups with harmful or beneficial effects compared to the five match performance measures. EWPI; equally weighted performance indicators, CWPI; coach weighted performance indicators, CR; coach ratings, CWPI + CR; combined coach weighted performance indicators and coach ratings, EWPI + CR; combined equally weighted performance indicators and coach ratings, Sm; smoothed load; Diff; differential load, ACR; acute to chronic workload ratio, Mon; training monotony.

The mean ± within-subject SD for wellness questionnaire variables by position are presented in Table 7.2. All comparisons between wellness questionnaires and match performance were either trivial or unclear for all positions.

The mean ± within-subject SD for CMJ variables are presented in Table 7.3. Substantial relationships between CMJ and the five measures of match performance match performance for all position groups are reported in Figure 7.2. For shooters there are 16 training loads with substantial effects across all five measures of match performance (ES -0.38 to 0.35). All other comparisons between CMJ measures and match performance were either trivial or unclear.

Table 7.2. Mean ± within-subject SD data of wellness measures.

	Defenders		Mid-courts			Shooters	
	GK	GD	WD	C	WA	GA	GS
Wellness %	74.5 ± 6.3	76.5 ± 4.9	77.2 ± 6.1	76.1 ± 5.2	74.2 ± 5.3	70.5 ± 7.2	74.3 ± 5.8
Sleep hours	8.9 ± 1.4	8.5 ± 1.4	8.1 ± 1.4	8.2 ± 1.6	7.8 ± 1.6	7.2 ± 1.3	8.4 ± 1.4
Soreness	4.4 ± 0.4	4.5 ± 0.4	4.6 ± 0.3	4.4 ± 0.4	4.3 ± 0.4	4.5 ± 0.5	4.4 ± 0.4
Sleep quality	3.7 ± 0.6	3.8 ± 0.5	3.8 ± 0.4	3.8 ± 0.4	3.8 ± 0.5	3.4 ± 0.7	3.7 ± 0.5
Fatigue	3.5 ± 0.5	3.6 ± 0.5	3.8 ± 0.5	3.5 ± 0.5	3.6 ± 0.6	3.2 ± 0.6	3.6 ± 0.5
Stress	3.5 ± 0.5	3.5 ± 0.4	3.6 ± 0.7	3.4 ± 0.7	3.4 ± 0.6	3.1 ± 0.6	3.3 ± 0.5
Mood	4.0 ± 0.3	4.1 ± 0.3	4.0 ± 0.3	4.1 ± 0.3	4.0 ± 0.3	4.0 ± 0.4	4.0 ± 0.3
Motivation	3.8 ± 0.5	3.9 ± 0.3	3.9 ± 0.4	4.1 ± 0.4	3.9 ± 0.4	3.7 ± 0.4	3.9 ± 0.5
Ill feeling	4.9 ± 0.5	5.0 ± 0.2	4.9 ± 0.3	4.9 ± 0.3	4.9 ± 0.3	4.8 ± 0.5	4.8 ± 0.5

Wellness %; mean percent wellness with 100% being a perfect score.

Table 7.3. Mean ± within-subject SD data of CMJ measures. Practitioners can use the SD's in this table to monitor changes in CMJ for shooters from Figure 7.2 to increase the chances of enhanced match performance.

	Defenders		Mid-courts			Shooters	
	GK	GD	WD	C	WA	GA	GS
PP (W/Kg)	71.7 ± 5.0	72.2 ± 6.1	72.0 ± 6.5	71.3 ± 5.6	72.1 ± 4.9	68.6 ± 4.6	68.1 ± 5.3
MP (W/Kg)	32.6 ± 2.0	32.8 ± 2.8	32.6 ± 3.0	32.5 ± 2.6	33.1 ± 2.3	31.1 ± 2.2	30.6 ± 2.5
MRPD (W/Kg)	53.8 ± 3.6	54.9 ± 4.9	54.7 ± 5.0	54.0 ± 3.9	55.5 ± 3.6	51.9 ± 3.2	50.9 ± 3.6
TPP (s)	0.72 ± 0.09	0.78 ± 0.10	0.76 ± 0.08	0.75 ± 0.08	0.74 ± 0.08	0.80 ± 0.08	0.75 ± 0.09
PF (N/Kg)	20.2 ± 1.0	20.0 ± 1.1	21.1 ± 1.3	20.6 ± 1.2	20.9 ± 1.0	20.1 ± 1.2	19.9 ± 1.2
MF (N/Kg)	16.5 ± 0.8	16.4 ± 0.8	16.9 ± 0.9	16.6 ± 0.9	16.7 ± 0.8	16.1 ± 0.8	16.1 ± 0.8
MRFD (N/Kg)	20.0 ± 1.0	19.8 ± 1.1	20.9 ± 1.3	20.4 ± 1.2	20.6 ± 1.0	20.1 ± 3.3	19.7 ± 1.2
TPF (s)	0.77 ± 0.13	0.86 ± 0.21	0.78 ± 0.11	0.76 ± 0.13	0.73 ± 0.15	0.83 ± 0.14	0.80 ± 0.15
Jheight (m)	0.39 ± 0.03	0.38 ± 0.03	0.37 ± 0.02	0.37 ± 0.03	0.38 ± 0.04	0.37 ± 0.03	0.35 ± 0.03
P Vel (ms)	3.91 ± 0.23	4.02 ± 0.27	3.87 ± 0.30	3.90 ± 0.28	3.96 ± 0.25	3.88 ± 0.22	3.80 ± 0.23
Min Vel (ms)	-3.19 ± 0.30	-3.27 ± 0.31	-3.21 ± 0.29	-3.17 ± 0.31	-3.27 ± 0.32	-3.28 ± 0.31	-3.14 ± 0.30
Vel PP (ms)	3.83 ± 0.24	3.91 ± 0.27	3.74 ± 0.28	3.78 ± 0.30	3.83 ± 0.24	3.76 ± 0.24	3.72 ± 0.27
Tot Imp (N/Kg)	814.5 ± 115.1	859.1 ± 133.7	792.1 ± 93.9	780.2 ± 112.1	794.7 ± 128.7	860.4 ± 95.3	808.8 ± 122.2
FT (s)	0.47 ± 0.01	0.48 ± 0.02	0.47 ± 0.01	0.46 ± 0.02	0.47 ± 0.02	0.47 ± 0.01	0.45 ± 0.02
FT:CT (s)	0.61 ± 0.07	0.57 ± 0.08	0.57 ± 0.07	0.57 ± 0.07	0.58 ± 0.07	0.54 ± 0.07	0.54 ± 0.08
F@0V (N/Kg)	19.0 ± 1.1	18.9 ± 1.0	19.6 ± 1.4	19.4 ± 1.4	20.0 ± 1.4	18.9 ± 1.7	18.6 ± 1.4
FV (N/Kg/ms^2)	21.8 ± 4.9	18.8 ± 5.2	18.5 ± 3.2	18.6 ± 4.3	19.2 ± 4.3	17.3; ± 2.8	18.1 ± 3.8
ECMP (W/kg/s)	5.7 ± 1.2	5.0 ± 1.3	4.9 ± 1.2	4.9 ± 1.2	5.2 ± 1.2	4.6 ± 1.1	4.8 ± 1.2
EDur (s)	0.51 ± 0.07	0.56 ± 0.08	0.55 ± 0.06	0.54 ± 0.07	0.53 ± 0.07	0.57 ± 0.07	0.55 ± 0.07
CDur (s)	0.29 ± 0.02	0.29 ± 0.03	0.28 ± 0.02	0.28 ± 0.03	0.28 ± 0.02	0.30 ± 0.02	0.28 ± 0.02
TotDur (s)	1.27 ± 0.09	1.34 ± 0.10	1.30 ± 0.07	1.28 ± 0.08	1.28 ± 0.08	1.34 ± 0.08	1.28 ± 0.09

PP; Peak power, MP; Mean power, MRPD; Max rate of power development, TPP; time to peak power, PF; Peak force, MF; Mean force, MRFD; Max rate of force development, TPF; Time to peak force, Jheight; Jump height, P Vel; Peak velocity, Min Vel; Minimum velocity, Vel PP; Velocity at peak power, Tot Imp; Total impulse, FT; Flight time, FT:CT; Flight time to contraction time ratio, F@0V; Force at zero velocity, FV; Force velocity area under the curve, ECMP; Eccentric and concentric mean power, EDur; Eccentric duration, CDur; Concentric duration, TotDur; Total duration, W/Kg; watts per kilogram of body mass, s; Seconds, N/Kg; Newtons per kilogram of body mass, m; Metres, ms; metres per second, N/Kg/ms^2; Newtons per kilogram of body mass per metres per second squared, W/Kg/s; Watts per kilogram of body mass per second.

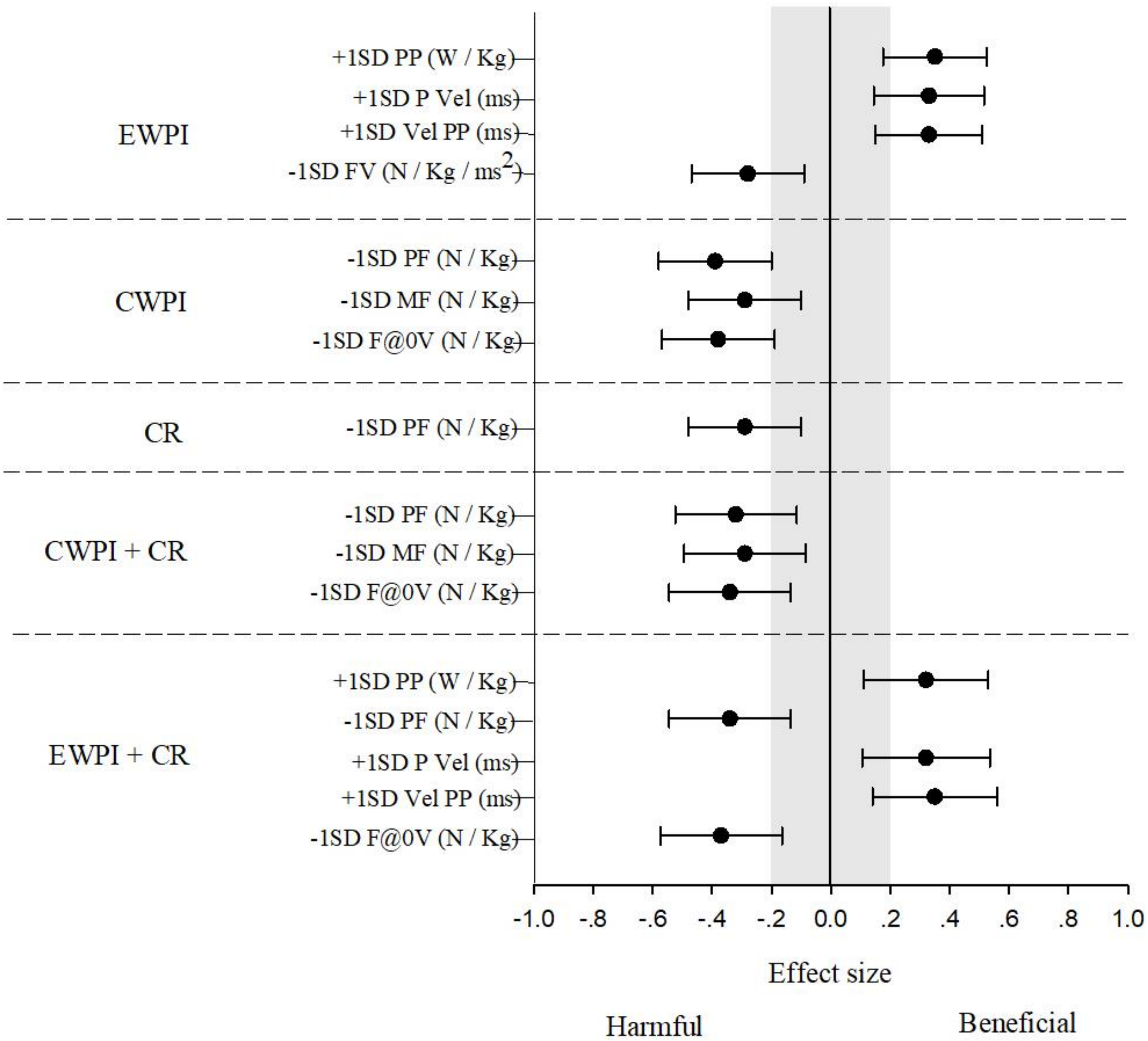

Figure 7.2. Substantial CMJ measures for shooters with harmful or beneficial effects on the five match performance measures. EWPI; equally weighted performance indicators, CWPI; coach weighted performance indicators, CR; coach ratings, CWPI + CR; combined coach weighted performance indicators and coach ratings, EWPI + CR; combined equally weighted performance indicators and coach ratings, PP; peak power, P Vel; peak velocity, Vel PP; velocity at peak power, FV; force velocity area under the curve, PF; peak force, MF; mean force, F@0V; force at zero velocity.

7.4 Discussion

This is the first study to investigate multiple monitoring strategies and their potential impact on multiple measures of match performance. Despite numerous training load indices reporting relationships with match performance, no single training load measure was consistently related to either beneficial or harmful match performance across positions. No subjective wellness category was related to any of the five match performance measures across the three position groups, which raises doubts surrounding the implementation of this monitoring strategy for predicting match performance. Only the shooters reported substantial relationships with CMJ variables and match performance, which should be considered when assessing the necessity for all positions to be subjected to this monitoring strategy. Sport scientists can implement the findings of this study as a guideline for monitoring netball players in order to increase the likelihood of enhanced match performance.

For the defender position, all substantial findings between training load and match performance were in favor of an increase in training load being beneficial for performance, with one exception only. This finding is against the conventional notion that less training load leading into competition will be better for performance (Bosquet et al. 2007, Mujika 2009, Le Meur et al. 2012). A potential explanation may lie in the performance measures, where all match performance variables are impacted by coach ratings either solely or in combination with performance indicators. The coaches may either consciously or sub-consciously place an importance on defenders training longer / harder. By extension, when a defender trains particularly hard / completing more training volume, a more favorable perception may be held by the coach when assessing an athlete/s match performance. Indeed, the idea of coach favoritism is well documented throughout team-sport literature (Gearity and Murray 2011, Rowe 2011, Norman and French 2013). Increased training load has also been reported as beneficial for certain positions in Australian soccer players (Rowell et al. 2018). An explanation was the possibility that the mean training load may have been an insufficient stimulus to prepare this positional group for match-play, which may also be the case for the current study. Nevertheless, the training load dose strategies identified for defenders can be implemented with some confidence that a more beneficial outcome on match performance will be attained.

Discordant findings to the defenders are reported when analysing the effect of training on performance for mid-court athletes. All substantially beneficial findings for the mid-court positions indicated 2SD of less training being favorable for enhanced match performance. For mid-court athletes an explanation may be evident in the volume of physical work completed in training and competition relative to both defenders and shooters. For example, in matches the mid-court positions complete substantially greater work over the course of a match (Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). Therefore, a reduction in training may provide a super-compensatory effect for these athletes allowing for enhanced match performance outputs (Bosquet et al. 2007, Mujika 2009, Le Meur et al. 2012).

Analysis of shooters was the most incongruous in relation to beneficial and harmful outcomes for match performance. The beneficial effects of training load on performance resulted in -2SD change in load being favorable for match performance. However, there were eight out of 12 occasions where a -2SD reduction in training load was harmful for performance. Similar to defenders, the results for this position group are contrary to conventional notion that a reduction in training load will lead to improved performance. Shooters will typically complete less total work in training and competition compared to mid-court athletes and defenders (Chandler et al. 2014, Cormack et al. 2014), as reported in the current study (Table 7.1), which may highlight a consistently insufficient training stimulus for this position group. Conditioning and coaching professionals have options when selecting the training load and match performance measure they wish to manipulate in order to positively impact match output, however they must be mindful of the position-specific guidelines put forward by this study.

There were no training load measures substantially associated with match outcome when using EWPI or CWPI as the measure of match performance for defenders and mid-court athletes. It would appear for these positional groups a coaches rating must be considered when assessing match performance. An assessment on the tactical nature of how defenders and mid-courts played (e.g., how they positioned themselves about the court both offensively and defensively) may provide more pertinent findings to infer match performance in these positional groups.

Assessment of wellness reported no substantial relationship between any of the predictor variables, nor the five measures of match performance for any position group. This is despite findings in other sports showing wellness questionnaire results being able to predict reductions in training output (Thorpe et al. 2015, Gallo et al. 2016), and changes in training load over time (Buchheit et al. 2013, Buchheit et al. 2013). The current study has reported that whilst wellness questionnaire monitoring may be beneficial for assessing changes in other variables, caution should be utilised when attempting to predict match performance based on this data.

Finally, only substantial findings for the CMJ measures were reported for the shooter position group. A potential explanation may be a greater dependence on explosive movements in this position. For example, shooters perform less overall work compared to other positions (Cormack et al. 2014, Young et al. 2016, van Gogh et al. 2018). Therefore, over the course of a game, the ability for shooters to be more explosive may be more beneficial for their overall performance. Conditioning and coaching professionals should consider the results of this study before implementation of CMJ monitoring to predict match performance across an entire team.

Limitations of this study include the use of a global measures training load. This study did not split training into any sub-categories (e.g., court-based training and strength training) which may provide a more descriptive insight into the impacts of certain types of training on match performance. A further limitation, considering the extensive analysis performed, indicates that training load measures in the current study have a limited impact on netball performance.

Chapter 8 - General Conclusions And Major Findings, Practical Applications And Future Research

8.1 Introduction

This thesis aimed to determine the predictive ability of monitoring strategies on match performance within a state-level netball cohort. In order to achieve this, several preceding studies were initially required. These included a better understanding of physical profiles of netballers by position, the activity profiles of different positional group in netball matches, is there a best measure of match performance for netball? Finally, once the overarching theme of the thesis was justified an appraisal of the predictive ability of three currently implemented athlete monitoring strategies was investigated, in comparison to match performance. The results of this thesis have been discussed in earlier in chapters 3 to 7; therefore, this section will assimilate and provide conclusions and the major findings from these investigations.

8.2 Conclusions and Major Findings

This thesis produced many novel findings, with several substantial differences found between positions, positional groups and teams that highlights the need for an intricate approach to athlete monitoring within the sport of netball. Specifically, substantial differences were found between physical capacities and peak intensities achieved during matches (Chapter 3 and 5). Position and team specific measures of match performance must be applied and continuously critiqued to ensure that assessments of athlete performance are relevant to points differential (i.e., wins and losses) (Chapter 6). Finally, a position-specific approach to training load monitoring should be adopted to optimise netball match performance, as there are numerous inconsistencies between positions in relation to the type of training load and the amount of change in training volume to elicit performance changes. Pre-match CMJ may provide small predictions of match performance for shooters, whilst the use of wellness questionnaires is not recommended for any position group (Chapter 7). The major findings from the thesis are summarised below:

- Substantial differences exist between positions in physical capacities, with the greatest physical requirements being placed on the mid-court positions.
- The Player Load^{TM} metric has acceptable inter-unit reliability (CV 4.8%) within a court-based sport environment.
- During the most intense periods of netball match-play there is no substantial difference between position groups in peak Player Load^{TM}.
- The peak Player Load^{TM} between all position groups post the 30-second epoch are substantially different. This finding is in accordance with previous works highlighting that volumes of work during games do differ between positions (Cormack et al. 2014, Young et al. 2016), but not the peak intensities during the most physical exertive periods of play (i.e., the 30-second timeframe).
- Across 13 instances, performance indicators and coach ratings produced the strongest relationship to points differential, compared to performance indicators and coach ratings assessed in isolation. Combining these two measures has merit for assessing an athlete's match performance within team-sport.
- In 16 out of 24 comparisons, equally weighted performance indicators outperformed a coach weighted performance indicator score when compared to points differential. Therefore, expert opinion may not always be directly associate with match outcome.
- It should not be assumed that measures of performance are in fact related to match outcome.
- The five measures of match performance from this thesis do not produce the same strength of correlation with match outcome between positions, competitive levels or between the same positions across competitive levels.

- Typically, a 2SD change in a given training load can create a beneficial, or harmful effect, on match performance.
- Defenders typically favor an increase in training load volume for improving position specific match performance. This finding is against the typical notion that a reduction in training load volume will lead to enhanced performance in team-sport athletes.
- Wellness questionnaire data do not relate to match performance in state-level netball athletes.
- CMJ performance variables provides small predictions of match performance in the shooter position of netball. Using CMJ data to predict match performance of defenders or mid-courts is not recommended.

8.3 Practical applications

Netballers who intend to play in the mid-court and defender positions may need to spend more time developing capacities in acceleration and change-of-direction as there appears to be a greater demand compared to the shooter positions. Conditioning professionals involved in netball should incorporate a testing battery that assesses the same capacities (stature, acceleration, change-of-direction, jumping, bounding and intermittent endurance) investigated in this study, as all tests were in some way able to identify meaningful differences between positions. The variations in physical profiles between positions should assist coaches in designing training programs to maximise position-specific adaptations, as the disparities may be indicative of positional requirements in matches. For example, conditioning professionals could spend more time developing acceleration and deceleration capacities of mid-court athletes, and vertical jumping ability of defenders. Shooters appear to require the least physical capacity development in this high-performance cohort, possibly a greater focus on technical and tactical development should be considered. Conditioning professionals should continue to devote time and effort towards developing all capacities measured in this thesis, regardless of position, as the performance tests implemented are deemed important for netball (Tanner and Gore 2012). Future research should investigate the influence of maximum strength capacities on all performance tests, as well as differences between competitive levels of similar ages to this thesis.

Sport scientists working with court-based sports can use the Player Load^{TM} metric with confidence to compile the external load of these intermittent, acceleration reliant athletes. When inferring changes in Player Load^{TM} over a training cycle, the variation of values recorded between units, whilst small, should be considered when using different units between individual players over multiple sessions. The inter-unit reliability was acceptable in all comparisons, therefore sport scientists can allow players to be equipped with any device when necessary, though should avoid if possible.

Netball athletes who associate with the three-third positional group (centers) should complete longer duration intermittent drills than their two-third (goal attack, wing attack, wing defence and goal defence) and one-third (goal shooter and goalkeeper) counterparts. Two-third athletes should perform longer duration drills than one-third athletes because of the greater intensity required of these positions over a longer period. Conditioning professionals and coaches developing drills to meet, or exceed, match intensity can utilise the PL.min^{-1} reported in this thesis (Chapter 5) as a benchmark. Accounting for positional work rates in drill development need only be considered for durations equal to or greater than one-minute, as no substantial differences exist between positions at the 30-second epochs. Sport scientists will be able to apply the methodology of this study (Chapter 5) to their own training environments, which may improve programming outcomes via better replication of the peak intensities of matches, in training more often. In doing so, the physical preparation of athletes for the most physically exertive passages of play can be better refined, via the implementation of more intensity specific training drills.

Coach / expert weighted performance indicators is not a consistently stronger predictor of match outcome compared to EWPI, so should only be implemented in a position-specific manner if substantial relationships exist. Sport scientists and coaches should combine multiple performance measures to achieve superior relationships with points differential, an important indicator of match performance. Practitioners should utilise a position-specific approach to match performance predictions, instead of utilising a sole measures across positions.The novel method of combining match performance criteria may provide a stronger indication of how well a particular team / position / or athlete competed in a given match, by accounting for both technical and tactical aspects of match-play.

Conditioning professionals and netball coaches should monitor the individual training loads of their athletes, whilst tracking the dose of these loads to increase the likelihood of winning matches. Typically, fluctuations of 2SD for a given measure of training load is required to provide a beneficial, or harmful change in match performance, for all three positional groups. The use of wellness questionnaires for prediction of match performance is not recommended, as no relationships was reported across a two-year data collection period. CMJ data for shooters only, provides a small indication of athlete performance and may be used as a match preparedness measure. The use of CMJ data for defenders and mid-courts for predicting match performance is not recommended, based on the findings of this thesis.

8.4 Future research

This thesis provides evidence for position-specific monitoring strategies to improve performance outcomes on five different measures of match performance. A number of questions remain for future investigation involving monitoring strategies and match performance within a netball population, these include:

- What differences exist between positions during training and matches based on kinematic variables (e.g., total distance covered, distance travelled per minute of match-play etc.)? Findings would provide more easily manipulated aspects of training sessions for conditioning and coaching professionals.
- Do sub-categories of training load have effect on match performance? What do sub-qualities of load such as strength training, running, cross-training, etc. have on match performance?
- What is the interaction between physical capacities and match performance / position specific indicators? Do netball athletes with higher intermittent endurance capacities perform better in competition?
- Can wellness questionnaires predict other aspects of athlete preparation / performance, such as injury?

References

Abdelkrim, B., C. Castagna, I. Jabri, T. Battikh, S. Fazaa and J. Ati (2010). "Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness." *Journal of Strength and Conditioning Research* **24**(9): 2330-2342.

Allison, B. (1978). "A practical application of specificity in netball training." *Sports Coach* **2**(2): 9-13.

Association, N. B. (2014). "Official rules of the National Basketball Association." from https://www.nba.com/media/dleague/1314-nba-rule-book.pdf.

Aughey, R. J. (2011). "Applications of GPS technologies to field sports." *International journal of sports physiology and performance* **6**(3): 295-310.

Australia, N. (2018). Official rules of netball, Melbourne: Netball Australia.

Bailey, S. P., T. J. Willauer, G. Balilionis, L. E. Wilson, J. T. Salley, E. K. Bailey and T. L. Strickland (2015). "Effects of an over-the-counter vented mouthguard on cardiorespiratory responses to exercise and physical agility." *Journal of Strength and Conditioning Research* **29**(3): 678-684.

Bangsbo, J., F. Iaia and P. Krustrup (2008). "The Yo-Yo Intermittent Recovery Test." *Sports Medicine* **38**(1): 37-51.

Barrett, S., A. Midgley, M. Reeves, T. Joel, E. Franklin, R. Heyworth, A. Garrett and R. Lovell (2016). "The within-match patterns of locomotor efficiency during professional soccer match play: Implications for injury risk?" *Journal of science and medicine in sport* **19**(10): 810-815.

Batterham, A., Hopkins, W. (2006). "Making meaningful inferences about magnitudes." *International Journal of Sports Physiology and Performance* **1**(1): 50-57.

Behm, D. and A. Chaouachi (2011). "A review of the acute effects of static and dynamic stretching on performance." *European Journal of Applied Physiology* **111**(11): 2633-2651.

Bosquet, L., J. Montpetit, D. Arvisais and I. Mujika (2007). "Effects of tapering on performance: a meta-analysis." *Medicine and science in sports and exercise* **39**(8): 1358-1365.

Boyd, L., K. Ball and R. Aughey (2011). "The reliability of minimaxX accelerometers for measuring physical activity in Australian football." *International Journal of Sports Physiology and Performance.* **6**(3): 311-321.

Boyd, L., K. Ball and R. Aughey (2013). "Quantifying external load in Australian football matches and training using accelerometers." *International Journal of Sports Physiology and Performance.* **8**(44-51).

Bradley, P. S. and T. D. Noakes (2013). "Match running performance fluctuations in elite soccer: indicative of fatigue, pacing or situational influences?" *Journal of sports sciences* **31**(15): 1627-1638.

Bray, C. D. and D. E. Whaley (2001). "Team cohesion, effort, and objective individual performance of high school basketball players." *The Sport Psychologist* **15**(3): 260-275.

Buchheit, M., S. Racinais, J. Bilsborough, P. Bourdon, S. Voss, J. Hocking, J. Cordy, A. Mendez-Villanueva and A. Coutts (2013). "Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players." *Journal of Science and Medicine in Sport* **16**(6): 550-555.

Buchheit, M., B. M. Simpson, L. A. Garvican-Lewis, K. Hammond, M. Kley, W. F. Schmidt, R. J. Aughey, R. Soria, C. Sargent and G. D. Roach (2013). "Wellness, fatigue and physical performance acclimatisation to a 2-week soccer camp at 3600 m (ISA3600)." *Br J Sports Med* **47**(Suppl 1): i100-i106.

Bush, M., C. Barnes, D. T. Archer, B. Hogg and P. S. Bradley (2015). "Evolution of match performance parameters for various playing positions in the English Premier League." *Human movement science* **39**: 1-11.

Carling, C. (2013). "Interpreting physical performance in professional soccer match-play: should we be more pragmatic in our approach?" *Sports Medicine* **43**(8): 655-663.

Carling, C., J. Bloomfield, L. Nelsen and T. Reilly (2008). "The role of motion analysis in elite soccer." *Sports medicine* **38**(10): 839-862.

Carré, J., C. Muir, J. Belanger and S. Putnam (2006). "Pre-competition hormonal and psychological levels of elite hockey players: relationship to the 'home advantage'." *Physiology and Behavior* **89**(3): 392-398.

Castagna, C. and E. Castellini (2013). "Vertical jump performance in Italian male and female national team soccer players." *The Journal of Strength & Conditioning Research* **27**(4): 1156-1161.

Chandler, P., S. Pinder, J. Curran and T. Gabbett (2014). "Physical demands of training and competition in collegiate netball players." *Journal of Strength and Conditioning Research* **28**(10): 2732-2737.

Cohen, L., L. Manion and K. Morrison (2013). Research methods in education, Routledge.

Comfort, P., A. Stewart, L. Bloom and B. Clarkson (2014). "Relationships between strength, sprint, and jump performance in well-trained youth soccer players." *The Journal of Strength & Conditioning Research* **28**(1): 173-177.

Cook, C. and B. Crewther (2012). "The effects of different pre-game motivational interventions on athlete free hormonal state and subsequent performance in professional rugby union matches." *Physiology and behaviour* **106**(5): 683-688.

Cormack, S., M. Mooney, W. Morgan and M. McGuigan (2013). "Influence of neuromuscular fatigue on accelerometer load in elite Australian football players." *International Journal of Sports Physiology and Performance.* **8**(4): 373-378.

Cormack, S., R. Newton, M. McGuigan and P. Cormie (2008). "Neuromuscular and endocrine responses of elite players during an Australian rules football season." *International Journal of Sports Physiology and Performance.* **3**: 439-453.

Cormack, S., R. Smith, M. Mooney and W. Young (2014). "Accelerometer load as a measure of activity profile in different standards of netball match play." *International Journal of Sports Physiology and Performance.* **9**(2).

Cormack, S. J., R. U. Newton, M. R. McGuigan and T. L. Doyle (2008). "Reliability of measures obtained during single and repeated countermovement jumps." *International journal of sports physiology and performance* **3**(2): 131-144.

Cormie, P., J. M. McBride and G. O. McCaulley (2009). "Power-time, force-time, and velocity-time curve analysis of the countermovement jump: impact of training." *The Journal of Strength & Conditioning Research* **23**(1): 177-186.

Coutts, A., J. Quinn, J. Hocking, C. Castagna and E. Rampinini (2010). "Match running performance in elite Australian Rules Football." *J Sci Med Sport* **13**(5): 543-548.

Coutts, A., P. Reaburn, T. Piva and G. Rowsell (2007). "Monitoring for overreaching in rugby league players." *European Journal of Applied Physiology* **99**(3): 313-324.

Coutts, A. J. and R. Duffield (2010). "Validity and reliability of GPS devices for measuring movement demands of team sports." *J Sci Med Sport* **13**(1): 133-135.

Curtner-Smith, M., S. Wallace and M. Q. Wang (1999). "Relationship of coach and player behaviors during practice to team performance in high school girls' basketball." *Journal of Sport Behavior* **22**(2): 203.

Davidson, A. and G. Trewartha (2008). "Understanding the physical demands of netball: A time-motion investigation." *International Journal of Performance Analysis in Sport* **8**(3): 1-17.

Dawson, B., J. Hamson-Utley, R. Hansen and M. Olpin (2014). "Examining the effectiveness of psychological strategies on physiolgic markers: evidence-based suggestions for holistic care of the athlete." *Journal of Athletic Training* **49**(3): 331-337.

De Villiers, J. and R. Venter (2014). "Barefoot training improved ankle stability and agility in netball players." *International Journal of Sport Science and Coaching* **9**(3): 485-495.

Delaney, J. A., G. M. Duthie, H. R. Thornton, T. J. Scott, D. Gay and B. J. Dascombe (2016). "Acceleration-based running intensities of professional rugby league match play." *International journal of sports physiology and performance* **11**(6): 802-809.

Delaney, J. A., T. J. Scott, H. R. Thornton, K. J. Bennett, D. Gay, G. M. Duthie and B. J. Dascombe (2015). "Establishing duration-specific running intensities from match-play analysis in rugby league." *International journal of sports physiology and performance* **10**(6): 725-731.

Delaney, J. A., H. R. Thornton, A. E. Rowell, B. J. Dascombe, R. J. Aughey and G. M. Duthie (2018). "Modelling the decrement in running intensity within professional soccer players." *Science and Medicine in Football* **2**(2): 86-92.

Delextrat, A. and M. Goss-Sampson (2010). "Kinematic analysis of netball goal shooting: A comparison of junior and senior players." *Journal of Sport Sciences* **28**(12): 1299-1307.

Di Salvo, V., W. Gregson, G. Atkinson, P. Tordoff and B. Drust (2009). "Analysis of high intensity activity in Premier League soccer." *International journal of sports medicine* **30**(03): 205-212.

Drew, M. K. and C. F. Finch (2016). "The Relationship Between Training Load and Injury, Illness and Soreness: A Systematic and Literature Review." *Sports Medicine* **46**(6): 861-883.

Duthie, G. M., H. R. Thornton, J. A. Delaney, D. R. Connolly and F. R. Serpiello (2018). "Running Intensities in Elite Youth Soccer by Age and Position." *Journal of strength and conditioning research*.

Eom, H. J. and R. W. Schutz (1992). "Statistical analyses of volleyball team performance." *Research quarterly for exercise and sport* **63**(1): 11-18.

Farrow, D., W. Young and L. Bruce (2005). "The development of a test of reactive agility for netball." *Journal of Science and Medicine in Sport* **8**(1): 40-48.

Farrow, D., W. Young and L. Bruce (2005). "The development of a test of reactive agility for netball: a new methodology." *J Sci Med Sport* **8**(1): 52-60.

Felson, R. (1981). "Ambiguity and bias in the self-concept." *Social Psychology Quarterly*: 64-69.

Ferreira, M. A. and E. J. Spamer (2010). "Biomechanical, anthropometrical and physical profile of elite university netball players and the relationship to musculoskeletal injuries." *South African Journal for Research in Sport, Physical Education and Recreation* **32**(1): 57-67.

Fessi, M., N. Zarrouk, V. Di Salvo, C. Filetti, A. Barker and W. Moalla (2016). "Effects of tapering on physical match activities in professional soccer players." *Journal of Sport Sciences*: 1-6.

Foster, C., J. A. Florhaug, J. Franklin, L. Gottschall, L. A. Hrovatin, S. Parker, P. Doleshal and C. Dodge (2001). "A new approach to monitoring exercise training." *The Journal of Strength & Conditioning Research* **15**(1): 109-115.

Fowler, P., R. Duffield and J. Vaile (2014). "Effects of domestic air travel on technical and tactical performance and recovery in soccer." *International Journal of Sports Physiology and Performance.* **9**(3): 378-386.

Fox, A., M. Spittle, L. Otago and N. Saunders (2013). "Activity profiles of the Australian female netball team players during international competition: Implications for training practice." *Journal of Sport Sciences*.

Fullagar, H. H., R. Duffield, S. Skorski, D. White, J. Bloomfield, S. Kölling and T. Meyer (2016). "Sleep, travel, and recovery responses of national footballers during and after long-haul international air travel." *International journal of sports physiology and performance* **11**(1): 86-95.

Gabbett, T. (2016). "The training-injury prevention paradox: should athletes be training smarter and harder?" *British Journal of Sports Medicine* **50**(5): 273-280.

Gabbett, T. and S. Ullah (2012). "Relationship between running loads and soft-tissue injury in elite team sport athletes." *The Journal of Strength and Conditioning Research* **26**(4): 953-960.

Gallo, T., S. Cormack, T. Gabbett, M. Williams and C. Lorenzen (2015). "Characteristics impacting on session rating of perceived exertion training load in Australian footballers." *Journal of Sport Sciences* **33**(5): 467-475.

Gallo, T. F., S. J. Cormack, T. J. Gabbett and C. H. Lorenzen (2016). "Pre-training perceived wellness impacts training output in Australian football players." *Journal of sports sciences* **34**(15): 1445-1451.

Gastin, P., B. Fahner, D. Meyer, D. Robinson and J. Cook (2013). "Influence of physical fitness, age, experience, and weekly training loadon match performance in elite australian football." *Journal of Strength and Conditioning Research* **27**(5): 1272-1279.

Gastin, P., D. Meyer and D. Robinson (2013). "Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football." *The Journal of Strength and Conditioning Research* **27**(9): 2518-2526.

Gathercole, R., B. Sporer and T. Stellingwerff (2015). "Countermovement jump performance with increased training loads in elite female rugby athletes." *International Journal of Sports Medicine* **36**(9): 722-728.

Gathercole, R., B. Sporer and T. Stellingwerff (2015). "Countermovement jump performance with increased training loads in elite female rugby athletes." *International journal of sports medicine* **36**(09): 722-728.

Gathercole, R., B. Sporer, T. Stellingwerff and G. Sleivert (2015). "Alternative countermovement jump analysis to quantify acute neuromuscular fatigue." *International Journal of Sports Physiology and Performance.* **10**: 84-92.

Gathercole, R., T. Stellingwerff and B. Sporer (2015). "Effect of acute fatigue and training adaptation on countermovement jump performance in elite snowboard cross athletes." *The Journal of Strength and Conditioning Research* **29**(1): 37-46.

Gearity, B. T. and M. A. Murray (2011). "Athletes' experiences of the psychological effects of poor coaching." *Psychology of sport and exercise* **12**(3): 213-221.

Gustavsson, A., C. Neeter, P. Thomeé, K. G. Silbernagel, J. Augustsson, R. Thomeé and J. Karlsson (2006). "A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction." *Knee Surgery, Sports Traumatology, Arthroscopy* **14**(8): 778-788.

Halson, S. (2014). "Monitoring training load to understand fatigue in athletes." *Sports Medicine* **44**(2): 139-147.

Heasman, J., B. Dawson, J. Berry and G. Stewart (2008). "Development and validation of a player impact ranking system in Australian football." *International Journal of Performance Analysis in Sport* **8**(3): 156-171.

Higham, D. G., W. G. Hopkins, D. B. Pyne and J. M. Anson (2014). "Performance indicators related to points scoring and winning in international rugby sevens." *Journal of sports science & medicine* **13**(2): 358.

Hiscock, D., B. Dawson, J. Heasman and P. Peeling (2012). "Game movements and player performance in the Australian Football League." *International Journal of Performance Analysis in Sport* **12**(3): 531-545.

Hopkins, W., S. Marshal, A. Batterham and J. Hanin (2009). "Progressive statistics for studies in sports medicine and exercise science." *Medicine and Science in Sports and Exercise.* **41**(1): 3-12.

Hopkins, W. G. (2017). "Spreadsheets for Analysis of Validity and Reliability." *Sportscience* **21**.

Hopkins, W. G., J. A. Hawley and L. M. Burke (1999). "Design and analysis of research on sport performance enhancement." *Medicine and science in sports and exercise* **31**(3): 472-485.

Howe, S., R. Aughey, W. Hopkins, A. Stewart and B. Cavanagh (2017). Quantifying important differences in athlete movement during collision-based team sports: Accelerometers outperform Global Positioning Systems. 2017 IEEE International Symposium.

Hughes, A., A. Barnes, S. M. Churchill and J. A. Stone (2017). "Performance indicators that discriminate winning and losing in elite men’s and women’s Rugby Union." *International Journal of Performance Analysis in Sport* **17**(4): 534-544.

Hulin, B., T. Gabbett, P. Blanch, P. Chapman, D. Bailey and J. Orchard (2013). "Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers." *British Journal of Sports Medicine* **48**(8): 708-712.

Hulin, B., T. Gabbett, P. Caputi, D. Lawson and J. Sampson (2016). "Low chronic workload and the acute: chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players." *British Journal of Sports Medicine*.

Hulin, B., T. Gabbett, D. Lawson, P. Caputi and J. Sampson (2016). "The acute: chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players." *British Journal of Sports Medicine* **50**(4): 231-236.

Hunkin, S. L., B. Fahrner and P. B. Gastin (2014). "Creatine kinase and its relationship with match performance in elite Australian Rules football." *Journal of science and medicine in sport* **17**(3): 332-336.

Hunter, J. S. (1986). "The exponentially weighted moving average." *Journal of quality technology* **18**(4): 203-210.

Impellizzeri, F., E. Rampinini, A. Coutts, A. Sassi and S. Marcora (2004). "Use of RPE-based training load in soccer." *Medicine & Science in Sports & Exercise* **36**(6): 1042-1047.

Johnston, R., T. Gabbett and D. Jenkins (2013). "Influence of an intensified competition on fatigue and match performance in junior rugby league players." *Journal of Science and Medicine in Sport* **16**(5): 460-465.

Johnston, R., M. Watsford, M. Pine, R. Spurrs, A. Murphy and E. Pruyn (2012). "Movement demands and match performance in professional Australian football." *International Journal of Sports Medicine* **33**(2): 89-93.

Jones, N. M., N. James and S. D. Mellalieu (2008). "An objective method for depicting team performance in elite professional rugby union." *Journal of Sports Sciences* **26**(7): 691-700.

Jones, P., N. James and S. D. Mellalieu (2004). "Possession as a performance indicator in soccer." *International Journal of Performance Analysis in Sport* **4**(1): 98-102.

Kinchington, M., K. Ball and G. Naughton (2012). "Relation between lower limb comfort and performance in elite footballers." *Physical Therapy in Sport* **13**(1): 27-34.

Krespi, M., G. Sporiš and N. Trajković (2018). "Effects of two different tapering protocols on fitness and physical match performance in elite junior soccer players." *Journal of strength and conditioning research*.

Krustrup, P., M. Mohr, T. Amstrup, T. Rysgaard, J. Johansen, A. Steensberg, P. Pedersen and J. Bangsbo (2003). "The yo-Yo Intermittent Recovery Tests: Physiological Response, Reliability and Validity." *Medicine and Science in Sports and Exercise* **35**(4): 697-705.

Lago-Peñas, C., J. Lago-Ballesteros, A. Dellal and M. Gómez (2010). "Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league." *Journal of Sport Science and Medicine* **9**(2): 288-293.

Lazarus, B. H., A. M. Stewart, K. M. White, A. E. Rowell, A. Esmaeili, W. G. Hopkins and R. J. Aughey (2017). "Proposal of a global training load measure predicting match performance in an elite team sport." *Frontiers in physiology* **8**: 930.

Le Meur, Y., C. Hausswirth and I. Mujika (2012). "Tapering for competition: A review." *Science and Sports* **27**(2): 77-87.

League, A. F. (2017). Laws of Australian football, AFL.

Liow, D. K. and W. G. Hopkins (2003). "Velocity specificity of weight training for kayak sprint performance." *Medicine and science in sports and exercise* **35**(7): 1232-1237.

Lloyd, R. S. and J. L. Oliver (2012). "The youth physical development model: A new approach to long-term athletic development." *Strength and Conditioning Journal* **34**(3): 61-72.

Malina, R. M., C. Bouchard and O. Bar-Or (2004). Growth, maturation, and physical activity, Human kinetics.

Malone, J. J., C. F. Murtagh, R. Morgans, D. J. Burgess, J. P. Morton and B. Drust (2015). "Countermovement jump performance is not affected during an in-season training microcycle in elite youth soccer players." *The Journal of Strength & Conditioning Research* **29**(3): 752-757.

Mcbride, J. M., S. Nimphius and T. M. Erickson (2005). "The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance." *Journal of Strength and Conditioning Research* **19**(4): 893.

McGarry, T. (2009). "Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges." *International Journal of Performance Analysis in Sport* **9**(1): 128-140.

McKeown, I., D. Chapman, K. Taylor and N. Ball (2016). "Time course of improvements in power characteristics in elite development netball players entering a full time training program." *The Journal of Strength and Conditioning Research* **30**(5): 1308-1315.

McLean, B., A. Coutts, V. Kelly, M. McGuigan and S. Cormack (2010). "Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players." *International Journal of Sports Physiology and Performance.* **5**(3): 367-383.

McLellan, C., G. Lovell and G. Gass (2011). "Markers of postmatch fatigue in professional Rugby League players." *The Journal of Strength and Conditioning Research* **25**(4): 1030-1039.

McMillian, D., J. Moore, B. Hatler and D. Taylor (2006). "Dynamic vs static stretching warm up. the effect on power and agility performance." *The Journal of Strength and Conditioning Research* **20**(3): 492-499.

McNamara, D., T. Gabbet, G. Naughton, P. Farhart and P. Chapman (2013). "Traininig and competition workloads and fatigue responses of elite junior cricket players." *International Journal of Sports Physiology and Performance.* **8**(5): 517-526.

Medeiros, A. I., R. Marcelino, I. M. Mesquita and J. M. Palao (2017). "Performance differences between winning and losing under-19, under-21 and senior teams in men’s beach volleyball." *International Journal of Performance Analysis in Sport* **17**(1-2): 96-108.

Memmert, D., K. A. Lemmink and J. Sampaio (2017). "Current approaches to tactical performance analyses in soccer using position data." *Sports Medicine* **47**(1): 1-10.

Mero, A. (1998). "Power and speed training during childhood." *Pediatric anaerobic performance*: 241-267.

Mohr, M., P. Krustrup and J. Bangsbo (2005). "Fatigue in soccer: a brief review." *Journal of sports sciences* **23**(6): 593-599.

Mooney, M., S. Cormack, B. O'Brien, W. Morgan and M. McGuigan (2013). "Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football." *The Journal of Strength and Conditioning Research* **27**(1): 166-173.

Mooney, M., B. O'Brien, S. Cormack, A. Coutts, J. Berry and W. Young (2011). "The relationship between physical capacity and match performance in elite Australian football: a mediation approach." *Journal of Science and Medicine in Sport* **14**(5): 447-452.

Mothersole, G. A., J. B. Cronin and N. K. Harris (2013). "Key prerequisite factors influencing landing forces in netball." *Strength and Conditioning Journal* **35**(2): 47-54.

Mujika, I. (2009). Tapering and Peaking for Optimal Performance. Champaign, IL, Human Kinetics.

Mujika, I. (2010). "Intense training: the key to optimal performance beforeand during the taper." *Scandinavian Journal of Medicine and Science in Sports* **20**(s2): 24-31.

Mujika, I., M. Spencer, J. Santisteban, J. J. Goiriena and D. Bishop (2009). "Age-related differences in repeated-sprint ability in highly trained youth football players." *Journal of sports sciences* **27**(14): 1581-1590.

Neave, N. and S. Wolfson (2003). "Testosterone, territoriality, and the 'home advantage'." *Physiology & behavior* **78**(2): 269-275.

Nicolella, D. P., L. Torres-Ronda, K. J. Saylor and X. Schelling (2018). "Validity and reliability of an accelerometer-based player tracking device." *PloS one* **13**(2): e0191823.

Nikolaidis, P., J. Calleja-González and J. Padulo (2014). "The effect of age on positional differences in anthropometry, body composition, physique and anaerobic power of elite basketball players." *Sport Sciences for Health* **10**(3): 225-233.

Norman, G. (2010). "Likert scales, levels of measurement and the "laws" of statistics." *Advances in health sciences education* **15**(5): 625-632.

Norman, L. and J. French (2013). "Understanding how high performance women athletes experience the coach-athlete relationship." *International Journal of Coaching Science* **7**(1): 3-24.

Oliver, J., N. Armstrong and C. Williams (2008). "Changes in jump performance and muscle activity following soccer-specific exercise." *Journal of sports sciences* **26**(2): 141-148.

Otago, L. (1983). "A game analysis of the activity patterns of netball players." *Sports coach* **7**(1): 24-28.

Patsiaouras, A., A. Moustakidis, K. Charitonidis and D. Kokaridas (2011). "Technical skills leading in winning or losing volleyball matches during Beijing Olympic Games." *Journal of Physical Education and Sport* **11**(2): 149.

Pearce, A. J., D. J. Kidgell, J. Zois and J. S. Carlson (2009). "Effects of secondary warm up following stretching." *European journal of applied physiology* **105**(2): 175-183.

Piggot, B., M. McGuigan and M. Newton (2015). "Relationship between physical capacity and match performance in semiprofessional Australian rules football." *Journal of Strength and Conditioning Research* **29**(2): 478-482.

Plessner, H., C. Unkelbach, D. Memmert, A. Baltes and A. Kolb (2009). "Regulatory fit as a determinant of sport performance: How to succeed in a soccer penalty-shooting." *Psychology of Sport and Exercise* **10**(1): 108-115.

Powell, S. M. and A. V. Rowlands (2004). "Intermonitor variability of the RT3 accelerometer during typical physical activities." *Medicine and Science in Sports and Exercise* **36**(2): 324-330.

Puente, C., J. Abián-Vicén, F. Areces, R. López and J. Del Coso (2017). "Physical and physiological demands of experienced male basketball players during a competitive game." *Journal of strength and conditioning research* **31**(4): 956-962.

Pyne., D., Gardner., A, Sheehan., K & Hopkins., W. (2006). "Positional differences in fitness and anthropometric characteristics in Australian football." *J Sci Med Sport* **9**(1-2): 143-150.

Rampinini, E., F. M. Impellizzeri, C. Castagna, A. J. Coutts and U. Wisløff (2009). "Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level." *Journal of Science and Medicine in Sport* **12**(1): 227-233.

Read, D. B., K. Till, G. Beasley, M. Clarkson, R. Heyworth, J. Lee, J. J. Weakley, P. J. Phibbs, G. A. Roe and J. Darrall-Jones (2018). "Maximum running intensities during English academy rugby union match-play." *Science and Medicine in Football*: 1-7.

Richmond, L., B. Dawson, G. Stewart, S. Cormack, D. Hillman and P. Eastwood (2007). "The effect of interstate travel on the sleep patterns and performance of elite Australian rules footballers." *Journal of Science and Medicine in Sport* **10**(4): 252-258.

Robertson, S. J. and D. G. Joyce (2015). "Informing in-season tactical periodisation in team sport: development of a match difficulty index for Super Rugby." *Journal of sports sciences* **33**(1): 99-107.

Rowe, E. (2011). "An Investigation into the Factors Affecting Drop-out Across Individual and Team Sports, Focusing on Gymnastics and Netball."

Rowell, A. E., R. J. Aughey, W. G. Hopkins, A. Esmaeili, B. H. Lazarus and S. J. Cormack (2018). "Effects of training and competition load on neuromuscular recovery, testosterone, cortisol, and match performance during a season of professional football." *Frontiers in physiology* **9**.

Rowell, A. E., R. J. Aughey, W. G. Hopkins, A. M. Stewart and S. J. Cormack (2017). "Identification of sensitive measures of recovery after external load from football match play." *International journal of sports physiology and performance* **12**(7): 969-976.

Saw, A., L. Main and P. Gastin (2015). "Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review." *British Journal of Sports Medicine* **50**(5): 281-291.

Sawczuk, T., B. Jones, S. Scantlebury and K. Till (2018). "The influence of training load, exposure to match play and sleep duration on daily wellbeing measures in youth athletes." *Journal of sports sciences*: 1-7.

Scott, M. T., T. J. Scott and V. G. Kelly (2016). "The validity and reliability of global positioning systems in team sport: a brief review." *The Journal of Strength & Conditioning Research* **30**(5): 1470-1490.

Seitz, L. B., A. Reyes, T. T. Tran, E. S. de Villarreal and G. G. Haff (2014). "Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis." *Sports medicine* **44**(12): 1693-1702.

Shields, B. J. and G. A. Smith (2009). "The potential for brain injury on selected surfaces used by cheerleaders." *Journal of athletic training* **44**(6): 595-602.

Silvestre, R., C. West, C. M. Maresh and W. J. Kraemer (2006). "Body Composition And Physical Performance In Men's Soccer: Astudy Of A National Collegiate Athletic Association Division Iteam." *The Journal of Strength & Conditioning Research* **20**(1): 177-183.

Spiteri, T., J. L. Cochrane, N. H. Hart, G. G. Haff and S. Nimphius (2013). "Effect of strength on plant foot kinetics and kinematics during a change of direction task." *European journal of sport science* **13**(6): 646-652.

Spiteri, T., R. U. Newton, M. Binetti, N. H. Hart, J. M. Sheppard and S. Nimphius (2015). "Mechanical determinants of faster change of direction and agility performance in female basketball athletes." *J Strength Cond Res*.

Steele, J. and K. Chad (1991). "An analysis of the movement patterns of netball players during match play: implications for designing training programs." *National Sports Research Centre*.

Stewart, P. F., A. N. Turner and S. C. Miller (2014). "Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests." *Scandinavian journal of medicine and science in sports* **24**(3): 500-506.

Suarrez-Arrones, L., L. Portillo, J. Gonzalez-Rave, V. Munoz and F. Sanchez (2012). "Match running performance in Spanish elite male Rugby Union using global positioning system." *Isokinetics and Exercise Science* **20**(2): 77-83.

Suchomel, T. J., S. Nimphius and M. H. Stone (2016). "The Importance of Muscular Strength in Athletic Performance." *Sports Med* **46**(10): 1419-1449.

Sullivan, C., J. Bilsborough, M. Cianciosi, J. Hocking and A. Coutts (2014). "Match score affects activity profile and skill performance in professional Australian Football players." *Journal of Science and Medicine in Sport* **17**(3): 326-331.

Sullivan, C., J. C. Bilsborough, M. Cianciosi, J. Hocking, J. T. Cordy and A. J. Coutts (2014). "Factors affecting match performance in professional Australian football." *International journal of sports physiology and performance* **9**(3): 561-566.

Sweeting, A. J., R. J. Aughey, S. J. Cormack and S. Morgan (2017). "Discovering frequently recurring movement sequences in team-sport athlete spatiotemporal data." *Journal of Sports Sciences*: 1-7.

Tangalos, C., S. J. Robertson, M. Spittle and P. B. Gastin (2015). "Predictors of individual player match performance in junior Australian football." *International journal of sports physiology and performance* **10**(7): 853-859.

Tanner, R. and C. Gore (2012). Physiological Tests for Elite Athletes 2nd Edition, Human Kinetics.

Taylor, K., D. Chapman, J. Cronin, M. J. Newton and N. Gill (2012). "Fatigue monitoring in high performance sport: a survey of current trends." *J Aust Strength Cond* **20**(1): 12-23.

Thomas, A., B. Dawson and C. Goodman (2006). "The yo-yo test: reliability and association with a 20-m shuttle run and VO2max." *International Journal of Sports Physiology and Performance* **1**(2): 137-149.

Thomas, C., P. Comfort, P. A. Jones and T. Dos' Santos (2017). "Strength and Conditioning for Netball: A Needs Analysis and Training Recommendations." *Strength & Conditioning Journal* **39**(4): 10-21.

Thomas, C., K. T. Ismail, R. Simpson, P. Comfort, P. A. Jones and T. Dos'Santos (2017). "Physical profiles of female academy netball players by position." *Journal of Strength and Conditioning research*.

Thorpe, R. T., A. J. Strudwick, M. Buchheit, G. Atkinson, B. Drust and W. Gregson (2015). "Monitoring fatigue during the in-season competitive phase in elite soccer players." *International journal of sports physiology and performance* **10**(8): 958-964.

Twist, C. and J. Highton (2013). "Monitoring fatigue and recovery in rugby league players." *International Journal Of Sports Physiology and Performance* **8**(5): 467-474.

Uchida, M., L. Teixeira, V. Godoi, P. Marchetti, M. Conte, A. Coutts and R. Bacurau (2014). "Does the timing of measurement aletr session-RPE in Boxers?" *Journal of Sports Science and Medicine* **13**(1): 59-65.

Unick, J., H. S. Kieffer, W. Cheesman and A. Feeney (2005). "The acute effects of static and ballistic stretching on vertical jump performance in trained women." *Journal of strength and conditioning research* **19**(1): 206.

van Gogh, M., L. Wallace and A. Coutts (2018). "Positional Demands and Physical Activity Profiles Of Netball." *The Journal of Strength & Conditioning Research*.

Varley, M. C., I. H. Fairweather and R. J. Aughey (2012). "Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion." *J Sports Sci* **30**(2): 121-127.

Vaz, L., M. Van Rooyen and J. Sampaio (2010). "Rugby game-related statistics that discriminate between winning and losing teams in IRB and Super twelve close games." *Journal of sports science & medicine* **9**(1): 51.

Verrall, G. M., Y. Kalairajah, J. Slavotinek and A. Spriggins (2006). "Assessment of player performance following return to sport after hamstring muscle strain injury." *Journal of Science and Medicine in Sport* **9**(1): 87-90.

Watkins, C. M., S. R. Barillas, M. A. Wong, D. C. Archer, I. J. Dobbs, R. G. Lockie, J. W. Coburn, T. T. Tran and L. E. Brown (2017). "Determination of vertical jump as a measure of neuromuscular readiness and fatigue." *The Journal of Strength & Conditioning Research* **31**(12): 3305-3310.

Wehbe, G., T. Gabbett, T. Hartwig and C. Mclellan (2015). "Reliability of a cycle ergometer peak power test in running-based team sport athletes: a technical report." *The Journal of Strength and Conditioning Research* **29**(7): 2050-2055.

Williams, C. A., J. L. Oliver and J. Faulkner (2011). "Seasonal monitoring of sprint and jump performance in a soccer youth academy." *International journal of sports physiology and performance* **6**(2): 264-275.

Wood, A., V. Kelly and T. Gabbett (2013). "Neuromuscular and perceptual fatigue responses to an elite level netball match." *Journal of Australian Strength and Conditioning* **19**: 120-126.

Woolford, S. and M. Angove (1991). "A comparison of training techniques and game intensities for national level netball players." *Sports Coach* **14**(4): 18-21.

Woolford, S. and M. Angove (1992). "Game intensities in elite level netball: position specific trends." *Sports Coach* **15**: 28.

Wright, P. M., D. L. Smart and G. C. McMahan (1995). "Matches between human resources and strategy among NCAA basketball teams." *Academy of Management journal* **38**(4): 1052-1074.

Yeadon, M., T. Kato and D. Kerwin (1999). "Measuring running speed using photocells." *Journal of Sports Sciences* **17**(3): 249-257.

Young, C., P. Gastin, N. Sanders, L. Mackey and D. Dwyer (2016). "Player load in elite netball: Match, training and positional comparisons." *International Journal of Sports Physiology and Performance.*

Young, W. B. (2006). "Transfer of strength and power training to sports performance." *International journal of sports physiology and performance* **1**(2): 74-83.