Monitoring the Countermovement Jump Throughout a Netball Season: Potential Implications for Performance

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Abstract

Netball is a sport which demands high intensity locomotion across the court. As a result, athletes must be physically resilient. While there has been a lot of research on fatigue monitoring and perceived risk of injury, few studies have investigated fatigue in netball and how it influences performance capacity. The aim of this study was to investigate the relationship between acute chronic workload (ACWL) ratios and the capacity to perform. Eight provincial representative athletes (age = 20 ± 3 years, body mass = 76.2 ± 9.9 kg, height = 179 ± 7cm) volunteered to complete countermovement jump (CMJ) testing twice a week throughout the season, while also monitoring their physical exertion using session rating of perceived exertion (RPE). All data was analysed using R-Studio software. Pearson correlation coefficients, ANCOVA and paired sample t-tests were calculated. The results indicated that relative mean power output significantly increased across the season (p<0.001), with the relationship remaining significant when adjusted to remain within the ACWL ratio of 0.8-1.3. Mean velocity did not appear to have any significant changes throughout the season. However, when adjusted to only include velocity data within 0.8-1.3 ACWL ratio, the relationship became significant indicating a clear relationship (p<0.001). A case study directly investigating the difference between a well-trained and youth athlete revealed that there was a significant difference in mean velocity and relative mean power output (p<0.001). The case study also showed a strong correlation between relative mean power and mean velocity (p<0.001) both inside and outside the identified 0.8-1.3 ACWL zone. A relationship between each individual's perceived capacity for performance based on quantifiable fatigue was identified. Practitioner's should look to implement affordable, and efficient monitoring if it helps to inform future strength and conditioning delivery ultimately improving performances.

Table of Contents

List of Figures

List of Tables

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed _____

Date___14/03/2018___

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Chapter 1. Introduction

Thesis Organisation

This thesis consists of six chapters. Chapter One provides background context as to why this research was conducted. Chapter Two is a review of the current literature available specific to the research question being investigated in the thesis. It reviews the demands of netball as a sport and how fatigue influences athletes capacity for performance. It then breaks down internal and external athlete monitoring methods. The use of ACWL ratios and rating of perceived exertion (RPE) are also investigated. The CMJ is also discussed while also identifying and how the information gathered from this research study could help to understand performance. Chapter Three outlines the methodological process, formulated from the themes developed throughout the completion of the literature review. Chapter Four presents the results from statistical analyses completed at the conclusion of the data collection. Chapter Five discusses the results presented, while providing context with previous literature as to the practical outcomes of these results. The influence of some variables on others is discussed at length, while always referring back to possible performance implications. The sixth and final chapter will outline a general conclusion, research limitations and practical applications. An appendix containing relevant material including the consent form, participant information sheet and ethical approval as well as the reference list for this entire thesis can be found at the end of the final chapter.

Thesis Rationale

Netball is a sport where performance can be quickly influenced by the activity profile of the sport and a lack of preparation (Davidson & Trewartha, 2008). Put simply,

if you cannot sprint faster than your opposition you will not get the ball before them in a one on one contest. While this concept can be easy to understand, as strength and conditioning coaches we need to be able to disseminate an athletes progress throughout the season to ensure we are impacting performance positively. Having the ability to identify why, for example, they cannot sprint faster than their opposition during competition despite having quicker testing times during pre-season is critical. To be effective, coaches must have to ability to identify where they can make performance improvements with their athletes. Without the knowledge of where athletes are constrained in their performance, a well-tailored programme cannot be delivered (Davidson & Trewartha, 2008; Thomas, Comfort, Jones, & Dos'Santos, 2017).

The recent emphasis put on athlete monitoring has highlighted some gaps in previous strength and conditioning delivery, especially within a netball context. Practitioners and sports scientists now have a wide array of monitoring tools available to them (Harris, Cronin, Taylor, Boris, & Sheppard, 2010). The introduction of technology such as linear position transducer's (LPT's) into strength and conditioning delivery has allowed for exceptional growth in the complexity of athlete monitoring. Strength and power are considered critical to many athletic tasks, so to improve the capacity of these qualities they must be quantified, hence the use of LPT's (Harris et al., 2010). For example, the GymAware™ tool has made monitoring more time and cost effective (O'Donnell, Tavares, McMaster, Chambers, & Driller, 2018). Due to its practicality and ease of use, it can be used throughout the gym with little restriction, providing a significant amount of data on the strength and power qualities of athletes. This data can help to quantify the difference between good and bad performances, not only in training, but also during competition (Stares, Dawson, Heasman, & Rogalski, 2015).

While the increased implementation of monitoring has improved practitioners understanding of the physical responses, it has also increased debate about the amount of monitoring going on within the industry. Some are critical that there is too much monitoring happening within sports creating a greater awareness of 'weaknesses' resulting in suboptimal performances (Maxwell, Masters, & Poolton, 2006). Others have been critical in the past that monitoring distracting from the development of key skills, an opinion which needs to be considered when implementing a monitoring with any athlete. Monitoring should be encouraged if it will be valuable to the strength and conditioning coach, coaching staff and the athletes performance. As Saw, Main, & Gastin (2015, p. 137) stated, "monitoring athletic preparation facilitates the evaluation and adjustment of practices to optimise performance". Performance must always be the first consideration for strength and conditioning coaches when implementing anything into their delivery.

The acute chronic workload (ACWL) ratio monitoring compares the acute training load (e.g. previous seven days) with the chronic workload (e.g. previous 21 days) of an athlete (Blanch & Gabbett, 2016). This measure identifies athletes perceived risk of injury, and is a concept commonly understood within the sporting industry due to its frequency of use. For example, a ACWL ratio of 0.5 would suggest than an athlete has trained half as much in the past week, as to what they had prepared for in the previous three (Blanch & Gabbett, 2016). Spikes in training or playing load are observed when an athletes ACWL ratio exceeds 1.5, potentially highlighting an increased injury risk (Blanch & Gabbett, 2016).

The reliability and validity of internal monitoring in comparison to external monitoring has been another hotly contested topic (Foster et al., 2001; Stamford, 1976),

and a point of discussion which will be further developed throughout. This thesis was designed with the intention of providing a deeper understanding of the relatability of testing data to real life scenarios. Fatigue reduces the capacity for performance (Taylor, Cronin, Gill, Chapman, & Sheppard, 2010), and as netball competitions at the provincial representative level run across months, the demand to turn up on game day physically prepared to perform is critical. While peak on-court performance will not be quantified in this thesis, the possible influence of training demands on performance, both positive and negative, will be critically evaluated throughout. Clearly fatigue is understood in a general context, but a weakness of strength and conditioning coaches in the past has been monitoring this correctly, and as a result, making adjustments based on the findings and pervious literature. Therefore, the purpose of this research was to:

1. Establish a greater understanding of how internal and external monitoring can identify potential for performance in netball.

2. Establish a greater understanding of how ACWL monitoring can identify potential for netball performance

3. Identify relationships between workload monitoring and internal/external markers and how these correlate with each other in netball athletes.

It was hypothesised;

1. GymAware™ variables mean power output ($W \cdot kg^{-1}$) and mean velocity ($m \cdot s^{-1}$) would improve across the season for all athletes.

2. The ACWL ratio of 0.8-1.3 would correlate with countermovement jump (CMJ) data enabling a key performance zone to be identified for both reduced injury risk and improved performance.

Little published evidence exists on the influence of a competitive netball season on the accumulative fatigue of an athlete or team and as a result their ability to produce power across 11 weeks of competitive games. The aim of this study was to investigate the effect of an entire netball season on a domestic representative team by monitoring the CMJ twice a week. The training requirements of this team could almost be comparable to professional netballers, however these athletes also have to juggle commitments often unseen by professional athletes.

Significance of Thesis

The art of delivering a well-tailored strength and conditioning programme to a team of athletes presents challenges to practitioners. This thesis looked to develop an understanding of the relationship between external and internal athletic monitoring methods and how capacity for performance can be informed from this data. The more understanding practitioners can have on the interactive effects of different internal and external monitoring methods, the higher the level of delivery to athletes, particularly within netball. Every athlete has a different background, a different way of learning, and a different level of resilience to stressors. So, while it is easy to deliver what is assumed to be 'correct' based on previous literature, the effect of this must also be understood. If the effects of training are not monitored how will coaches or athletes know if it has been successful?

This thesis may help guide strength and conditioning coaches to a different style of delivery, it may encourage them to implement some degree of monitoring in their programme. It may also provoke thought and consideration which is also a successful outcome given the lack of research on monitoring the longitudinal effects of training on

netballers. Providing athletes and coaching staff with the best possible support is a key role for strength and conditioning coaches, and any opportunity to improve this should be taken.

Chapter 2. Literature Review

Netball is a team sport which is keenly followed by the New Zealand public. It is played on a 30.50 x 12.25m court divided into even thirds (Thomas, Comfort, Jones, & Dos'Santos, 2017). Games consist of four 15 minute quarters, separated by eight minutes at half time and three minutes' in-between quarter breaks. Each team has seven players on court who all play a different position. These positions include goal shoot (GS), goal attack (GA), wing attack (WA), centre (C), wing defence (WD), goal defence (GD), and goal keep (GK) (All Australia Netball Association, 1983). Only one of these positions is allowed access to all three sections of the court (C), with four players being restricted to two thirds and two players restricted to just one third of the court. There are always three to five athletes on the bench ready to play at any stage.

As these positions on the court have differing physiological requirements, the response to play and training volumes differ from player to player (Chandler, Pinder, Curran, & Gabbett, 2014). The requirements within a team not only differ due to their positional requirements, but strength and conditioning coaches must also take into consideration player limitations. These include training age, injury status, fatigue status and adapt to these as necessary, particularly at the semi-professional level. The ability to modify based on these limitations at an individual level can impact the outcome of team performances.

Concurrent training is generally undertaken by most netballers throughout their pre-season and in-season training. A time motion analysis conducted by Fox, Spittle, Otago, & Saunders (2013), identified that netball demands high frequencies of short work periods suggesting players require highly conditioned anaerobic energy systems. Meanwhile, the production of aerobic energy is highly demanding due to the time spent

active during a game (Fox et al., 2013). While it is critically important to understand these aspects, the physical outputs of netball can be better understood by breaking down the specific skills for analysis.

Fox et al., (2013) found the frequency of activities performed differ widely with the varying positions across the court. Large physical outputs are placed on a netballer, indicating that all positions on the court have both aerobic and anaerobic contributions (Davidson & Trewartha, 2008). However, the intensity and frequency of these demands differ between position as identified by Fox et al., (2013). For example, a WD is required to jump 51 (SD = ± 4.4) times, sprint 59.3 (± 11) times, and pass 66 (± 4) times during a match, while a GA is required to jump 54.7 (± 19.5) times, sprint 58 (± 19) times and pass 72.3 (± 26.4) times in a match (Fox et al., 2013). It is critical that the large array of physiological demands are understood with clarity, therefore ensuring the athletes needs are catered for when delivering a strength and conditioning plan. While it is easy to identify the anaerobic demands, their contribution, and its general overarching relationship with the aerobic energy system, this must be well understood for each individual too. Chandler, Pinder, Curran, & Gabbett (2014) showed similar results in their time motion analysis of eight collegiate level netballers in Australia. They concluded that athletes playing at C had the highest player load per minute in comparison to all other positions in the vertical, horizontal and lateral planes monitored. Jumps, passes, sprinting, shuffling, rebounding all require different elements of anaerobic fitness such as strength, power and balance (Thomas, Comfort, Jones, & Dos'Santos, 2017). However, a high degree of aerobic fitness enables these anaerobic skills to be completed to the highest level possible throughout the entire duration of a match (Chandler et al., 2014; Thomas, Comfort, Jones, & Dos'Santos, 2017). This indicates that it is vital both

the anaerobic and aerobic needs of a netballer are considered, as both play an important role in performance. It is also critical to understand the physiological mechanisms behind how fatigue affects an individual's ability to perform the skills demanded by the sport, as highlighted by Fox et al., (2013).

Fatigue

Stretch shortening cycle (SSC) fatigue is related to a number of metabolic, and neural factors which are important to understand when monitoring athletes (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015). Recovery is biphasic in nature with an immediate decrease in neuromuscular function which is regained within one to two hours of activity cessation (Gathercole et al., 2015). A secondary decrease around two days post exercise, is recovered within four to eight days, highlighting the use of athlete monitoring tools such as training load, monotony and ACWL ratio's (Blanch & Gabbett, 2016; Gathercole et al., 2015; Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016). Monitoring tools are critically important in athlete well-being and performance, and are discussed in detail later.

Neuromuscular fatigue must be understood before appreciating the mechanisms through which CMJ defines SSC capacity and neuromuscular fatigue. While fatigue can be difficult to quantify, it can be defined as "a loss of force-generating capability or an inability to sustain further exercise at the required level" (Strojnik et al., 1998, p. 344). Neuromuscular fatigue of the SSC exhibits in a manner which is much more complex than that observed in maximal voluntary contractions, such as a one repetition maximum squat (Sánchez-Medina & González-Badillo, 2011). It is apparent that neural control depends on reflexively induced activation (Strojnik et al., 1998), this

reflex can be significantly dampened when fatigued. Strojnik et al., (1998) noted that sub-maximal SSC fatigue results in reduced muscle activation in the eccentric phase. Reducing the monosynaptic response to the sudden stretch of the soleus during the eccentric phase, causes a reduction in maximal shortening velocity when fatigued (Cairns, Knicker, Thompson, & Sjøgaard, 2005). Concentric shortening and peak force also decrease with muscle soreness, affecting cross-bridge cycling (Cairns et al., 2005). Exercise induced fatigue results in prolonged contraction and halved relaxation times, as a result of a decline in the amplitude of the calcium (Ca^{2+}) directly inhibiting cross bridge cycling (Fitts, 2007). More intense exercise induces high rates of adenosine triphosphate (ATP) hydrolysis and glycolysis, both resulting in reduced force output and contraction velocity (Fitts, 2007). The movements produced in netball, are largely based around eccentric absorption and loading resulting in rapid concentric shortening (Thomas, Comfort, Jones, & Dos'Santos, 2017). Support staff working together to ensure a team is consistently performing to their peak would not implement a training programme which reduces an athletes neuromuscular firing and contraction efficiency.

The CMJ is a practical monitoring test providing insight into numerous components of neuromuscular function (Gathercole et al., 2015). Tools such as LPT's are portable, practical, and commonly used to assess neuromuscular function in athletes (O'Donnell et al., 2018). The software that LPT's use can provide an enormous amount of data with relative ease. This data can range from peak power and relative peak power, to mean power, mean velocity, dip displacement, and concentric displacement such as jump height. A LPT commonly used by New Zealand strength and conditioning coaches, is the GymAware™.

While athletic profiles, and muscular assessments can be obtained with an LPT, other tests to determine force and velocity capacity, or the effects of training interventions such as, force plate data, isometric testing and max strength tests are still incredibly important (Abernethy, Wilson, & Logan, 1995). Data obtained from these other modes of testing help to provide the context for variables which are being monitored, hence why it is crucial not to conduct one test in isolation unless it can be well justified. For example, if athlete A is 'weaker' than athlete B, it would be no surprise that their CMJ data was different. However, if their strength levels were similar but there was a large disparity in their CMJ testing profiles then that could be investigated. Understanding the interactive effects between strength and velocity is critical to developing a physical profile (Abernethy et al., 1995).

It is important to remember, that when identifying and utilising tests to measure fatigue, they must have functional relevance to the physiologically identified performance variables specific to the athlete and their sport (Cairns et al., 2005). That way, variables directly influencing performance within a sport can be truly understood. As netball athletes jump up to 53.7±6.7 times in a 60 minute game (Fox et al., 2013), the CMJ is a useful test in identifying fatigue and readiness to perform in netball. The intricacies of this test will be discussed below.

Training load

Monitoring training load has become a key part of modern strength and conditioning delivery. Training load is a useful tool for monitoring how much internal and external load the athletes can tolerate (Coutts, Lee, & Slattery, 2004). When session

RPE is collected, training load can be quantified with the following equation (Coutts et al., 2004):

$$\text{Training load} = \text{session RPE} \times \text{session duration (minutes)}$$

This equation allows for a better understanding of individuals and their tolerance to training (Coutts et al., 2004), a factor vitally important within netball due to the varying positional requirements. Active monitoring of training load throughout a pre-season and in-season phase can be critical to the success of a team. Monitoring provides a scientific explanation for performances (Halson, 2014) and an ability to auto regulate load with more certainty. Data gives a management team the ability to act or react both before or after trends in data arise, which can be an exceptionally powerful tool. Cumulative fatigue has been found to compromise high intensity running and maximal accelerations which, based on the needs of a netballer (Fox et al., 2013), will influence capacity for performance no matter their position on the court (Johnston et al., 2012).

Session RPE has been demonstrated as a valid measure of both aerobic and anaerobic exercise if correct procedures are followed (McGuigan & Foster, 2006). Session RPE can be used across a variety of different resistance-training modes, such as strength, muscular endurance and power, as Day et al., (2004) found this to be reliable and valid method. While session RPE can be useful for monitoring training load, it too is a great tool in prescribing work intensities (Day et al., 2004; McGuigan & Foster, 2006). While a great deal of research is conducted around training sessions, RPE monitoring can be included into competition to allow for a holistic understanding of athletes progress through a training week, phase or competitive season (Halson, 2014).

While monitoring training loads of all training modalities is critical, resistance training is particularly important within a team sport such as netball (Sweet, Foster, McGuigan, & Brice, 2004). Having the ability to predict and observe the neuromuscular and hormonal adaptive responses induced by training quantitatively is important (Bosco, Viru, Von Duvillard, Bonomi, & Colli, 2000). Coaches and support staff regularly have discussions about 'intensity' and how this will be regulated throughout a microcycle, mesocycle or macrocycle. Tracking training load allows for a clear understanding of the intensity felt by the athlete, rather than that prescribed. (Bosco et al., 2000) This perceptual analysis allows for a more accurate insight of the potentially harmful adaptive responses to resistance training giving support staff the time in advance to make adjustments to the planned training loads.

Internal Athlete Monitoring

As athletes and support staff strive to improve performance, modifications in training load, volume and intensity are required (Halson, 2014). Ensuring that fatigue and recovery is applied appropriately can be critical to both ensuring training adaptations occur, and the athletes remain physically capable of performing in competition (Halson, 2014). Overreaching is a common problem in team sport for two reasons. Firstly, the relationship between training load and performance encourages athletes and coaches to keep pushing in the quest for small improvements (Foster, 1998). Secondly, the response by coaches to performances which are below 'expectations' is to increase the effort in subsequent training sessions to compensate (Foster, 1998). While these methods may work for a few, without monitoring, the true extent of the effect on performance may never be known. When fatigue is a result of

overreaching, and consistent performance is compromised the most inappropriate response is to increase training load (Foster, 1998). As a result, it is clear that practitioner's need to know how their prescribed trainings are influencing their athletes physically, and one common way to achieve this is through asking for RPE.

Rating of Perceived Exertion

The RPE scale developed by Borg has seen widespread use in research studies since its inception in 1962 (Borg, 1990). The original scale consists of numbers from 6 to 20, with descriptive phrases appearing with each odd number ranging from "very very light" at number seven to "very very hard" with number 20 (Stamford, 1976). While being ground breaking at the time, the psychophysical problem of relating a physical stimulus to perceived magnitude of exertion with so many numbers to choose from put a high level of uncertainty on the methods or monitoring available to researchers (Borg & Kaijser, 2006). While the original 6-20 scale was validated against heart rate and oxygen uptake, increased awareness on perceived exertion in relation to lactate, ventilation and muscle pain response led to the category ratio (CR-10) scale being developed (Borg & Kaijser, 2006).

The CR-10 RPE scale has more recently become the common method for evaluating athletes perception of exertion due to its validity when marked against objective markers, as well as its simplicity (Zamunér et al., 2011). The CR-10 scale is shown in Figure 1.

Score	Intensity	
0	Nothing at all	
0.5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4		
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost max)

Figure 1: Borg CR-10 scale adapted from (Borg, 1990) including the category scale (C) with ratio (R) properties

The Borg CR-10 scale was designed with the aim of improving subjective uncertainty (Borg, 1990), and providing a clearer link between perceived intensity for lactate responses (Winter, Jones, Davison, Bromley, & Mercer, 2007). The Borg CR-10 scale is an extremely useful tool for coaches, as they can tell an athlete explicitly how hard they want them to train. This tool, as identified below ensures further calculations referencing training load across a large duration is possible (Alexiou & Coutts, 2008). The athlete can better understand what that prescribed session will feel like, replicating the prescribed intensity with accuracy and subjective confidence in the future (Winter et al., 2007; Zamunér et al., 2011)

Session RPE has been correlated with an individual's average heart rate reserve, and to the percentage of training session time during which the heart rate is in blood lactate training zones (Foster, 1998). This is important from a conditioning perspective,

because coaches can be confident that the data they are receiving from the athletes perspective is an accurate measure of the outcome of their programming. Ensuring athletes are able to understand what they physically experience is essential in strength and conditioning, particularly when athletes are unsupervised, a common modality of training in provincial representative netball due to financial and time limitations.

Another important finding to consider from the Chandler et al., (2014) investigation of collegiate netballers is that mean heart rate while training was lower than match play, while peak heart rate and RPE in training was similar to match play. An athlete may reach the same level of intensity during training as in a game, but this may be for a significantly shorter amount of time while still rating the experience the same. Foster (1998) observed that a session lasting up to 120 minutes is often not indicative of the true workload being undertaken by the athlete as RPE may have been high for 20 minutes, and low for the remaining 100. What athletes commonly remember is the 20 minutes in blood lactate training zones, forgetting most of their time was spent being inactive (McGuigan & Foster, 2006). This is evidence of how anaerobic experiences leave powerful memories with us, influencing our judgement on exertion (Winter et al., 2007). These findings are important to consider when reflecting upon player's perception of exertion in comparison to the real work done, a point which will be reflected on throughout this thesis. Educating the athlete to view the training session globally is key to ensuring the reliability of session RPE for both conditioning and resistance training (Borg & Kaijser, 2006; McGuigan & Foster, 2006)

Using one fatigue scale for all modes of training and competition can provide problems in producing data with clear meaning. As mentioned above, the CR-10 scale has been found to be a useful tool in quantifying exercise intensity in aerobic and

anaerobic exercise, however there has often been some scepticism with how this crosses over to resistance training (Day et al., 2004; Sweet et al., 2004). As resistance training has been found to improve athletic performance (Myer, Ford, Palumbo, & Hewett, 2005), it is critical that its internal effects, such as RPE, are understood along with its external effects. With this in mind, we must be sure that RPE data collected post-resistance training is accurate and a clear reflection on the actual intensity of the session. Particularly if this data is then going to be utilised to calculate variables such as stress, strain and monotony (Foster, 1998). Day et al., (2004) undertook an investigation with 19 participants to observe if there was a relationship between resistance exercise intensity and RPE scores obtained. They found that performing 15 repetitions of a lighter resistance was perceived to be 'less difficult' than performing ten and five repetitions of heavier loads (Day et al., 2004). The average RPE for each trial was compared with its corresponding RPE value for the entire session, and analysis of this data did find that there was no statistical difference between the values (Day et al., 2004). This can give strength and conditioning coaches great confidence that if they prescribe a 'lighter weights session', the athletes will in fact perceive it that way.

As mentioned earlier, RPE can be a useful coaching tool for prescribing intensities. However, strength and conditioning coaches would be naive to assume that RPE is a perfect science as noted by Foster (1998). While interpreting RPE data is critically important as a strength and conditioning coach, it is what we do with it next which may have the biggest influence on an athletes performance. RPE can be utilised in many formulas to develop a clearer understanding of the fatigue and stress put on the athletes, as identified below.

Acute Chronic Workload Ratio

Monitoring RPE and training duration is simple, and with this data measures such as the ACWL ratio can be calculated (Hulin, Gabbett, Lawson, et al., 2016). Acute workload refers to the workload performed within a short period of time such as 7 days, while chronic workload typically identifies a rolling 21 day or 28 day workload (Hulin, Gabbett, Caputi, Lawson, & Sampson, 2016). The ACWL ratio provides an indication of whether the athletes current workload is greater, less than or equal to the workload that the athlete has prepared for in the previous chronic workload phase (Hulin, Gabbett, Lawson, et al., 2016). As data constantly rolls over to match the current situation, this is an extremely useful tool for strength and conditioning coaches and support staff to observe. This type of monitoring can be used to guide future training prescription, while ensuring athlete welfare is the number one consideration.

Research has suggested that the higher the ACWL ratio, the greater the risk of injury to the athlete, hence the need for constant and consistent monitoring (Hulin, Gabbett, Caputi, et al., 2016). An ACWL ratio of 0.5 indicates that an athlete has completed half as much of the workload in the past week as what they had trained and prepared for in the past 4 weeks, suggesting that a ratio of 2.0 indicates and athlete performed twice as much of the workload than prepared for (Blanch & Gabbett, 2016; Hulin, Gabbett, Caputi, et al., 2016; Hulin, Gabbett, Lawson, et al., 2016). Gabbett (2016) identified a 'sweet spot' for athletic performance and low injury risk, which indicates that strength and conditioning coaches and support staff should look to work within an ACWL of approximately 0.8-1.3. Remaining within this zone ensures that the athlete is at their lowest risk of injury (Blanch & Gabbett, 2016). Gabbett (2016) also highlighted

a danger zone when the ACWL exceeds 1.5, suggesting this increases the risk of injury by two to four times in the subsequent seven-day period.

Fatigue can be expressed as the athletes acute workload, whereas chronic workload defines an athletes fitness (Hulin, Gabbett, Caputi, et al., 2016; Hulin, Gabbett, Lawson, et al., 2016). Therefore, we can assume that a moderate acute workload combined with a high chronic workload is associated with a smaller injury risk than a situation involving low chronic workload (Blanch & Gabbett, 2016; Hulin, Gabbett, Caputi, et al., 2016). Low chronic workloads can be attributed to undertraining, but also injury, illness, significant sponsor commitments or suspension. A holistic approach must be undertaken when interpreting data collected, and making decisions on an athletes future training commitments (Blanch & Gabbett, 2016). The chronic workload theoretically lays the platform for acute workload, highlighting the importance of periodising training plans to ensure the athletes are capable of performing what is asked of them. For example, asking a netballer to complete a half marathon at the start of pre-season after a sedentary off-season would cause problems for that athlete in the future.

Hulin, Gabbett, Lawson, et al., (2016) stated that previous studies have failed to find any association between heavily congested periods of play and higher injury incidence. They indicate that higher workloads can occur because of longer between-match recovery times, and as a result, abrupt increases in workloads (Hulin, Gabbett, Caputi, et al., 2016; Hulin, Gabbett, Lawson, et al., 2016). In an important finding, Hulin, Gabbett, Lawson, et al., (2016) indicated that higher acute values are associated with winning in elite team sport, however when the ACWL ratio was pushed above 1 the probability of losing increased. This finding suggests that there is a fine balance between too much, or too little, and as a result, winning and losing. While it can be difficult to

predict how an athlete is going to react to each stimulus, the ACWL ratio is an extremely useful tool in ensuring support staff make the best informed decision they can in the lead up to key performances.

External Athlete Monitoring

External load refers to measures detached from the internal responses of athletes, including variables such as training duration, jump velocity, distance travelled, running speed and the number of accelerations (Scanlan, Wen, Tucker, & Dalbo, 2014). This has traditionally been the foundation of most monitoring systems in the past (Halson, 2014). Externally derived measures provide a training stimulus, and cause and a magnitude for both adaptation and internal responses. The technologies available to athletes and coaches largely determine the level of external monitoring to be completed (Halson, 2014). Technology therefore is both a limiter and enabler of external data collection within sport. For example, measures of neuromuscular function can be obtained from a standardised drop jump performance with a LPT to calculate mean power. However, for this to be calculated, there must be access to this resource. From there, progress can be measured and monitored by utilising, what can be considered for most easily accessible technology (Halson, 2014)

Scanlan et al., (2014) observed a relationship between internal and external monitoring, but noted that practitioners should not assume a linear dose-response with both sources of data. Ultimately, internal and external variables inform and possibly dictate the resultant training response and dose, but results must be understood on their own, and then in conjunction with each other to form a response (Scanlan et al., 2014).

Countermovement jump

The CMJ has been found to be one of the most reliable measures of lower limb explosive power, fatigue, and supercompensation in team sport athletes (Claudino et al., 2017; Gathercole et al., 2015). The CMJ has a high degree of practicality within the elite sporting contexts due to its low physiological strain as well as its capacity to be replicated across multiple athletes over a small amount of time (Gathercole et al., 2015). The ability to generate high velocity is a key determinant of performance, particularly in netball (Fox et al., 2013; Giroux, Rabita, Chollet, & Guilhem, 2014). During a CMJ the velocity obtained at take-off is determined by the force the athletes exert against the ground, and the time in which this is applied, often referred to as mechanical impulse (Giroux et al., 2014). Athletes must be able to exert forces appropriate to the tactical moment on court, and due to the demands of netball these are often maximal efforts (Chandler et al., 2014; Christopher Thomas et al., 2017). As discussed earlier, it is believed that fatigue limits the ability of an individual to exert force against the ground. Testing with CMJ helps to continually develop an understanding of the basic properties and function of the neuromuscular system, and the abilities of athletes to complete the competitive demands of netball (Giroux et al., 2014).

Investigations into neuromuscular training adaptations and fatigue related changes highlight that traditional CMJ analysis typically overlooks the eccentric component. However with this being fundamental to the SSC it must be considered when observing athletes fatigue patterns (Gathercole et al., 2015). The SSC fatigue is bi-phasic with neuromuscular function recovered within one to two days, followed by a secondary decrease around two days which is recovered within four to eight days

(Gathercole et al., 2015). Gathercole et al., (2015) determined the suitability of the CMJ test for the assessment of fatigue, and while they found it to be a suitable test, they found the need to observe alternative variables such as eccentric duration, mean concentric power and total jump duration.

As mentioned earlier, CMJ can provide a large array of values for testing when utilizing the tools such as GymAware™ and the associated software. An important question to consider is the use of the highest value for each variable versus the use of average values. Some research has suggested that a practitioner has a higher probability of finding the true score when utilizing average values, rather than the highest value (Claudino et al., 2017). Claudino et al., (2017) showed that average CMJ height was more sensitive than peak CMJ height in monitoring the effects of fatigue on performance. Claudino et al., (2017) also observed variables such as peak power, mean power, peak velocity and peak force were all appropriate variables to measure supercompensation. When CMJ variables recorded on GymAware™ are averaged across all trials their sensitivity in detecting change is enhanced, particularly with large sample sizes (Claudino et al., 2017). This was important to consider when completing the data analysis process of this thesis.

The force velocity relationship indicates that the capacity to produce muscular force decreases as velocity increases, resulting in an optimal balance between both variables corresponding to the production of maximal power output (Giroux et al., 2014). This means that there is an optimal speed to produce force, therefore an optimal speed to move across the court in a netball game. Taylor & Taylor, (2014) found mean power output peaked at body weight during CMJ testing in their analysis of 32 Australian state level hockey, basketball and netball athletes. They also found that when external

load was increased, participants CMJ outputs such as peak velocity, jump height and mean power all gradually declined (Taylor & Taylor, 2014). This implies that rate of force development is compromised with increased loads, a clear indicator that an athletes training status largely influences their ability to overcome external forces (Taylor & Taylor, 2014). When Taylor & Taylor, (2014) looked at data on an individual level, they noted that power outputs increased between body weight and 10% bodyweight CMJ trials for one participant. This highlights the importance of designing and implementing individualised training programmes throughout a season to ensure every athlete has the ability to improve. The same concept must apply for monitoring as well. Fatigue at an individual level must be observed, as observing the team as its entirety could lead to missing important individual changes (Taylor & Taylor, 2014).

Strength and conditioning coaches can train the physiological properties involved in force production to make them 'quicker' or slower' based on the athletes needs. As netball is a multi-dimensional sport requiring a combination of different joint rotations and movements it is considered a quasi-linear sport (Thomas, Comfort, Jones, & Dos'Santos, 2017). Generally, increasing maximal power output improves athletic performance, as is the case in netball (Chandler et al., 2014; Davidson & Trewartha, 2008; Thomas, Comfort, Jones, & Dos'Santos, 2017). Improvements in well-trained athletes can be observed as 'subtle', hence the inclusion of variables sensitive to change (Giroux et al., 2014). Observing small changes in performance is vitally important to monitoring, ensuring that physiological changes in athletes are not missed and performance is not compromised.

Markovic, Izdar, & Ukic, (2004) showed that CMJ testing had high reliability with a coefficient of variation (CV) of 2.8%, the second lowest level of variability behind the

single leg long jump. Meanwhile, Gathercole et al., (2015) identified that CMJ variables exhibited CV's of <5%, also identifying that the CMJ test can produce highly consistent inter and intraday results. The CMJ was found to have the greatest estimation of explosive leg power (Markovic et al., 2004), and therefore is an appropriate determinant of performance within a team sport like netball while also being a useful tool for analysing fatigue (Gathercole et al., 2015).

The reproducibility, practicality and simple nature of the CMJ enables the detection of very small changes in performance. The test can be completed anywhere, at any time with a GymAware™ tool, confirming its practicality in elite and professional sport. Gathercole et al., (2015) highlighted the importance in considering not only the reduction in CMJ variables as a key indicator of neuromuscular fatigue, but also altered movement strategies. Well trained athletes have the neuromuscular intelligence to adjust their movement strategy to improve the outcome, a factor which must be considered when analysing data (Gathercole et al., 2015; Yarrow, Brown, & Krakauer, 2009).

Linear Position Transducers

The LPT has become increasingly popular over the years due to its ease of use, and ability to provide accurate and reliable assessments of variables fundamental to sports training and rehabilitation, such as power, velocity and speed (Crewther et al., 2011). One example of an LPT is the GymAware™ tool which is made up of four key parts: "the measuring cable, spool, spring and a rotational sensor such as a potentiometer or encoder" (Harris et al., 2010, p. 67). As the transducers cable extends, the spool and sensor rotates creating an electrical signal proportional to the cables linear velocity or

extension (Harris et al., 2010). A second rotational sensor encodes this data which is then processed through the GymAware™ Kinetic software, providing key information on the variables selected for assessment (Crewther et al., 2011; Harris et al., 2010).

The GymAware™ power tool has a signal driven sampling scheme, where position points are time stamped when a change in position is detected, it then down samples this to a maximum of 50 points per second (Taylor & Taylor, 2014). The ability of the GymAware™ software to down sample, and adjust based on displacement-time data highlights why this is one of the most sophisticated, yet simple tools on the market (Harris et al., 2010; Taylor & Taylor, 2014). A key consideration with regards to GymAware™ is that the only raw data you can obtain from this tool is velocity. The remaining data such as mean power and peak power is calculated from algorithms based on the velocity and various other variables such as load and lift type which is entered into the software prior to testing. Crewther et al., (2011) demonstrated that the GymAware™ has strong validity, and is a useful tool when testing athletes power. It is important to understand the validity of the variables being measured when researching, not just the system itself. Claudino et al., (2017) identified that 35% of fatigue variables have a CV greater than 30%. Average CMJ height was found to be sensitive to changes in fatigue with a large effect size (ES) indicating a strong correlation between average jump height and fatigue [ES = -0.56 (95% CI = -0.89-0.24)] (Claudino et al., 2017). The GymAware™ system records displacement-time data using a signal driven sampling scheme (Taylor & Taylor, 2014).

O'Donnell, Tavares, McMaster, Chambers, & Driller, (2018) found Pearson correlation coefficients for jump height across trials to be 'almost perfect' when using the GymAware™ with netball players (r=0.90). They also found intraclass correlation

coefficient (ICC) values of 0.70 for jump height, 0.90 for peak velocity and 0.91 for mean velocity, indicating that peak velocity and mean velocity have a strong degree of reliability (O'Donnell et al., 2018). This is reinforced by the mean CV values for jump height (6.2%), peak velocity (4.7%), and mean velocity (6.7%). The data observed in this study suggests that elite female athletes produce reliable test-retest measures, and the GymAware™ device is suitable to ensure data correlation and low typical error (O'Donnell et al., 2018).

Summary

The literature review showed that there is limited research on netball, particularly regarding the ideal physical preparation for peak performance. While there is equipment and software readily available to collect and analyse monitoring data, there is a gap in putting together this data to understand its true influence. Establishing a clear connection between internal and external monitoring will help to develop a clearer understanding of an athletes readiness for performance. As a result, strength and conditioning delivery quality can be improved, ultimately improving the athletes physical welfare, and on-court performances.

Chapter 3. Methods

Experimental approach to the problem

This observational study investigated the physiological effects of a competitive netball season on regional level athletes, while also monitoring their readiness to perform based on session RPE. Internal and external monitoring was completed throughout the season to investigate physical performances within representative netball. There was no intervention applied to the athletes, only data for the purpose of athlete monitoring was collected.

Subjects

Eight amateur netball athletes (mean ± SD: body mass = 76.2 ± 9.9 kg, age = 20 ± 3 years, height = 179 ± 7 cm) volunteered to participate in this study. The athletes were part of the South Zone Beko Netball League team. The team competed in the Beko Netball League which is designed to improve the performance pathway for athletes in New Zealand. All participants had been free of injury for at least 3 months prior to agreed participation. The procedures for this study were approved by the Auckland University of Technology Ethics Committee (Approval number 17/53) and adhered to throughout its entirety. The subjects provided informed consent when made fully aware of the risks and benefits of participation in the study as identified in the participant information sheet (Appendix 2). Subjects had to show they met the research inclusion criteria after informed consent was obtained. Athletes were required to have at least 12 months' previous resistance training experience, be aged between 16-35 years, and have been injury-free the three months prior to pre-season, as mentioned above.

Participants remained injury free throughout the entire testing period and no athlete spent any longer than 7 days away from regular training.

At the beginning of the study participants were identified as well-trained, or youth. Well-trained encompassed athletes (N=4) who have had at least three years' strength and conditioning experience. Youth athletes (N=4) were those who have had at least a year's strength and conditioning experience, but no more than two.

Case study

Two athletes were identified to be appropriate to investigate as individuals in a case study when all of the data was collected. These two athletes completed the CMJ testing the most consistently, and the most frequently, providing a large set of data representative of the true effects of the season on each individual. One was well-trained and one was a youth athlete, enabling both training groups to be represented. It is important to clarify that the findings observed within the case study seen in Chapter four and five are not a representation for all participants, rather an opportunity to review and analyse data using a case study approach.

Methodology

All participants completed a familiarisation period of four weeks throughout the pre-season schedule. During this time, athletes completed the same testing protocol that was conducted throughout the season under the same conditions. Athletes completed their jump testing and RPE monitoring with no reports of discomfort so the protocol, as seen in Figure 2, remained the same throughout the competitive season.

Figure 2: A visual demonstration of the countermovement jump testing protocol. GymAware™ position is shown attached to the waist belt.

Countermovement Jump

The GymAware™ powertool (Kinetic Performance Technology, Australia), sampling at 50Hz, was used to obtain CMJ data. The athletes were required to complete their warm-up involving movement preparation and activation designed specifically for their resistance training session prior to testing. The GymAware™ tool was placed on a 10kg metal plate to attach the magnets, ensuring the tool did not move while the participants were jumping. The tether from the GymAware™ tool was attached to a clasp on a waist belt, this clasp was always placed directly on top of the belly button of the participants, ensuring the setup was standardised for each individual throughout the season. The GymAware™ tool was placed directly underneath the athlete between their feet (Figure 2). Once the belt was securely fastened the participants were instructed to place their hands on their waist, and to keep them there throughout the completion of their maximal effort jumps. The participants were then instructed to "jump as high as they could", resetting at the bottom of each jump. This process was repeated three

times and then again after two minutes' rest. Measures obtained from GymAware™

kinetic software included mean power output (Watts), mean power output relative to

body weight (W·kg^{-1}), and mean concentric velocity (metres/second). The six data points

for each jump, and each variable was then averaged to increase its reliability in the

statistical analysis (Claudino et al., 2017). The GymAware™ tool has previously been

shown to have a CV ranging from 5.6-8.9% for the CMJ (Legg, Pyne, Semple, & Ball,

2017).

Session Rating of Perceived Exertion

Participants were familiarised with the modified Borg CR-10 scale (Figure 1)

during their first CMJ testing session (Zamunér et al., 2011). The session RPE data was

obtained from every participant, after every conditioning session, every resistance

training session, every skill based training and every game. The athlete's session RPE was

obtained immediately after the training or game using the question "how hard was your

session/match?". Uchida et al., (2014) determined in their analysis of eight boxers that

RPE can be collected as soon as 10 minutes after the session with no loss of

measurement quality. The CV for the Borg CR-10 scale has been shown to be 31.9%

(Scott, Black, Quinn, & Coutts, 2013) and ICC 0.766 (Coutts et al., 2004).

Training Load analysis

All sessions in which RPE was obtained had to be also defined by their duration

(minutes) to calculate ACWL ratios. The duration of every conditioning session,

resistance training session, skill based training and match minutes for each athlete were

recorded to establish a clear season profile. Training load was calculated from the following equation (Coutts et al., 2004):

Total training load = session RPE x duration (minutes)

A daily rolling ACWL ratio was calculated from the training load scores. Total load for each day was calculated with the equation above, and from this the chronic rolling 21-day average was calculated. The previous 21 days were accounted for following the equation below identified by Gabbett, (2016):

Chronic workload = $\dfrac{\text{(sum of previous 21 days training load)}}{3}$

The acute 7-day total was also calculated from the training load data collected for each athlete. The equation utilised from Gabbett, (2016) was:

Acute workload = sum of previous 7 days training load

Finally, the ACWL ratio was obtained from these two data points each day throughout the season utilising the formula below (Hulin et al., 2014; Hulin, Gabbett, Lawson, et al., 2016):

Acute: chronic workload ratio = $\dfrac{\text{acute workload}}{\text{chronic workload}}$

In addition to the workload data identified, weekly monotony and strain variables were calculated from the following equations (McGuigan and Foster, 2006):

Monotony = Average weekly load/SD of weekly training load

Strain = Weekly workload * Weekly monotony

Netball performance testing

The Yo-Yo intermittent recovery level 1 test (Yo-Yo IR1), broad jump and vertical jump were completed to establish a physical profile for each athlete at the start and towards the end of the season. These tests help to establish an athletes readiness to perform, informing selection. The first performance testing day was conducted immediately after selection into the South Zone Beko netball team. The second testing day was completed five weeks before the season concluded at the same time of day.

Yo-Yo Test

The Yo-Yo IR1 is a conditioning test completed on a field or court marked out as shown in Figure 3 (Bangsbo et al., 2008). Athletes were required to complete 1 x 20 metre shuttle run (to the end and back) inside the specified time identified by the track playing over audio speakers. The Yo-Yo IR1 test started at a low speed and increased in speed at a moderate rate as the levels progressed. This test assessed the athletes ability to perform repeated bouts of intense exercise (Bangsbo et al., 2008). When the athlete completed their 20 metre shuttle run they were required to walk to the end of the 5 metre recovery zone and be stationary before the next beep. The recovery time between every single effort was 10 seconds in duration. The CV for the Yo-Yo IR1 is 1.9%

and ICC is 0.95 in team sport athletes, indicating this test is reliable (Thomas, Dawson, & Goodman, 2006).

Figure 3: A visual representation of the physical set up for the Yo-Yo intermittent recovery level 1 test (Bangsbo et al., 2008).

Broad jump testing:

Athletes were required to jump as far as possible horizontally. Athletes started with their toes just behind the tape measure and were instructed to jump out as far as possible, and stick the landing. Once the athlete landed safely, a measurement was taken from the back of the heel closest to the start of the measure tape. The measure obtained was the athletes final score. The athletes were given three trials and the maximum score was used for analysis. The CV scores for the broad jump are 2.4% with ICC scores of 0.95 in team sport athletes (Markovic et al., 2004).

Vertical Jump testing:

A Swift Yardstick tool was utilised for this testing protocol allowing for a measurement to the nearest centimetre to be obtained. Once set up the apparatus was placed so the athletes could reach up, while keeping their feet and shoulders flat to knock off markers with this initial distance being recorded. From here, athletes were instructed to jump as high as possible, knocking off as many markers as possible. The difference between the final score, and the original height marker score is identified as

the athletes final vertical jump score. The athletes were given three trials and the maximum score was used for analysis. Vertical jump testing in a similar population has a CV of 6.7% and a ICC of 0.97 (Meylan et al., 2009).

Season periodisation

The training plan for the entire netball season can be observed in Figure 4. This figure identifies the different training focuses throughout the entire netball season, when competition games were, and when the focus changed from pre-season to in-season. Competition games were played on a Saturday or a Sunday, with the locations of these games also changing throughout the season. The training progressed throughout the season to become more specific to netball performance in the hope of making the competition final, an outcome which unfortunately did not eventuate.

	Feb	March				April				May					June	
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Competition					x	x	x		x	x	x	x	x	x		x
Phase	Pre-season				In-season											
Focus	**Resilience/General prep 1** Max strength and Aerobic capacity				**Performance prep 1** Contrast phase and aerobic power				**Performance prep 2** Rate of force development and aerobic maintenance/anaerobic capacity				**Peak performance 1** Strength maintenance, power production, aerobic maintenance unloaded			
Key focus	Squat Bench press Hip thruster Sled drag (heavy) Chins				Hip thrust + jump DB press + MB press Split squat + lunge jump Squat jump contrast				Power clean complexes Band resisted exercises DB snatches KB swing				Day 1 strength/RFD focus Day 2 power + 2 key strength lifts			

Figure 4: Season long periodisation applied across the entire squad, with games, phases and specific training focuses identified.

Statistical analysis

Statistical analyses were performed by the statistical software package, *R-Studio* (The R foundation for statistical computing, Version 2.12.2, Auckland, New Zealand). Means and standard deviations (means ± SD) were expressed throughout as measures of centrality and spread of data. Linear mixed-effect models were used to perform ANCOVA, with mean power, mean velocity, and relative mean power (and related parameters) as dependent variables, training groups as factors, individual trial number as random effects variables, and CMJ as a covariate.

ANCOVA evaluated whether means of the dependent variables were equal across levels of a categorical independent variable, while controlling for covariates. Dependent on the parametricity of data (Ahmetov et al., 2011) and knowing that ANCOVA is robust to one violation of parametricity, Pearson correlation coefficient was used to assess the relationships between selected variables. The magnitudes of the ES calculated (positive or negative) were interpreted using Hopkins scale (0.1-0.2 trivial; 0.2-0.6 small; 0.6-1.2 moderate; 1.2-2.0 large, 2.0-4.0 very large) (Hopkins, 2002). In the presence of statistical significance, post-hoc Tukey analyses were carried out using paired sampled t-tests. A critical alpha level of $p<0.05$ defined all tests of significance.

Chapter 4. Results

Data for all participants

Descriptive statistics of measures are detailed in Table 1. The results have been divided up to include four subjects in the 'Well trained' (WT) category and four subjects in the 'Youth' (Y) category. 'Well trained' includes athletes who had a minimum of three years' strength and conditioning experience while the 'youth' athletes had one to two years' strength and conditioning experience and were all under the age of 20. Mean scores for mean velocity throughout the season and when ACWL fell inside 0.8-13 were significantly different when comparing well-trained to youth (p=0.003). Weekly training load was higher with youth (1802 ± 669), but training strain (2371 ± 2103) was higher with the well trained group indicating a difference in training intensity between the two groups. Standard deviations in youth for power, velocity, monotony, and strain data are all smaller than those identified in the well trained group indicating a smaller spread of data throughout the season. Table two illustrates the difference between data throughout the season, in comparison to data when adjusted for ACWL. Athletes mean power ($W \cdot kg^{-1}$) increased throughout the season (p≤0.05) irrespective of ACWL scores, however no significant changes were observed when within the 0.8-1.3 ACWL ratio zone.

Table 1

Descriptive statistics (mean±SD) of countermovement jump data and monitors gathered throughout the season for well-trained (n=4) and youth (n=4). Effect size identified based on the Hopkins classification with asterisks (*, ** or ***) indicating a small, moderate and large magnitude of effect respectively

	Well trained	Youth	Effect size
Mean velocity (m·s^{-1})	1.775 ± 0.207	1.661 ± 0.180	0.61**
Mean power adjusted (W·kg^{-1})	31.94 ± 8.52	30.10 ± 7.50	0.24*
Mean power (Watts)	2432 ± 604	2178 ± 411	0.51*
Weekly training load	1799 ± 526	1802 ± 669	-0.00
Monotony	1.50 ± 1.83	1.23 ± 1.36	0.16
Strain	2371 ± 2103	2105 ± 1646	0.14

Table 2

The relationships between training age, and training throughout the year with countermovement jump variables. Asterisks (*, ** or ***) beside data indicates a significant difference (p<0.05, p<0.01, p<0.001) respectively.

	Entire season		Inside ACWL 0.8-1.3	
	Mean power (W·kg^{-1})	Mean velocity (m·s^{-1})	Mean power (W·kg^{-1})	Mean velocity (m·s^{-1})
Athlete group (WT v Y)	-1.791	-.011***	-1.521	-0.141***
Days from first test	0.059*	-0.431	0.073	0.134

Linear mixed-effect models were utilised to determine the differences when splitting the data based on its correlation with the athletes ACWL ratio at the time of testing each week (Table 3). All three conditions identified below were significantly correlated with mean power when adjusted for body weight. There was no significant difference between the well trained and youth athletes when adjusting for ACWL zones. The relationship between an ACWL ratio of 0.8-1.3 and mean velocity was found to be a strong (p=0.052), but not statistically significant. Figure 5 identifies the ACWL ratio pattern across pre-season and in-season for both groups. Guidelines on Figure 5 indicate the suggested ACWL ratio zone of 0.8 – 1.3. Both groups had visibly different ACWL ratio responses to the seasons training. Pre-season and in-season testing data highlight the physical abilities of the two groups at different times (Table 4). Analysis of ES indicates that there was a very large (ES = 1.24) difference between the two groups at pre-season and in-season testing based on Hopkins, (2002) scale.

Table 3

Descriptive statistics (mean±SD) of key performance parameters for three conditions; across the season, when acute chronic workload ratios were within 0.8-1.3 and when the acute chronic workload ratio fell outside 0.8-1.3 for all participants. Asterisks (, ** or ***) beside data indicates a significant difference (p<0.5, p<0.01, p<0.001) respectively.*

	Entire season	Within ACWL 0.8-1.3	Outside ACWL 0.8-1.3
Mean power (W·kg^{-1})	31.01 ± 7.65***	30.54 ± 7.65**	31.90 ± 7.63**
Mean velocity (m·s^{-1})	1.71 ± 0.18	1.70 ± 0.19***	1.72 ± 0.19
Strain	2119 ± 1870	2271 ± 2204	1860 ± 1070**
Training load	1800 ± 598	1698 ± 603	1915 ± 486
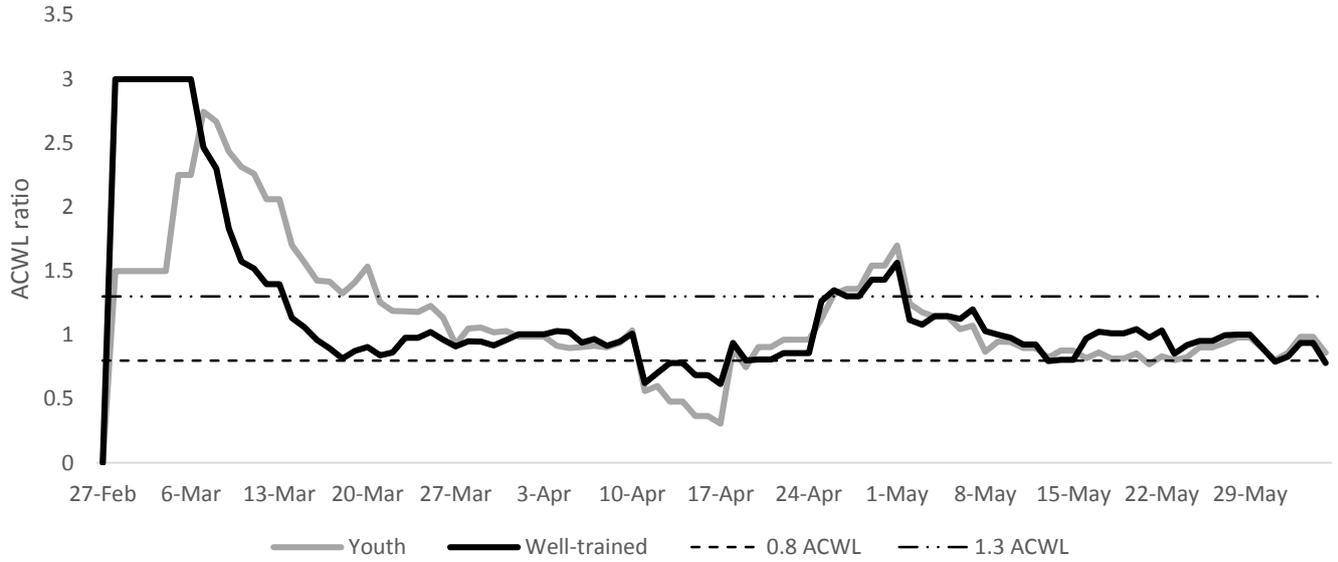
Figure 5: Acute chronic workload data collected throughout the season for both well trained and youth participant groups. Acute chronic workload recommended zones are also identified.
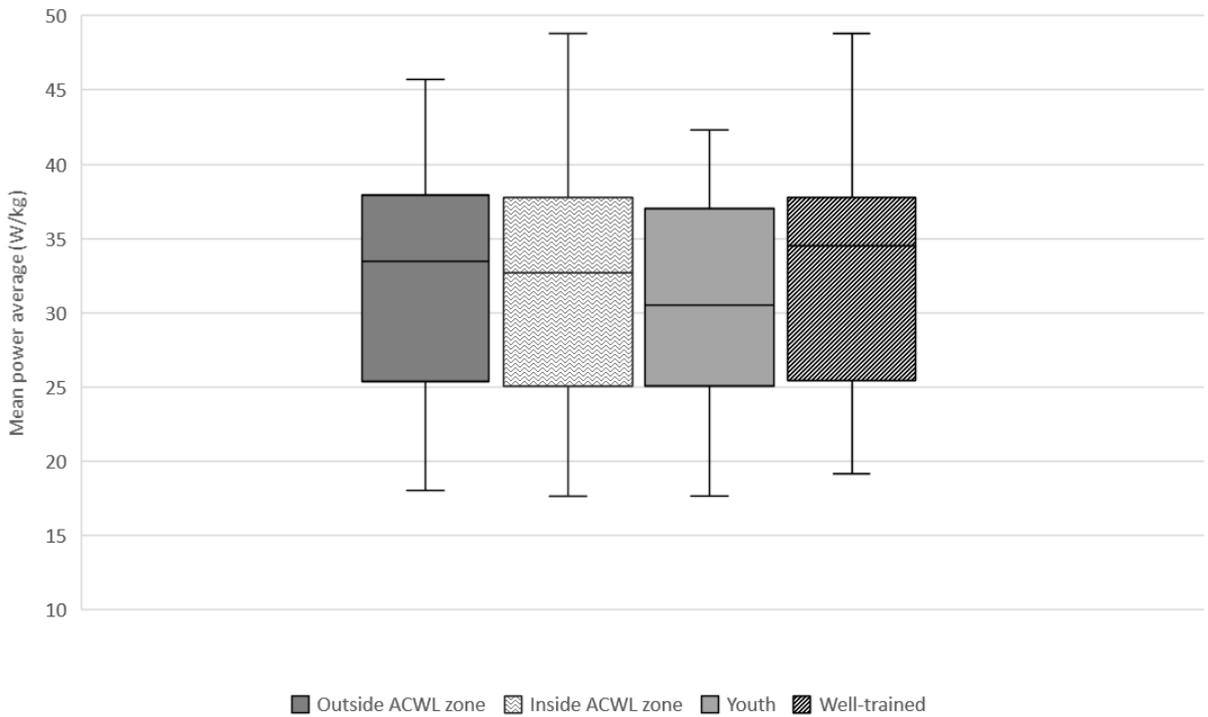
Figure 6: Relative mean power throughout the season when meeting specific criteria. Criteria includes relative peak power data when ACWL is outside 0.8-1.3; and when ACWL inside 0.8-1.3; also for the youth group, and well-trained group.

Table 4

Pre-season and final test results in-season for all participants with mean ± SD for the team and player groups. Percentage change from pre-season identified within brackets for end of season data. Training status for each individual has been identified in brackets. WT= Well trained, Y = youth. Effect size identified based on the Hopkins classification with asterisks (*, **, ***) indicating a small, moderate, and large magnitude of effect respectively

	Pre-season			5 weeks before season end		
	Yoyo (Level)	Broad jump (cm)	Vertical jump (cm)	Yoyo (Level)	Broad jump (cm)	Vertical jump (cm)
Athlete 1 (WT)	18.1	222	56	18.2 (5.6%)	225 (0.5%)	58 (1.8%)
Athlete 2 (WT)	17.2	236	61	16.5 (-6%)	231 (-0.4%)	59 (-1.6%)
Athlete 3 (WT)	16.3	210	49	17.1 (6.4%)	217 (0.5%)	52 (2.2%)
Athlete 4 (WT)	Absent	175	37	15.6 (0%)	178 (0.6%)	39 (2.8%)
Well-trained average	17.2 ± 0.9	211 ± 27	51 ± 10	17.0 ± 1	213 ± 24	50 ± 8
Athlete 5 (Y)	16.6	221	58	16.8 (6.1%)	218 (-0.4%)	57 (-1.7%)
Athlete 6 (Y)	15.6	227	51	Absent	229 (0.4%)	55 (2.1%)
Athlete 7 (Y)	16.1	217	53	16.2 (6.2%)	230 (0.5%)	59 (2.1%)
Athlete 8 (Y)	16.7	222	56	16.3 (-6.0%)	214 (-0.4%)	54 (-1.7%)
Youth average	16.2 ± 0.5	222 ± 4	54 ± 3	16.4 ± 0.7	223 ± 8	56 ± 2
Team average	16.7 ± 0.8	216 ± 18	53 ± 7	16.7 ± 0.8 (6.0%)	218 ± 17 (0.5%)	54 ± 7 (1.9%)
Effect size WT v Y	1.31***	0.05	0.12	1.24***	0.05	0.14

Case study data

As identified earlier, the case study encompasses data from one youth athlete, and one well-trained athlete. Means and standard deviations for both the youth and well-trained athlete are shown in Table 5. The only significant relationship identified was between the youth athletes when inside the ACWL ratio zone and mean power data.

Table 5

Descriptive statistics (mean±SD) for case study participants within specific acute chronic workload parameters and the significance of those relationships. Asterisks (*, ** or ***) beside data indicates a significant difference (p<0.05, p<0.01, p<0.001) respectively.

	Youth athlete		Well-trained athlete	
	Inside 0.8-1.3 ACWL	Outside 0.8-1.3 ACWL	Inside 0.8-1.3 ACWL	Outside 0.8-1.3 ACWL
Mean power ($W \cdot kg^{-1}$)	23.28 ± 3.40*	23.30 ± 3.27	29.42 ± 6.88	33.08 ± 3.87
Mean velocity ($m \cdot s^{-1}$)	1.48 ± 0.08	1.50 ± 0.08	1.77 ± 0.08	1.78 ± 0.08
Strain	1998 ± 1202	2130 ± 1275	2385 ± 1188	2018 ± 1417
Training load	1839± 804	1921 ± 600	1853 ± 491	1886 ± 75

As seen in Table 5, there was a significant difference between the youth and well-trained athletes during testing of their relative mean power output ($W \cdot kg^{-1}$), and mean velocity. These trends can be observed in Figures 7 and 8. The figures show the large disparity in capacity for performance between a youth athlete and a well-trained athlete. The well trained athlete was able to achieve significantly higher scores in CMJ testing. Figure 9 identifies the ACWL ratio pattern across pre-season and in-season for both case-study participants with both athletes have visibly different ACWL ratio responses to the seasons training.
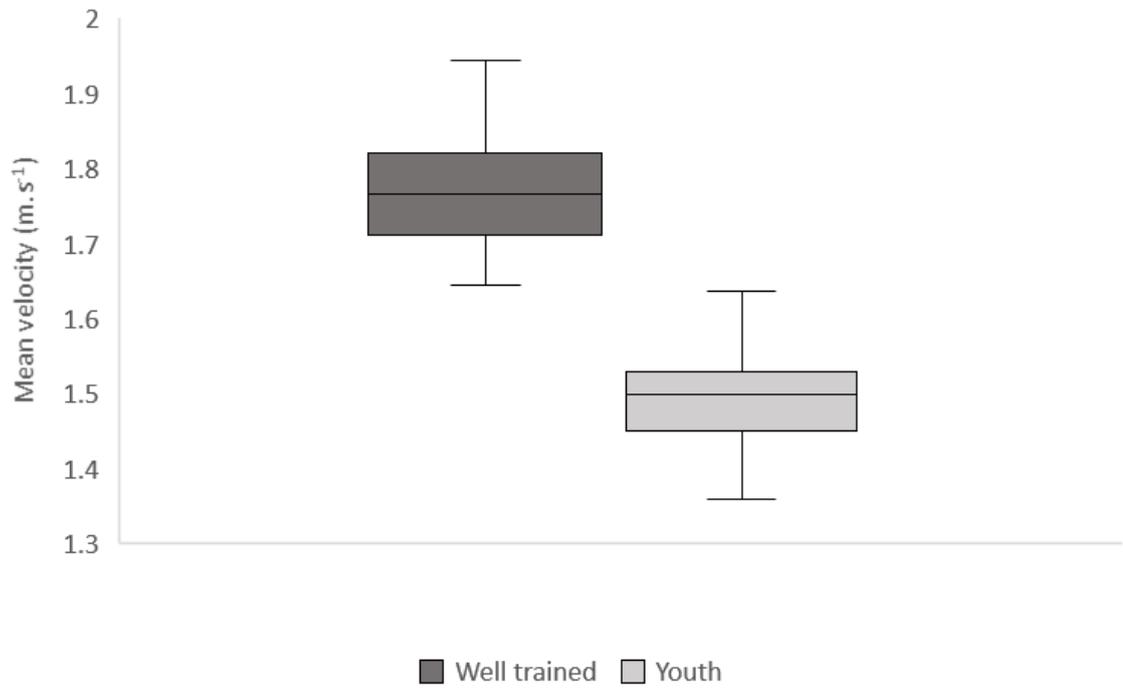
Figure 7: A case study box-plot highlighting the difference in mean velocity (m·s⁻¹) obtained in countermovement jump testing for a well-trained athlete and a youth athlete
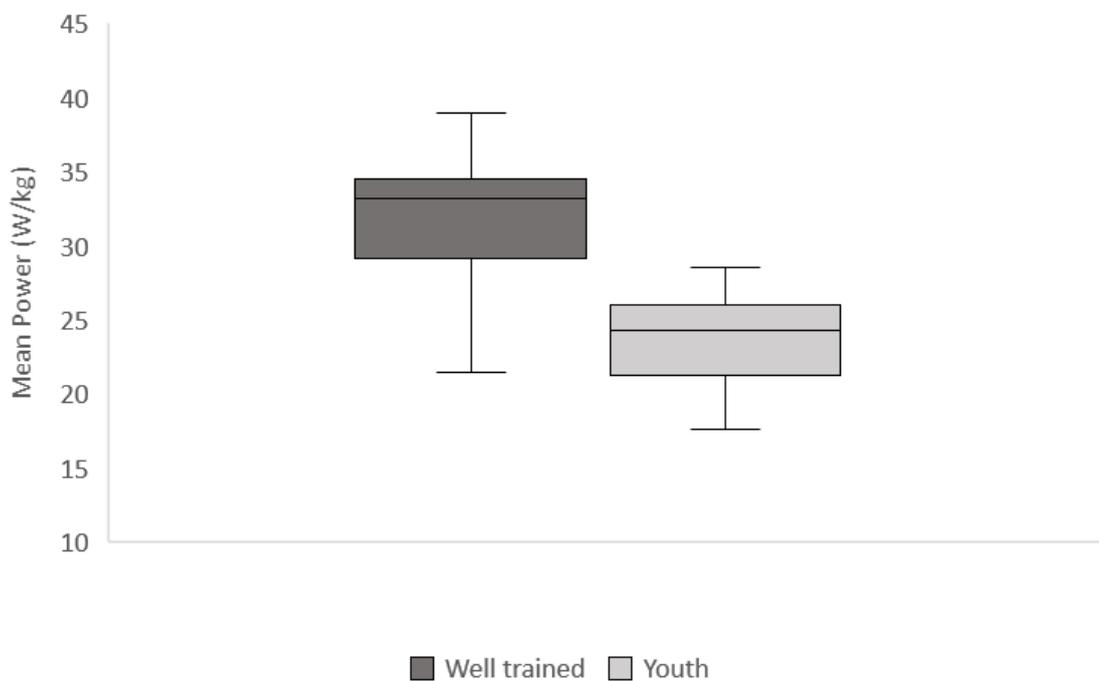
Figure 8: Case study box-plot highlighting the difference in relative mean power (W·kg⁻¹) produced in countermovement jump testing for a well-trained athlete and a youth athlete

Table 6

T-test results for corresponding variables to identify a significant difference between the well-trained and youth athlete in case study. Asterisks (*, ** or ***) beside data indicates a significant difference (p<0.05, p<0.01, p<0.001) respectively.

|	Well trained			
	Mean power (W·kg^{-1})	Mean velocity (m·s^{-1})	Strain	Weekly training load
Inside 0.8-1.3 ACWL Youth				
Mean power (W·kg^{-1})	0.002***			
Mean velocity (m·s^{-1})		3.348e-11 ***		
Strain			0.54	
Weekly training load				0.96
Outside 0.8-1.3 ACWL Youth				
Mean power (W·kg^{-1})	0.00***			
Mean velocity (m·s^{-1})		0.0004***		
Strain			0.54	
Weekly training load				0.89
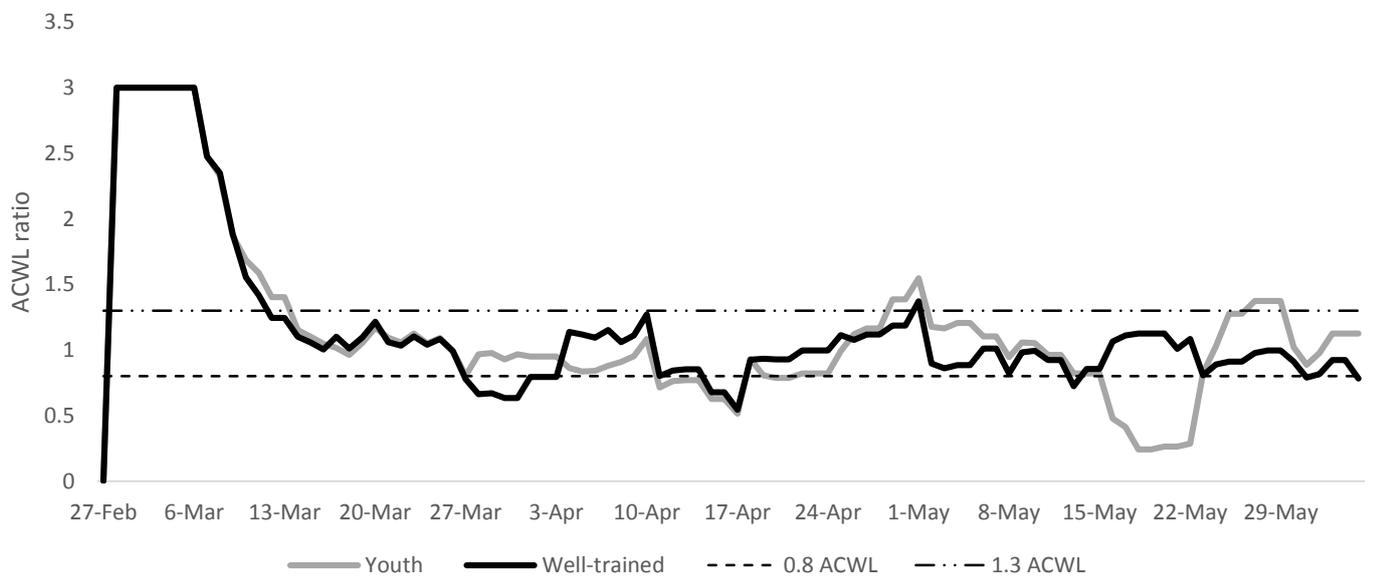
Figure 9: Acute chronic workload data collected throughout the season for both well trained and youth athletes. Acute chronic workload recommended zones also identified.

Chapter 5. Discussion

This thesis examined the influence of a season of competitive netball on athletes with differing levels of training experience. The results indicated that relative mean power output significantly increased throughout the season (p<0.001), with the relationship continuing to remain significant when adjusted to fit within the ACWL ratio of 0.8-1.3. Mean velocity did not significantly improve as the season progressed. However, mean velocity did have a significant relationship (p<0.001) with the ACWL ratio of 0.8-1.3, as did relative mean power (p<0.002). Comparison of the mean velocity between youth and well-trained athletes resulted in a large difference. Despite a large difference between the two groups being observed in mean power outputs, when the data was adjusted for individuals (W·kg^{-1}) the difference no significant result was found. There was a significant correlation between strain and the ACWL ratios outside of the 0.8-1.3 zone which suggests that there is a direct relationship with fatigue, and/or low training levels and mechanical strain.

The case study investigating the differences between one well-trained and one youth athlete revealed that there was a significant difference between the two in mean velocity and relative mean power output in CMJ testing (p<0.001). The case study also showed a strong correlation between relative mean power and mean velocity (p<0.001) when data fell both inside and outside the identified 0.8-1.3 ACWL zone. Data analyses showed that weekly training loads did not have a significant influence on the well trained or youth athletes. However, when CMJ data was analysed across the season relative to ACWL and individual RPE, stronger correlations were observed. This confirmed the hypothesis that were highlighted earlier. These were:

1. GymAware™ variables mean power output and mean velocity significantly improved throughout the season for all athletes

2. The ACWL ratio zone of 0.8-1.3 correlated with CMJ data, establishing a relationship between peak performance and the perceived injury risk within an athlete.

The findings of this study allow for a contextual and in-depth discussion on the trends observed though the season for all athletes. When the data was split to allow for a case study analysis between youth and well trained, the trends and outcomes become more applicable to the real life scenarios seen in team sports. A case study approach assists with understanding how important training age is when planning a season for athletes with varying backgrounds; a concept familiar to most provincial representative teams.

This chapter will interpret and summarise key themes identified from this research process, discuss the appropriateness of specific aspects of the methodology, consider the limitations of this research, and propose ideas for practical application.

Performance and countermovement jump variables

Locomotion, particularly across a netball court, is an energetically expensive behaviour (Wakeling, Blake, & Chan, 2010). Maximal power output from muscles occurs "while they are maximally active and shorten at their 'optimal speed', that is approximately 25-36% of their maximum intrinsic speed" (Wakeling et al., 2010, p. 487). If a muscles optimal shortening speed is compromised, then the effectiveness of the athlete will be compromised. Vigorous activity, or fatigue, can result in the metabolic

rate reaching 20 times resting levels, and as a result, increase the metabolic cost of peak power performances (Wakeling et al., 2010). This is due to limbs requiring greater effort for the same power outputs, meaning that all movements are extremely inefficient (Wakeling et al., 2010). However, training during pre-season and in-season phases is completed with the aim of ensuring athletes move as efficiently as possible during competition, therefore, some degree of fatigue is expected during this time.

While netball is a sport which has shown it does not demand maximal muscular power output for every movement (Fox et al., 2013), these aspects are certainly a requirement of the game if a team wants to be successful. The CMJ data collected may provide some insight into how efficiently the athletes move and their physical readiness to perform. The small variability in standard deviation values with regards to youth athletes (Table 1), indicates that while they may not have been able to emulate outputs achieved by well-trained athletes, they have established a means of completing movements successfully. They are able to do this, with little variation in movement strategies. The evidence of minimal movement leaning being required by the youth athletes emphasises their athletic potential, and their physical aptitude.

Untrained athletes often take time to create muscle synergies when learning a new motor task (Frère & Hug, 2012). The time taken to learn these movements tends to be longer for more complex movements (Frère & Hug, 2012). The testing data shown (see Table 4) indicates that all youth athletes improved in testing, with the exception of one YoYo test. Physical progression, and muscular synergies were achieved throughout the season when the athletes were in competition, indicating that the training prescribed did improve the athletes capacity for performance. Interestingly, the variability observed during the pre-season was small, possibly due to the similarities

between the CMJ and the motor skills that are specific to netball. It was also encouraging to see that despite the relatively small training age in comparison to their team mates, youth athletes are still able to learn and progress physically. The exposure to constantly varying movement patterns in skill specific training and gym-based training, helps to decrease the variability in movement. This confirms that youth athletes become progressively more efficient and effective in their movements across the court.

Cormie, McBride, & McCaulley (2009) illustrated in a longitudinal analysis of CMJ variables, that power training elicited significant changes to power, velocity and displacement variables in athletes. This is confirmed by the data collected in this study of athletes. The results indicated that training from day 1 to day 94 did significantly, and positively influence relative mean power output. No significant relationship was found with velocity, despite its apparent strength. This was interesting as mean power output was adjusted for the participant's body weight, while velocity was measured as a raw value. The results could have possibly been different if velocity had been adjusted for individual differences. It is also important to remember that velocity is the only true value identified by the GymAware™ tool, and that power data is measured through a computer generated algorithm, which suggests some degree of variability in the data prior to the analysis taking place. However, despite this, the data does suggest that the periodisation of the season, which aimed to progressively produce more relative power for each athlete, was a success.

Strength foundations laid in the pre-season and early stages of the in-season phase allowed more power to be produced towards the end of the season. However, the velocity data suggests that this power may not necessarily have been produced over a shorter amount of time. As power is a product of force multiplied by velocity, it can be

concluded that despite the athletes being able to produce more force it was not produced over a shorter amount of time.

While specific training phases undertaken throughout the season have not been directly investigated, Figure 4 shows that the desired outcome by the end of the season was to have the athletes fast, strong, powerful and aerobically resilient. As the participants mean velocity data did not significantly improve throughout the season it can be concluded that the rate of force development training identified in during the middle of the season was not successful.

Rate of force development is defined as "the rate of rise in contractile force at the onset of contraction" (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002, p. 1318). The results indicated that the athletes ability to quickly produce force, or their power, was not improved. It instead suggests, as previously discussed, that the athletes ability to produce force, also known as their strength, was enhanced in training. As velocity was not improved, this may have possibly reduced the athletes capacity to produce on-court performances. However, when considering the main objective of the programme was to develop a netballers capacity to step up to the professional level, the results take a more positive meaning. If selected, these players are expected to have the capacity to produce high level performances in a professional team from day one. As the data suggests, this programme does benefit their preparation on this journey highlighting the importance of development programmes within sport in New Zealand.

While it can be concluded that the relative power outputs of the participants progressed throughout the season, the potential effects of fatigue throughout the entire pre-season and competitive season should also be considered. Fatigue experienced after a heavy game, a heavy week, or even a singular training can be detrimental to not

only individual, but also team performances. As mentioned earlier, SSC fatigue results in reduced activation during the eccentric phase, limiting the monosynaptic response to a sudden stretch (Strojnik et al., 1998). Maximal shortening velocity can slow during fatigue (Cairns et al., 2005); an outcome which can be observed in Table 2. Full recovery from physiological stress can take up to 8 days which is a significant amount of time when the weekly turnaround for games is never longer than 7 days (Blanch & Gabbett, 2016; Gathercole et al., 2015). Monitoring this allows weekly training loads to be adjusted to ensure that adequate recovery can be achieved. This will then help to promote an optimal performance being achieved each week. Such testing also provides a quantifiable measure of improved or diminished physical abilities. Performance jump data collected towards the end of the season indicated that the majority of athletes jump results improved (Table 4). The exceptions were two youth athletes and one well trained athlete. As mentioned above, improvements during the season may be attributed to improved movement efficiencies, often as a result of improved neuromuscular function and improved biomechanical awareness (Wakeling et al., 2010). Interestingly, these three athletes actually regressed throughout the season in the performance specific tests identified by Netball New Zealand (Kritz & Thompson, 2010). This could have been due to several factors such as fatigue, poor performance or de-training.

Figure 6 identifies that when athletes remained within the ACWL of 0.8-1.3 they are able to obtain higher mean power scores. This suggests that athletes are more efficient when this level of conditioning is behind them. Ting & McKay, (2007) have recognised that the nervous system uses muscle synergies to perform tasks with a specific order of muscle activation. This is an important finding as netball demands fast,

explosive movements from athletes while under physiological stress while being played over 60 minutes (Davidson & Trewartha, 2008). It suggests that athletes are better able to produce potentially match winning movements across the court when they are physically 'fresh' and are at a significantly reduced risk of injury (Hulin, Gabbett, Caputi, et al., 2016; Hulin, Gabbett, Lawson, et al., 2016).

This trend, while not significant throughout the season indicates that there may be performance implications if athletes are unable to recover full neuromuscular function in between training sessions, and matches. The testing conducted during this research was also useful in identifying athletes readiness for performance based on the SSC demands of netball. This is a concept that is supported in the research conducted by Gathercole et al. (2015). Most current literature has a clear relationship between CMJ monitoring and fatigue in relation to an athletes readiness for performance (Gathercole et al., 2015). However, it is still difficult to quantify how much fatigue truly affects performances in a team sport such a netball.

While the individual may be physically limited in their relative potential for power production, this may not mean they are going to be less effective on court tactically. If this is the case, then we need to have a way of quantifying the relationship effectively. Some athletes may, for example, perform better coming into competition with some degree of fatigue or soreness. While this concept is not explored in this research, it is nonetheless, still worth investigating as it is an important consideration for coaches when selecting players.

Mean velocity loss has been found to be a significant indicator of neuromuscular fatigue in resistance training (Sánchez-Medina & González-Badillo, 2011), similar to what may occur in team sports (Cairns et al., 2005). The use of dynamic measures, such

as the CMJ, identify that muscular maximal shortening velocity can slow during fatigue, therefore limiting the rate of cross-bridge cycling (Cairns et al., 2005). Table 3 identified a significant, negative relationship with mean velocity while measurements were in the 0.8-1.3 ACWL zone. This indicates that as the ACWL gets closer to 1.3, the velocity of the athletes CMJ reduce, suggesting that the ACWL maximum marker of 1.3 may be too high for this group of athletes. Table 2 validates this trend by identifying a negative, although significant, difference between well trained and youth athletes mean velocity data through the season while they remain within the suggested ACWL zone.

While this indicates that athletes were able to complete their CMJ at quicker velocities when inside the suggested ACWL zone, there is clearly an ACWL score which needs to be identified for this group to attain peak performance. The strong association that sprint performance has with CMJ results (Hennessy & Kilty, 2001; Smirniotou et al., 2008) is a key finding, and therefore an important consideration when utilising ACWL, not only for injury prevention, but also for performance insights. While the risk of injury is significantly reduced within the range of 0.8-1.3, the margin of error for peak performance, based on the findings above, may be even smaller.

The results observed when testing the team as a whole appeared to align with the findings of Gathercole et al., (2015). They identified CMJ to be a suitable, non-invasive method, to monitor neuromuscular fatigue. The protocol for this research study was designed to cause as little disruption to training as possible, which is important when working with a team in-season. While the testing had some logistical disruptions to training sessions, the CMJ testing did not appear to inhibit their future physical performances, an observation previously made by as Gathercole et al., (2015).

The cues for the testing protocol used by Gathercole et al., (2015) mirrored those used throughout this study, with participants being instructed to jump as high as possible, emphasizing power generation. The variability identified by Gathercole et al., (2015) may be attributed to the neuromuscular strategy of the CMJ mechanics, a concept discussed above. They concluded that there may be greater variability in the CMJ movement strategy than that seen in the CMJ power output a results which is consistent with the results identified in the well-trained group. The subject of movement strategy differences between well-trained and youth athletes will developed when the data is analysed more deeply with regards to the sub-groups and the case study participants.

Is the acute chronic workload ratio an indicator of performance?

Monitoring an athletes ACWL ratio is key to understanding their training status, readiness to perform, and the potential to reduce the apparent risk of injury. This is often described as the cost-benefit analysis. In other words, aiming to push athletes to breaking point without breaking them, in order to achieve the greatest physiological gains, and ultimately the greatest physical performances (Gabbett, Windt, & Gabbett, 2016). However, there are numerous team factors, along with individual factors, that need to be considered when analysing aspects associated with provincial representative netball in New Zealand. Monitoring must be done well to ensure training load data is utilised correctly. This is a particularly important consideration when working with athletes who have different training backgrounds, which is common occurrence in every team sport, no matter the level. Within the current team there was two school girls, four who were in their first year of university and two who had previous experience at

national league level. Strength and conditioning coaches must be able to adapt their delivery based the athletes that coaches select, and ACWL monitoring ensures the athletes progress is monitored effectively.

It is apparent within the literature that inadequate workloads for individuals is a leading cause of injuries (Gazzano, 2017; Lu, Howle, Waterson, Duncan, & Duffield, 2017). It is also now common knowledge that the risk of injury increases when "high loads are applied to athletes who are psychologically and/or physically unfit to tolerate the prescribed workload, or when athletes are well trained, but in need of rest" (Gazzano, 2017, p. 4). This suggests that peak performance lies somewhere between those two situations. Coaches and support staff, view success as being able to prepare athletes for peak performance while simultaneously avoiding excessive fatigue, which can undoubtedly influence an athletes performance. Monitoring ACWL ratios can therefore give coaches and support staff the ability to retrospectively see how much influence recent weeks of training have had on an athletes potential for performance. The ACWL ratio also provides coaches with the evidence needed to manipulate upcoming training sessions and ensure that performance is the main focus.

As observed in Table 3, ACWL ratios between 0.8-1.3 were significantly correlated with athletes relative mean power output. Mean power on the other hand was significantly correlated with data outside of this zone, indicating that an individual's physical capability to produce power each day of testing is directly affected by their ACWL ratio. This implies that when athletes are determined to be at their lowest risk of injury, they are at their best physical state for peak performance, reaffirming the conclusion made by Hulin, Gabbett, Lawson, et al., (2016). Relative power output for netball athletes is vitally important based on the demands of the sport. Netballers are

required to move their bodies across the court, with the tactical play influencing the movement demand. While there has been limited research in the past on the relationship between ACWL ratio and physiological readiness for peak performance, the outcomes identified below indicate that there may be a key link here which should be developed further in the future.

As mentioned earlier, netballers are required to cover a lot of distance at sprinting speed, with C covering 555 ± 274 m, GK covering 69 ± 54 m and GS covering 370 ± 233 m while sprinting during a game (Davidson & Trewartha, 2008). Hennessy & Kilty (2001) found that CMJ scores significantly correlated with 30m sprint times (r= -0.60), highlighting the significance of these CMJ findings in this study. It is clear that sprint speed is going to influence each athletes ability to complete their roles in their positions on court successfully. For example, decreasing the overall time it takes for a goal keeper to cover their sprints throughout a game will have positive implications for performance for not only the individual, but also the team (Davidson & Trewartha, 2008).

Sprint efforts in most ball sports, including netball, are generally completed with the intention of covering a small distance in the shortest amount of time to achieve a turnover, complete an attacking or defensive off the ball manoeuvre, or receive a pass (Davidson & Trewartha, 2008; Fox et al., 2013). These efforts are often not longer than 1.7s in duration, but can be completed up to 83.3 ± 20.1 times based on the court restrictions and the restrictions on the players positions (Chandler et al., 2014; Fox et al., 2013). It appears, based on the findings and previous research that well-trained athletes are better prepared to handle the expected training loads week in, and week out. More care needs to be taken with the youth athletes to ensure they remain within

the recommended ACWL ratio zone of 0.8-1.3 for a larger proportion of the season. A reduced level of tolerance to training loads far exceeding what they have experienced in the past is a large contributor to this, hence why all athletes in a team cannot be treated the same.

Monitoring Strain

Strain is the sum of an individual's weekly training load multiplied by training monotony (Foster, 1998). This was monitored throughout the season, and it is interesting to note that mean strain values were higher when outside the key ACWL zone of 0.8-1.3 for the youth athletes, whereas strain values were well under the when outside the suggested 0.8-1.3 ACWL ratio for the well trained athletes. This shows that strain can be used as a simple measure to identify chronic workload, as strain is calculated across a seven-day period.

As this data is obtained from internal training loads, the assumption can begin to be made that the training loads from week to week were too high for the youth athletes. This indicates that there is value in monitoring more than just ACWL ratios when looking to understand athletes responses to training (Gazzano, 2017). Table 3 identified that strain was significantly correlated with ACWL ratios outside the 0.8-1.3 zone, again suggesting a clear relationship between the two. Table 3 also enabled correlations to be made with relative mean power, and mean velocity data enabling clear performance conclusions to be made with the assistance of ACWL ratio data. There was a large difference between relative mean power, and mean power, however only a small difference was found between the two groups with regards to strain (Table 1). It is clear that the youth athletes ability to recover and adapt from the chronic training effects are

clearly limited, causing physiological distress, particularly when at an increased risk of injury based on their rolling ACWL ratio which fluctuates from training to training.

The acute effects of training are more easily induced and observed in youth and untrained athletes as there is a greater window for adaptation (Barnett, 2006). Delayed onset muscle soreness (DOMS) is more commonly seen in less trained individuals, due to the athletes being unaccustomed to the increased intensity of the physical activity and training (Barnett, 2006). As a result, this training is generally associated with a large eccentric component in movement overload (Barnett, 2006). The prior training undertaken by the well-trained athletes in this study would have attenuated serum creatine kinase (CK) responses. Serum CK is a key enzyme in the utilisation of adenosine triphosphate to create phosphocreatine and adenosine diphosphate (Wallimann, Wyss, Brdiczka, Nicolay, & Eppenberger, 1992). While CK is commonly identified as a marker of muscle damage, such as that seen when athletes suffer from DOMS, it is important to understand that DOMS are a key part of athletic development. If athletes want to become more efficient, and as a result, perform to a higher level, it is a necessary response from training (Barnett, 2006; Wallimann et al., 1992). While it is likely that untrained athletes will be effected by DOMS, particularly in the early stages of pre-season, well-trained athletes also require this response to ensure adaptation from training is occurring to progress physically.

The physiological distress caused by training manifests itself not only as DOMS but also as neuromuscular fatigue. The result is an increase in the level of effort required to perform a task making athletes extremely inefficient (Sánchez-Medina & González-Badillo, 2011). Cormie et al., (2009) supported the ideas discussed by Barnett (2006), that neuromuscular fatigue results in ionic changes on the action potential, as well as

numerous other extra and intracellular changes. The outcome of this is a reduced ability to generate maximum power, an outcome observed throughout the completion of this thesis. Fatigue, not only reduces the concentric abilities of athletes, but also eccentric shortening velocity is compromised (Sánchez-Medina & González-Badillo, 2011). As a result, this markedly influences the athletes concentric power output, because the action potential and cellular shifts reduce the capacity for performance. In a practical sense, if netballers are unable to absorb the force efficiently when landing from a jump, the resultant concentric movement no matter the direction, will be limited by the reduced eccentric shortening velocity.

Why is training age important?

There has been a great deal of discussion as to why there is a difference in physiological responses between athletes with varied training backgrounds. The case study comparing the youth and well trained participant allowed for a greater understanding in regards to the relevance of the observed findings. It was clear that there were large differences in the physical abilities between a well-trained athlete and a youth athlete with only a year of basic strength and conditioning experience.

Table 5 identifies the difference in means for relative power output between the youth athlete (23.28 ± 3.40 W$\cdot$kg^{-1}) and the well-trained athlete (29.42 ± 6.88 W$\cdot$kg^{-1}). As this data is adjusted for by body weight it is clear, and expected, that the well-trained athlete can produce more power. Similar differences were found with the mean velocity data collected when ACWL ratios remained within the recommended zone during the season. The youth participant averaged 1.48 ± 0.08 m$\cdot$s^{-1} whereas the well-trained athlete averaged 1.77 ± 0.08 m$\cdot$s^{-1}, a difference found to be statistically significant.

Strain values were higher for the well-trained athlete (2385 ± 1188) within the 0.8-1.3 ACWL zone than the youth (1998 ± 1202), which is unsurprising due to their increased physical and psychophysical resilience (Gabbett, 2016). An intriguing point to note is that strain outside the suggested ACWL ratio zone was higher for the youth athlete (2130 ± 1275) than the well trained athlete (2018 ± 1417), possibly indicating that the teams needs may have been prioritised above the athletes needs and more importantly, their abilities.

Testing data for all participants showed that two of the youth athletes vertical jump, and horizontal jump measures decreased as the season progressed (Table 4), possibly due to the increased relative level of stress put on the athlete and which they may not have been able to physically recover from. The well-trained athletes testing data showed that all but one athlete improved their vertical and horizontal jump scores and their YoYo score. Based on the periodised plan identified in Figure 4, the testing outcomes observed by the well trained athletes better align with the desired outcomes of the season.

Figures 7 and 8 are useful in demonstrating the physical differences between the case study participants. It is apparent that there are clear differences between their abilities to produce high forces consistently with the median line for the well trained athlete much higher. It is important to acknowledge a larger breadth of mean power values for the well trained athlete, possibly indicating an increased sensitivity to fatigue throughout the season. Well-trained athletes are expected to be more physically capable than those who are just being exposed to the process (Tompsett, Burkett, & McKean, 2014). However, this level of sensitivity to fatigue is not based on the training level of the neuromuscular system (Viitasalo, Hämäläinen, Mononen, Salo, & Lahtinen,

1993). As mean velocity data does not indicate as large a spread across data, it can be concluded that an error in testing, software analysis or GymAware™ function has occurred.

Physical literacy, or movement competency is a key point to understand when considering the difference between two different groups (Tompsett et al., 2014). From a health perspective, physical activity participation relies on proficiency in fundamental sport skills resulting in individuals being exposed to characteristics of physical literacy such as balance, jump, sprint, catch, hop, leap and dodge (Tompsett et al., 2014). It is therefore key to understand the background of these two groups before diving too quickly into the physiological mechanisms behind the difference in CMJ responses throughout the season. All four athletes in the well trained group had at least one full season of elite competitive netball behind them, indicating they had experienced the increased level of physical literacy demanded by the sport. The youth group however had only experienced age group and school tournaments. While the physical outputs of those tournaments may have been high, they were always completed within seven days, and relative to their skill set. This limits the exposure to high levels of physical literacy such as that seen in the longitudinal competition observed during this research study. The youth's experience, or lack thereof, would have had a huge impact on their readiness to respond to training stimuli. Athletes who are provided with the opportunity to be exposed to a development strength and conditioning programme through their development at the school level often see success earlier in their careers. Having access from a young age to targeted coaching and programming based on the athletes needs is undoubtedly going to help a netballers progression through the levels.

Inter-limb coordination is vital in sporting success; it is also critically important when completing a CMJ test. Fine neuromuscular activation timing is vital for jump power output and coordinative processes (Cortis et al., 2009). If an individual is asked to complete the same task twice, the two actions produced will never be identical (Stergiou & Decker, 2011), but it is a matter of how great the variation is when defining how skilled an athlete is. The dynamical systems theory highlights that the biological systems self-organise according to "environmental, biomechanical and morphological constraints to find the most stable solution for the given movement" (Stergiou & Decker, 2011, p. 2). Table 5 indicates that well trained athletes have the neuromuscular intelligence to adjust their movement strategy to improve the outcome, a factor which must be considered when delving into data analysis (Gathercole et al., 2015; Yarrow et al., 2009).

Chapter 6. Conclusion

The key findings of this thesis were:

1. There was a significant difference in mean velocity production between the well trained and youth athletes when their ACWL ratios fell within the suggested 0.8-1.3 zone. This indicated that well trained athletes were more capable of jumping with high velocity.

2. There was a significant increase in relative mean power through the season for the entire group, suggesting the training plan implemented was successful. When relative mean power was adjusted for ACWL it still has a significant increase as the season progressed.

3. Strain was significantly correlated with ACWL inside the 0.8-1.3 zone, which is not surprising considering both ACWL and strain require RPE data to calculate. However, it does indicate that the monotony (or lack thereof) does play a role in influencing athletes perceived training intensities.

4. There was no statistical difference in ACWL between well trained and youth athletes indicating their abilities to perceive intensity and fatigue is not affected by their training age as all athletes completed the same programmes.

5. The case study data indicated that there was a significant difference between the well trained and youth athlete for both mean velocity and relative mean power when inside and outside the 0.8-1.3 ACWL zone. This indicates that the gap in the physical abilities of the two athletes did not get any closer throughout the season, and could possibly be getting larger.

6. As with the entire group, in the case study there was no significant difference in training load between the two athletes. This indicates that the difference in

physiological responses to the training and competition stimuli throughout the season is directly related to their abilities to tolerate the workload.

Practical Applications

For ease of prescription, some coaches and strength and conditioning practitioners may program such that all athletes undertake the same mechanical training load throughout the season. However, this study indicates that it is critically important to consider the needs of the athletes to ensure not just their performance, but health and welfare is also a priority. This study has made it clear that youth athletes can tolerate a training load similar to that of a well-trained athlete, but there are detrimental effects on their physical development and performance. The overall framework of the programme must be considered. This programme in particular was targeted to provide an opportunity for physical maturation if selected up into the professional league. While there were no major injuries throughout the season, the influence of minor injuries and excessive DOMS, which are unable to be quantified still need to be considered. A youth athletes reduced ability for movement efficiency and increased sensitivity to fatigue from training and competition inhibits their ability to produce force, therefore reducing their capacity to perform the expected skills of a netballer ultimately limiting performance. Physically, the athletes had an opportunity to progress, but in the future there is an opportunity to take more of a holistic approach with this level of athletes. Exposure and education should be prioritised over incremental improvements in performance testing data.

A positive to be taken from the youth athletes however is that they do have the ability to understand the intensity of the activity they have previously undertaken. This

is a skill they possibility learnt in their early exposure to strength and conditioning, and competitive sport. So, while this study, and previous evidence, shows that youth athletes training loads should not be as high as well-trained athletes, they should not be considered to be physically unaware of how the training affects them.

It is important to consider the monitoring process as a whole, and how effective it would be in a real world situation. Monitoring internal training load alongside CMJ appears to be an extremely useful and beneficial approach. While it is more time consuming than just completing one or the other, the data produced was useful in determining potential influences on performance and possible injury risk. The limitations observed below acknowledge that GymAware™ does provide some data and procedural constraints, and it may be useful to utilise different tools for monitoring in the future. Utilising tools such as a jump mat may be more practical, easier to use, and provide more reliable data if force output is going to be a key variable, rather than velocity which poses problems when monitoring over long periods of time.

It was clear when discussing the data above that the positional demands of each athlete must be considered to fully understand the data obtained, a consideration not made during this study. Without knowing specific metrics, such as the number of metres were covered in a game, or how many jumps were completed in a game, some conclusions are based merely on educated assumptions. Having access to data like this would complement the external CMJ monitoring and the internal RPE data. With this, the argument regarding too much data collection can start. However, as mentioned above, if the practitioner believes the monitoring is going to be useful to improving performance, and guide their delivery then an informed choice needs to be made about

the implementation of different methods. If the equipment and expertise is available a combination of monitoring techniques could be extremely useful in the future.

Limitations

There are several limitations to consider when interpreting the results of this thesis:

- The statistical power of this study was compromised due to the low number of participants (n=8). The exclusion criteria ensured that the participants were quality subjects, while also reducing their risk for possible harm. Increasing numbers to improve the statistical power by including athletes with a training age of zero would have compromised the validity of the results and the ability to critically evaluate the data.

- The findings of this study are largely reliant on the GymAware™ tool providing reliable and valid data throughout the entire testing period. While this was assumed throughout, due to the geographical challenges of this study the GymAware™ tool used for testing was also used by other practitioners throughout. The GymAware™ tool has been found to be reliable (Crewther et al., 2011; O'Donnell et al., 2018), however it is difficult to quantify the effect other users had on its ability to produce consistently reliable data. Also, the fluctuation in body weight for participants throughout the season was unaccounted for, introducing another degree of variability.

- Due to the amateur status of the team, training times were never consistent week to week would have influenced CMJ testing. At times the CMJ testing was completed at different times during the day. While there are conflicting theories about neuromuscular efficiency at different times of the day, it is important to

consider that this could have affected the results of this study (Guette, Gondin, & Martin, 2005; Seo et al., 2013).

Recommendations for future research

Ideally future research would require jump testing to be more specific to the demands of netball. For example, requesting athletes to complete depth jumps rather than a CMJ would better identify an athletes ability to overcome hysteresis, an ability hugely specific to the dynamic demands of netball (Thomas, Comfort, Jones, & Dos'Santos, 2017). This data would also provide invaluable information on the athletes tendon stiffness allowing future prescription of training to be better manipulated. The demands put on the SSC throughout a netball game are large, with minimal time spent stationary (Chandler et al., 2014; Christopher Thomas et al., 2017). Utilising the depth jump may identify fatigue reducing the efficiency of the muscle-tendon complex (Kubo, Ishigaki, & Ikebukuro, 2017). A stiffer muscle is desirable under active conditions seen during a competition game as this enables more elastic energy to be stored within the tendons during SSC exercises such as jumping and sprinting (Kubo et al., 2017). Any indication of contractile disturbances and motor unit inefficiencies due to fatigue can inhibit the hysteresis loop therefore reducing an athletes ability to perform at the peak capacity (Castronovo & D'alessio, 2014)

The introduction of GPS and accelerometry data on court during matches and training would help to establish a clearer understanding of training load alongside RPE and ACWL ratio data. The addition of this type of data when correlating workload with perceived workload and jump data would have been invaluable in accurately measuring on court performance (Sweeting, Aughey, Cormack, & Morgan, 2017).

The method of data collection could also be changed, and using a jump mat or force plate may provide more appropriate data on contact time, mean jump power, flight time and reactive strength index (Duthie, Thornton, Delaney, McMahon, & Benton, 2017). While the GymAware™ linear transducer provides reliable and valid data, the set up takes some time when testing one athlete at a time causing interruption to strength and conditioning sessions.

Finally, an emphasis on the treatment of athletes with differing training ages would be beneficial. While previous research, including this thesis, has shown that athletes with a training age of less than three years have a reduced ability to produce force, and longer recovery time, more research must be done quantifying the influence of this. With this data, coaches and support staff can be better prepared to support their athletes through their journey from amateur to elite athletes, possibly even reducing the transition time.

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Appendices

Appendix 1. Consent Form

# Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***"Monitoring of the vertical jump throughout a Netball season and implications for performance"***

Project Supervisor: **Professor Michael McGuigan**

Researcher: **Megan Gibbs**

○ I have read and understood the information provided about this research project in the Information Sheet dated 9th February 2017.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am not suffering from any illness or injury that impairs my physical performance, or any psychological disorder that may impact on my ability to understand what is required of me during the research process.

○ I agree to have height and weight measurements recorded during all testing sessions, as well as participating in lower limb strength and power test measurements.

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

○ I agree to data collected being shared actively with coaching staff throughout the season (please tick one)

Yes○ No○

Participant's signature:
…………………………………………….……………………………………………………

Participant's name:
………………………………………………………………………………………………

Participant's Contact Details (if appropriate):
………………………………………………………………………………………..
………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number. *Note: The Participant should retain a copy of this form.*

Appendix 2. Sample participant information sheet

Participant Information Sheet

Date Information Sheet Produced:

15/02/17

Project Title

Monitoring of the vertical jump throughout a Netball season and implications for performance

An Invitation

I, Megan Gibbs, am a Masters student based at the Sports Performance Research Institute New Zealand (SPRINZ) at AUT-Millennium, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study to assess changes in power production due to fatigue across a netball season. Participation is entirely voluntary and you may withdraw at any time prior to June 17th 2017 when data collection is completed without any adverse consequences.

What is the purpose of this research?

The purpose of this study is to investigate the changes in power output by monitoring body weight vertical jump. Team performances throughout a competitive sports season can be hard to predict. Previous research has found that monitoring of measures such as power improves the quality of delivery to athletes, as responses to training can be adjusted. Because a netball season contains many different phases and game specific demands, it is important to understand how athletes may respond to these.

Linear position transducers (GymAware™) will be used to measure jump performance allowing possible trends across the season to be identified. Appropriate utilization of this data gathered by support staff in the future will assist with tracking fatigue and help in understanding how netball players respond to in-season competition and training loads.

How was I identified and why am I being invited to participate in this research?

You were identified as a participant for this research due to your selection into the Beko South Zone netball squad and you are between the ages of 16-35 years.

Exclusion criteria includes any current injuries, or in the past six months which have hindered or stopped normal participation in training

What will happen in this research?

You will be assesed twice a week with body weight jump testing taking approximately 3 minutes each time. Testing will be conducted prior to programmed in-season resistance training sessions, but after the 10 minute session warm-up is complete. These sessions will take place at High Performance Sport New Zealands's training facility based in Dunedin. The first four weeks of pre-season will involve familirisation with the testing protocol. Each test involves three maximal effort body weight jumps which will be repeated twice. While jumping a linear position transducer will be attached to a belt around your waist to record data. These tests will be interspersed with a rest period of 2 minutes. No intervention will be applied between testing days, the data will be observed for trends or patterns but will in no way influence performance or selection within the team.

What are the discomforts and risks?

There are minimal anticipated discomforts and risks from participating in this testing. The velocity at which the tests are expected to be completed does pose some risk of delayed onset muscle soreness, injury, and fatigue, however this risk will be reduced with a session warm-up being completed prior to testing each time.

Also, data obtained will in no way disadvantage or advantage selection into the South Zone Beko team. Voluntary withdrawal from this study will be accepted throughout the entire data collection process, again with absolutely no adverse consequences.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedures throughout the 4-week pre-season training period, a requirement for participation. If you do not feel you are able to complete the testing required, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher if you have a current or previous injury that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains must be reported, specifically to the hip, knee and ankle and back.

What are the benefits?

By participating in this study, you will receive information about your lower body power output across a netball season season developing your understanding of how different phases of a season affect your performance capacity. Findings will assist in improving the future delviery of strength and conditioning programmes to netballers in-season. These findings may also enable you to change training practices in the future to improve your performances as a netballer.

Data collected will also allow me to complete my thesis and gain my Master of Sport and Exercise qualification.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

The findings of the research may be used in future publications, however the identity and individual results of each participant will be kept confidential. Only my primary supervisor (Prof. Mike McGuigan), and I will have access to, and analyze your results.

What are the costs of participating in this research?

Costs to participate is nil. This study will however require you to schedule your time to be available for testing and training for the Beko South Zone Netball squad (approximately 60 minutes each resistance training session twice a week). It is also expected that all participants complete both pre-season familiarization and in-season training as prescribed. In total there will be data collected at 22 resistance training sessions, costing participants approximately 66 minutes of time away from strength and conditioning programmes.

What opportunity do I have to consider this invitation?

A response to this invitation would be appreciated by no later than the 27th of March 2017.

How do I agree to participate in this research?

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to myself prior to participating in any of the tests.
If at any stage after volunteering you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any time without any prejudice prior to final data collection on June 17th 2017.

Will I receive feedback on the results of this research?

Yes, you can receive a summary of individual results once the information is ready for distribution (around one month after completing the study). Please check the appropriate box on the *Consent Form* if you would like this information. After the completion of the study you will be invited to an information session at AUT-Millennium where we will present the main findings of the study. You will also have the opportunity to ask the researcher any questions you have about your individual results.
The results of your testing performances will only be given to your coach with your permission (please check the appropriate box on the *Consent Form*).

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or (09) 921 9999 ext 7580

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , (09) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Megan Gibbs; email: megan.gibbs@hpsnz.org.nz; mobile: 027 6994589

Project Supervisor Contact Details:

Supervisor, Prof. Mike McGuigan; email: michael.mcguigan@aut.ac.nz or (09) 921 9999 ext 7580

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix 3. Ethics approval form

29 March 2017

Michael McGuigan

Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **17/53 Monitoring of the vertical jump throughout a netball session and the implications of performance**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 29 March 2020.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 March 2020;

- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 29 March 2020 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: meganlisagibbs@gmail.com