PHYSIOLOGICAL PROFILE AND VARIABILITY OF JUMP KINETICS IN NATIONAL LEVEL FEMALE BASKETBALL PLAYERS

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ABSTRACT

The purpose of this thesis was to investigate the lower body power attributes of elite female basketball players over the course of a competitive season. Minimal research currently exists on female basketball athletes and their physical performance variables such as power, speed, agility and aerobic capacity. Physical characteristics of national level female athletes were then determined, followed by assessing the impact that seasonal load had on key variables of power and movement variability. To date the majority of research on basketball performance variables has focused on the physiological requirements of male basketball players with an assumption that similar qualities are required in female athletes. No prior research has assessed power variables in female basketball athletes over the duration of a competition season or attempted to assess movement variability. Therefore an understanding of power attributes and movement variability of international standard basketball players and how competition seasons influence these capacities is needed. This will allow specialised training of these athletes with reference to season time point and promote enhanced performance outcomes.

A comprehensive literature review was conducted to provide an overview of the peer-reviewed research related to on-court physical performance on women's basketball players. The first finding was that the majority of the physiological markers outlined throughout the literature relating to female players had been conducted on junior players aged between 13 and 15 (40) and college athletes (72) rather than those of an international standard. Improvements in jump performance were described in male junior basketball players when in-season (80) as well as in female collegiate athletes over the course of a 22 week season (52). However in-season training loads and their consequent effect on jump performance in these studies was not reported. It was also noted, that the female collegiate athletes had a poor training base prior to the season commencing and that this most likely contributed to the observed improvements in jump performance across the season (52). Therefore a clear understanding of how training loads and competition could affect jump performance and kinetic variability in the countermovement jump (CMJ) remains unknown. From this review it was evident that further research is required to highlight the specific areas athletes can target in training to improve power production and jump performance.

The first investigative study used twenty six Australian female representative basketball players (24.1 ± 3.6 y; mean ± SD) categorized as guards (n=9), forwards (n=5) and centres (n=11) to establish physiological and anthropometrical profiles of international level female basketball players. The tests included anthropometric assessment of skinfolds (mm), height (m) and mass (kg), a 20m sprint test, and the Yo-Yo intermittent Recovery Level 1 test.

Countermovement jump (CMJ) data was collected via a Gymaware™ optical encoder and drop jump testing data was collected via a Swift Speed Mat. Physiological differences were evident between the positional playing groups with centres producing significantly ($p>0.05$) greater concentric peak force (2641 ± 864 N) than guards (2113 ± 134 N) during the CMJ. This was likely due to the significant differences in mass between centres (78.7 ± 7.2kg) and guards (67.0 ± 6.1kg). There were small but not clinically significant differences between playing position in CMJ variables for concentric peak power (Watts (W)), concentric peak power (W/kg) and concentric mean power (W) with centres scoring higher than forwards and guards. Guards recorded faster times to 5 m (1.16 ± 0.05s), than centres (1.22 ± 0.10s) and forwards (1.17 ± 0.16s) but again these differences were not clinically significant. Based on the lack of clear physiological and performance differences between the positional groups for these selected variables, it is suggested that these baseline performance markers are required across all positions to be considered for the Australian basketball team.

Following the establishment of baseline performance markers for elite female basketball players, study two aimed to assess the impact of in-season load variation in performance markers in the CMJ in a related group. The total training load was determined using the session-RPE method for each week was calculated as the total load sum of sessional data for each athlete aggregated as a group mean. Junior and senior female representative basketball players (n=10) aged 18 ± 2 y participated in this study. All subjects were post peak height velocity and had a training age greater than 1 year. Countermovement jump (CMJ) data was collected with a Gymaware™ optical encoder at pre-, mid- and post-season time points. Jump performance was maintained across the course of the full season with jump height values of (0.39 ± 0.05cm) in the pre-season, (0.40 ± 0.07cm) mid-season, and (0.39 ± 0.06cm) post-season. Concentric peak velocity, jump height and dip showed the most stability from pre- to post-season with the coefficient of variation (CV%) ranging from 5.6-8.9%. In the period of the highest training load (mid-season), variability of within-subject performance was reduced in all measures except for jump height, suggesting less variability in the jumps performed. The highest CV% however, occurred for the inter-set scores at mid-season in all measures except eccentric peak velocity, suggesting increased movement variability across the subjects. Therefore seasonal load influenced the range of scores within the group, however, the individuals themselves became more variable at the time point of highest seasonal load. This was evident through altered jump mechanics via increased dip patterns at mid-season. In-season training loads not only impaired jump performance of the basketball players but also altered movement variability.

This thesis profiled the performance markers indicative of international standard female basketball across all the playing positions. There are clear clinically significant ($p>0.05$) relationships between playing position and anthropometric characteristics, however, no significant differences were evident between performance markers. The ability of players to produce force and velocity efficiently throughout the competition season is considered imperative by basketball coaches and this study found that seasonal loads impaired the improvement of CMJ performance markers but did not to significant decrements in performance. When assessing how the athlete performed the exercise, subjects exhibited increased inter-set movement variability in all variables except eccentric peak velocity when undertaking high in-season training loads, however they were able to maintain jump height. This implies that athletes can utilise numerous NM strategies to achieve the same movement outcomes. This thesis has provided evidence of the physical attributes international standard female basketball players possess. It has also provided a greater understanding of how in-season training loads effect movement variability and jump performance. Further research into women’s basketball is needed to assess the strength characteristics of elite players and if this influences on-court performance markers as well as seasonal CMJ performance.

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LIST OF ABBREVIATIONS

BW	Bodyweight
CV	Coefficient of variation
CMJ	Countermovement jump
DJ	Drop jump
EF	External focus of attention
FIBA	International Basketball Federation
IF	Internal focus of attention
LPT	Linear position transducer
NM	Neuromuscular
RFD	Rate of force development
RSI	Reactive strength index
SSC	Stretch shortening cycle
W	Watts

Publications by the Candidate Relevant to the Thesis

Legg J, Williams K, Pyne D, Semple S, and Ball N. Physiological Profile of Australian Elite Female Basketball Players According to Playing Position. *Journal of Australian Strength & Conditioning* In Print, 2017.

Legg J, Pyne D, Semple S, and Ball N. Variability of Jump Kinetics Related to Training Load in Elite Female Basketball. *Journal of Sport Sciences* In Review, 2017.

Conference Presentation by the Candidate Relevant to the Thesis

Legg J, Developing Australian Basketball Players. Japanese Athletic Trainers Association (JATI) International Conference, December 14, 2015, Kyoto, Japan

Legg, J, Strength and Conditioning for Basketball, Basketball Australia Coaches Conference, May 5, 2016, Canberra, Australia.

Legg, J, Developing Australian Female Basketball Players. Southeast Asian Conference on Applied Strength and Conditioning, April 21, 2017, Singapore.

CHAPTER 1: INTRODUCTION

1.1 Background

Basketball teams are typically divided into the playing positions of guards, forwards and centres which allows for specialised strength and conditioning training for these roles (35,36,40). Guards are required to move the ball up the court and organise the play and as a result are often shorter and considered more agile, whereas centres and forwards play around the post encountering more physical contact as are therefore required to be tall and strong. The morphological differences of the players occupying these positions are well documented; with centres (both females and males) having a greater height and mass than both forwards and guards (41,72,93). Guards are generally characterised as having faster sprinting speeds and greater agility than forwards and centres (56). This is in part due to the varying on-court roles as guards are required to carry the ball up the court whilst directing play and are consequently not subject to the levels of physical contact that forwards and centres encounter. Research to date on the physiological and anthropometric profiles in elite male and junior female basketball players has illustrated the importance of a variety of physical traits for successful performance, including, aerobic and anaerobic power, strength and speed (35,41,93). Research into junior female basketball players has shown conflicting results however, on the influence of playing position on performance markers, with some studies proposing very little physiological differences between positions (41,72). However, this research was limited to junior players with minimal training history rather than international standard female players. Thus research to explore if the lack of positional differences shown at the junior level occurred in athletes at advanced level of competition with increased training history was warranted. Clarity on the performance markers linked to positional groups in female players in order to maximise performance through individualised strength and conditioning programs would allow these programs to be developed.

Jumping ability is an important action for success in basketball play, an indicator of lower body power, and shows good transfer into sprinting (59,103,106). Jump performances and kinetics of female basketball players has traditionally focused on the CMJ and further research is required on drop jump (DJ) to provide information regarding fast SSC muscle contractions (<0.25sec). Basketball players would utilise this reactive ability in sprinting up the court as well as when performing multiple jumps around the rim to obtain rebounds. The mechanical and psychological effect of a competition season remains unclear however RPE ratings of training sessions and the consequent calculations of training load could identify both the mental and physical fatigue athletes are experiencing (105). Given that these loads are not currently known practitioners are uncertain how the competition season affects the capacity to exert power in the CMJ in female basketball players. Basketball seasons can be long and demanding with the top tier Australian women's competition entailing upwards of 24 games in a 6 month period. Given the important role of power production in basketball it is vital to understand how training loads and competition impact jump performance. Kinetic variability is assumed to be relatively stable for resistance trained athletes in a CMJ (112), however, this is not proven in athletes in a competition phase. It is also unclear if performance increases such as increased jump height and reduced kinetic variability can be achieved in-season whilst balancing the demands of competition and increased on-court training loads. This information would provide valuable insight to coaches and highlight the specific areas to target when training to improve power production and jump performance when competing in long duration competition seasons.

1.2 Statement of the problem

Research to date has yet to determine the key performance markers of aerobic capacity, power attributes, sprint times or jumping performance in elite level females. Selected studies have shown reactive strength, aerobic and anaerobic power to differ according to player position however, these results remain inconclusive with differences more noticeable between sub elite players of varying skill levels. No studies to date have compared the performance markers between playing positions in international representative female basketball players.

This investigation also sought to determine if performance improvements in jump height and kinetic variables were evident in elite female basketball players within a 10 week in-season training period. Through this process the pattern of within-subject variability in jump height and kinetic variables in elite female basketball players will be quantified over the course of a competitive season. This information will provide valuable insight to coaches by highlighting the specific areas athletes can target during the season to improve power production and jump performance.

This thesis addresses the problem of the absence of such research by:

- Assessing the physiological and anthropometrical characteristics of elite female basketball players according to playing position, and
- Determining CMJ jump performance and variability in well trained basketball players during an in-season training phase.

1.3 Hypotheses

In view of the stated research problem, the following hypotheses were tested in this thesis:

- Centres and forwards would be taller and heavier than guards.
- Guards would exhibit higher concentric peak velocity than forwards and centres in the CMJ.
- Centres would exhibit the highest concentric peak power (W/kg) in the CMJ.
- Guards would exhibit the highest jump height (cm) in the CMJ.
- Jump performance as measured by CMJ height would not improve throughout a competition season.
- The within-subject variability of SSC parameters would decrease as a result of structured training throughout the competition phase.

1.4 Limitations

Limitations of the reported work in this thesis have been identified:

- Sample size per playing position was restricted to current members of the Australian women's national squad.
- Strength testing could not be conducted as part of the physiological assessment due to testing restrictions enforced by the national coach.
- Elite athletes do not undertake the same training programs, as each program is individualised, and specific to the athlete and their role within the team.

CHAPTER 2: LITERATURE REVIEW

2.1 Background of basketball

Basketball is a sport played around the world, with 215 recognised National Basketball Federations worldwide (1). Female basketball is increasing in popularity globally and the professionalism surrounding athlete preparation is becoming more sophisticated as a result. Based on the physical attributes required to play basketball, research into optimal preparation, game characteristics, athlete monitoring and injury risk factors is increasing. The vast majority of the research to date has focussed on male basketball players, with the research on female players dominated by landing mechanic strategies with the view to reduce risk of anterior cruciate ligament injury (47,89,95). As such the research pertaining to performance base characteristics of female basketball players is limited. This review aims to provide an overview of peer-reviewed research focussed on optimal physical preparation methods to improve on-court physical performance in female basketball athletes.

The International Basketball Federation (FIBA) is the world governing body for basketball and oversees the principal competitions in elite players including (but not limited to) the FIBA Basketball World Cup and the Olympic Basketball Tournaments. Whilst independent leagues around the world have differing rules around match duration all FIBA sanctioned games consist of 4 periods of 10 minutes each (2). These periods are separated by a 2 min interval of play between the first and second period and the third and fourth period, with a longer interval of 15min allocated at halftime. Regulation courts are 28m in length and 15m wide (1), with each team allowed a maximum of 12 listed players, with five allowed on the court at any one time. Teams are permitted to make unlimited substitutions throughout the match whenever a break in play occurs.

In 2000 significant changes to the rules of basketball occurred whereby the time each team had to attack was shortened from 30 to 24 seconds (s) and the time allowed to cross the median line was reduced from 10 to 8s. This coincided with the introduction of 4 10-minute quarters replacing two 20 minute halves. A longitudinal study of the physiological and anthropometric measures of elite level male basketball from 1994 to 2004 found players had an increased VO2max following the rule changes in 2000 (28). Time motion analysis of elite junior players following the rule changes also found an increase in game intensity with a large contribution from the anaerobic energy system tapering towards the ends of each half as players fatigued (5). The adaptations to the rules were most keenly felt by guards who spent significantly more time in high intensity activities (17.1%) than centres (14.7%) and forwards (16.6%) $p<0.05$ (5). As such this review focused on basketball following the 2000 rule changes.

Search Strategy

A search of the SPORTDiscus, MEDLINE and E-Journals was performed using the following search terms and Boolean operators:

("Basketball" AND "Jump" AND "Elite" AND "Women")

The following restrictions were applied:

- Documents written in English only
- Published between the years 2000 and August 2016
- Articles relating to injury, jump shot analysis and nutritional intake excluded
  Limited to original articles and review articles only
- No duplicates

This search discovered 16 papers and the abstracts were reviewed for eligibility. From the abstracts 2 articles had the potential to meet eligibility requirements and were read in full (66,106). It may be noted that when the search criteria "Women" was removed 154 articles were discovered.

An alternate search of the SPORTDiscus, MEDLINE and E-Journals was performed using the following search terms and Boolean operators:

("Basketball" AND "Physiology" AND "Elite" AND "Women")

This search discovered 32 papers and the abstracts were reviewed for eligibility. From the abstracts 7 articles had the potential to meet the eligibility requirements and were read in full (41,45,86,98,107,110,111). It should be noted that when the search criteria "Women" was removed 272 articles were discovered. Thus 9 articles in total were considered relevant to female basketball in elite athletes and focussed on physical performance. This is in contrast to > 400 articles on physical performance and basketball in male athletes.

This suggests that there is a distinct lack of research regarding the physiological and performance characteristics of elite level female basketball players. Whilst the differences between performance markers in junior sub elite, and elite athletes has been documented in men's basketball more research into international level female basketball players is warranted to enhance our understanding of the sport's demands on these athletes (3).

2.2 Physical Characteristics of Female Basketball Athletes

Research to date on the physiological and anthropometric profiles of elite male and junior female basketball players has illustrated the importance of a variety of physical markers for successful performance, particularly; aerobic and anaerobic power, strength and speed (35,41,93). Typically basketball teams are divided into the playing positions of guards, forwards and centres to allow for specialised strength and conditioning training for these roles. The morphological difference between these positions is well documented; with centres (both females and males) having a greater height and mass than both forwards and guards (41,72,93). Conversely, research into junior female basketball players has shown conflicting results on the influence of playing position on performance markers with some studies proposing very little physiological differences between positions (41,72). The exact reason for this remains unclear, but may be due to a slower rate of strength development in adolescent females compared with adolescent males, resulting in a reduced range of power and agility between guards, forwards and centres (75). Further research is required to provide clarity on the performance markers linked to positional groups in female players so that performance can be maximised by the targeted use of strength and conditioning programs.

As a result of the unlimited interchange rule and small court dimensions, basketball is a sport characterised by explosive movements such as multi-directional jumping actions, high intensity sprints as well as physical contact (5,28,64,81). Studies using time motion analysis have shown upwards of 600 short duration movements occur per player in a basketball game as a result of frequent accelerations, decelerations and changes of direction (81). Movement changes have been shown to occur on average every 2 to 3 seconds, with work to rest ratios of 1:4 indicating that short bouts of moderate to high intensity work is then complemented by longer periods of recovery (4). Research by Klusemann et al. (65) established that during both seasonal and tournament competitions male basketball players had playing and break periods of ~1.5 and 1 min respectively. This is similar to findings on state level female basketball players that showed the game to be highly intermittent in nature requiring frequent acceleration and deceleration movements with high metabolic demands (100). This suggests that female players require a high anaerobic and aerobic capacity to meet the competitive requirements of the game.

In order to understand the aerobic and anaerobic demands of basketball, researchers have monitored heart rate and blood lactate concentrations during competition. When examining the heart rates of female players in elite Spanish competition, differences were noted between International level and National level games (98). Mean relative heart rate during games was 94.6 %Heartrate(HR) max in International games compared to 90.8 %HRmax in National games (98). This finding was supported by an investigation into national level female players in the United Kingdom that found a mean heart rate of players of 89.1% maximum heart rate, which is suggestive of a large involvement of the cardiovascular system (81). Blood lactate concentrations can be used to estimate the contribution of anaerobic glycolysis to metabolism in team sports. Blood lactate concentrations in female basketballers have ranged from 5.0 to 5.3mmol/L in international level competition (98), mean concentrations of 5.2 ± 2.7 mmol/L in national level competition (81) and 3.7 ± 1.4mmol L in state level competition (100). This is comparable to other intermittent intensity team sports with women's football recording blood lactate of 5.1 ± 0.5mmol/L in the first half of matches (70). It should be noted however that limited research has been conducted on international representative female team sports and blood lactate concentrations in competition, and therefore the ability to make comparisons between sports is limited.

Anaerobic power and agility have been shown to differentiate elite and average female basketball players, whereas anaerobic capacity did not separate the groups (34). Despite some conjecture around the anaerobic capacity required to be successful in basketball, little doubt surrounds the need for players to possess high anaerobic power capacities for athletic movements such as acceleration sprints or vertical jumps. A large number of the sport specific skills (shooting, rebounding and blocking) that elite level basketball players are required to possess are closely linked with good vertical jump ability (64). It is therefore not surprising that research has shown that players' court time is consistently and positively correlated to their vertical jump height, speed and agility (59). Furthermore, research has demonstrated that elite level male players have greater vertical jump ability than players with less ability

(34,56). Whilst the importance of vertical jump performance and anaerobic characteristics is well established in male basketballers, its importance within female basketballers remains unclear.

Research relating to elite female basketball to date suggests that players can be categorised into positions based on their morphological attributes, with centres and forwards recording greater height and mass than guards (41,72,93). It has been established that basketball players require good aerobic and anaerobic capacities to withstand the high intensity nature of the games, however, it remains unclear just how important anaerobic capacity and anaerobic power is in elite female basketball. A definitive physiological profile of elite female basketball players is yet to be established and how important vertical jump capacity is to women's basketball is still to be determined.

2.3 Jump Performance in Female Basketball Athletes

Muscle function in jumping and sprinting play an important role in sports performance with these movements requiring the muscle to quickly transition from eccentric contractions to concentric contractions which is known as a stretch shortening cycle (SCC) (23,71,76). A variety of basketball on-court performance markers such as sprinting speed, agility and repeat rebounding ability are all linked to SCC capacity (8,13,28,101). Schmidtbleicher (67) suggested that the SSC can be classified as either slow or fast. Drop jumps are an example of a fast SCC whereby contact times are short (<0.25 seconds) and there is limited angular displacement of the hips, knees and ankles. This is seen in basketball when players are asked to complete repeat jump activities, as seen around the rim jumping for rebounds

Research into the jump performances of female basketball players has primarily focused on countermovement jump (CMJ) characteristics which allows for analysis of slow SSC muscle contractions (>0.25s) (43,67). The reported vertical jump values vary greatly in the literature from 22 to 48 cm in female players due to large variations in testing protocols (119). The strong research focus on the CMJ is understandable given that vertical jump height is considered a key performance indicator amongst basketball coaches and is positively correlated to acceleration (34,119). It could be argued however that to effectively measure the SCC and power characteristics of female basketball players, it is important that both of these jumping variables are assessed. Drop jump analysis provides insight into the neuromuscular

(NM) system of the players and their capacity to produce force rapidly (39). Ground contact time and flight time allows an estimated jump height to be calculated (39). In addition to this, drop jump analysis can determine the RSI of the athletes with use of the formula:

Reactive Strength Index (RSI) = Jump Height (m)/Ground Contact Time (s).

The above equation provides information into each athlete's ability to quickly change from an eccentric to concentric contraction, or in colloquial terms their "explosiveness" (43). Previous investigations of nationally ranked female sprinters and hurdlers found ground contact times of 0.19 ± 0.02s (55). Similarly another investigation into female collegiate track and field athletes found jump heights of 33.66 ± 6.58cm with a reactive strength index of 0.43 ± 0.16 $p>0.05$ (38). These are higher than the recorded values of female collegiate basketball players at the commencement of the season with jump heights of 25.4 ± 0.3cm with a RSI of 0.65 ± 0.25 (120). It is important to note that whilst contact times may be similar between male and female athletes, typically RSI values will be higher in men due to the differences in jumping ability between the genders and therefore markers should not be compared (37). The higher RSI values in men may be explained by typically higher strength levels and consequently increased tendon stiffness in male athletes than those of female athletes. An investigation by Barr and Nolte (14) found that female athletes with high levels of maximal relative leg strength were better able to absorb the eccentric forces of drop jumps and produce higher jump heights than weaker athletes. Further to this, tendon stiffness will only increase after heavy load resistance training and consequent strength development (78).

Power generation during sports performance is commonly considered an important component that separates competitors (68). Increasingly CMJ testing is being used not only to monitor power output but also to determine the changes in NM function from training and NM fatigue. Recent investigations of elite female rugby athletes and elite snowboard cross athletes has shown altered CMJ strategies when in a fatigued training state (48,49). Further to this, NM fatigue has been monitored with the use of CMJ throughout a competition season in youth rugby players and women's rugby sevens (24,92). Despite the vast amount of research concerned with vertical jump ability of basketball players there have been no studies since the rule changes in 2000 investigating how a competitive season effects jumping performance (51,58).

Given the depth of information jump analysis can provide it is of no surprise that the use of jump testing in both field and laboratory setting is highly popular amongst coaches (113). Recently the use of linear position transducer (LPT) technology as a reliable method to assess the CMJ has increased. Whilst force platforms are commonly thought to be the "gold standard" in force measurement they are limited in their application for many practitioners as assessments must take place in laboratory settings to ensure integrity of the signal. The cost associated with force platforms and their accompanying software is prohibitive to many, which has led to the increased use of cost effective and portable LPT's. Key variables that contribute to jumping performance such as peak displacement, velocity and force have been shown to have acceptable within and between session reliability when using an LPT (112,118).

In order for researchers and coaches to make informed decisions regarding changes in jump performance it is important to understand what the typical variability of the testing is. As LPT's can be directly attached to a barbell or dowel it allows for direct measurement of displacement of the athlete when they complete a vertical jump (53). Previous research has found acceptable within-subject reliability for force-related measures of the CMJ when using an LPT. This has been defined as a coefficient of variation (%CV) between 2.8 - 9.5% for single trials and 0.8 - 6.2% when 6 trials are used (27,112). The error rate for a six jump protocol is estimated between 1.1-3.2% for most kinetic and kinematic variables, except for rate of force development which may be as high as 13-16% (112). As such when using an LPT the variables relating to displacement and mass are considered the most valid and reliable and thus should be included in any assessment of the athlete.

2.4 Skill Development of the Countermovement Jump

Countermovement jumps are considered of high importance and consequently assessment and transfer of performance are of great value to ensure that coordinative patterns are employed and that power and velocity are maximised (50). This corresponds with a maximum transfer of the CMJ into sporting actions in addition to stimulating adaptation processes. The vertical jump is a fundamental movement skill acquired in childhood and its mastery underpins performance in many basketball specific skills. The execution of a vertical jump relies on complex coordination of segmental actions of the body that are a consequence of the interaction between muscle forces. This force is modulated by the central nervous system and the net moments that are generated around the joints to accomplish the mechanical demands of the jump (97).

The hip, knee and ankle joints all provide mechanical energy to the vertical jump and this action is commonly referred to as triple extension (46). Kinematic and electromyographic studies have shown that vertical jumps are performed in stereotyped manners, whereby movement patterns are very similar despite the number of joints that theoretically allow the movement to be executed in a number of ways (15). Research examining the variability of the vertical jump has shown a typical reduction in the variability of jump height with increasing age from childhood to adults (44,54).

Whilst training of the vertical jump is associated with increased jump height and lower variability in performance outcomes this isn't always associated with a decreased variability of skill execution. This may be explained by dynamic system theory and coordination profiling that suggests that as an athletes skill level and expertise improves the motor system variability will increase to achieve consistent performance outcomes (33). These theories propose that skilled performers adapt to their surroundings and any unique restraints (environmental, task and personal) to achieve stable task execution through movement variability. Therefore whilst elite athletes have a demonstrated ability to perform more consistently they may have an innate ability to use what is referred to as biomechanical degrees of freedom allowing for functional variability of performance (33).

It is currently unclear if when applying dynamic systems theory the adaptation mechanism only concerns open sport skills such shooting in basketball when under pressure, or if a more closed skill such as a CMJ in developing athletes also apply (25,62). A study of coordination variability and skill development in triple jumpers found that athletes of intermediate skill displayed the lowest coordination variability across the stance phase of a jump, whereas the most and least skilled athletes displayed the highest coordination variability (115). Whilst many strength and conditioning coaches would expect kinetic variability to be relatively stable in a CMJ, the impact of training on jump performance variability is unknown.

2.5 Response to Training Interventions in Female Basketball Athletes

Given the role of jumping in basketball performance, S&C coaches devote considerable focus in their programs to improving this capacity. To date, numerous investigations have shown a positive correlation between lower body strength and lower body muscular power as demonstrated by vertical jump height (9,94,109). Bobbert and Van Soest (16) established that maximum vertical jump height was dictated by muscle strength, however, jump performance was dependant on the coordinative control of muscle properties. Overall increases in strength as well as targeted increases in the strength of the knee extensors did not result in improved jump height until the muscle activation (control) was reorganized (re-optimized) (16). This helps to explain why observational and experimental studies of vertical jump in male and female basketball players demonstrate that strength training alone did not elicit improvements in vertical jump over a year of training (51,119).

As strength training alone isn't an effective method to improve jump performance researchers have looked at the effect of plyometric training on jump performance (34,51,57). Through the use of plyometric exercises the SSC is actioned as a rapid eccentric action is immediately followed by a concentric action of the muscle and connective tissue with maximum force development occurring in the shortest possible time (96). The training response of the muscles to this type of training was described by Schmidtbleicher (101) as the relationship between excitory and inhibitory mechanisms of the muscle in a specific movement or the "intramuscular coordination". Similar to strength only training interventions, plyometric training alone led to no significant improvements in jump performance in elite professional basketball players across a 6 week training period (74). It should be noted however, that in this investigation, resistance training was only included in the final two weeks of the protocol which is likely to have limited the impact on performance enhancement (74).

Research has demonstrated that a combination of resistance and plyometric training is viewed as the most effective way to enhance the SSC in the CMJ (42,43). A combination of strength training and plyometric training has resulted in improvements in vertical jump performance in male junior basketball players by approximately 10% when in season (8,20,80). Hakkinen (51) observed the changes in CMJ height over the course of a 22 week female collegiate competitive season when 1-2 explosive strength training sessions were incorporated into weekly training. Improvements in CMJ height from 24.9 ± 2.6cm to 26.3 ± 2.9cm from pre to post season were reported. The authors noted however that a limitation of the investigation may have been the preliminary poor explosive characteristics demonstrated by the squad which allowed for improvement throughout the season. It therefore remains unclear what the response in CMJ performance is over the course of a competitive season with well-trained female basketball players.

2.6 Conclusion

Numerous investigations into men's basketball have highlighted the physical attributes required to compete successfully on the international stage. Players must possess a high aerobic capacity as well as anaerobic power, speed and strength. These attributes are assumed to be relevant to female basketball however to date research with this athlete cohort has been limited. Many of the physiological markers outlined throughout the research relating to female players have been conducted on junior players rather than with the elite. Given that the differences between junior and senior male players is well documented it would be beneficial for strength and conditioning coaches to understand if these differences are relevant in the female athletes to ensure targeted training programs and athlete development.

Jumping ability is considered imperative by many basketball coaches but how a competition season effects this capacity in female basketball players remains unclear. Given the important role of power production in basketball it is important to understand how training loads and competition could impact jump performance. Kinetic variability is assumed to be relatively stable for resistance trained athletes in a CMJ however this is not proven in athletes in a competition phase. It also remains uncertain if performance increases in jump height and kinetic variables can be achieved in-season. This information would provide valuable insight to coaches by highlighting the specific areas athletes can target in training to improve power production and jump performance.

CHAPTER 3: PHYSIOLOGICAL PROFILE OF AUSTRALIAN ELITE FEMALE BASKETBALL PLAYERS ACCORDING TO PLAYING POSITION

3.1 Introduction

Elite-level basketball players are required to possess a multitude of sport-specific skills to be competitive. These skills are complemented by size and fitness measured in anthropometric and physiological tests. Basketball involves multi-directional jumping actions, high intensity sprints as well as physical contact that are enhanced by strength and power qualities. There has been numerous studies investigating the physiological and anthropometric profiles of male and junior female basketball players, with studies illustrating the importance of a variety of physical markers for successful performance, particularly aerobic and anaerobic power, strength and speed (35,41,93). Typically basketball teams are divided into the playing positions of guards, forwards and centres to allow for specialized strength and conditioning training for these roles. The morphological difference between these positions is well documented, with centres (both females and males) having a greater height and mass than forwards and guards (41,72,93).

To date there has been a distinct lack of research regarding the physiological and performance characteristics of international level representative female basketball players. The majority of existing research has focused on injury statistics, in particular landing mechanics and anterior cruciate ligament (ACL) ruptures (6,83). The differences between players in performance markers between junior sub elite, and elite athletes has been documented in men's basketball suggesting more research into international level female basketball players is warranted to enhance our understanding of the sport's demands (3). The investigations that have focused on performance markers have been limited to junior female athletes or players of a sub-elite level (40,119). These studies have formed the basis for prescription of position-specific training programs for each position given that physiological characteristics often differ between playing positions (98). It is interesting to note that research into junior female basketball players has shown conflicting results on the influence of playing position on performance markers with some studies suggesting very little physiological differences between positions (41,72). Greater clarity of the performance markers linked to positional groups will allow performance to be maximised through the targeted programs of strength and conditioning coaches for elite female players.

While basketball places high demands on the aerobic system, the predominant metabolic pathway is the anaerobic system (35). The anaerobic system contributes to the primary offensive and defensive actions involving jumping, sprinting and explosive accelerations. The highly intermittent nature of the game was emphasised in a recent investigation of female state-level basketball games in which a mean of 1752 movements were performed per match (100). The positional demands placed on the anaerobic system differ between positions with guards completing high intensity activities (sprints and jumps) 17.1% of live game time which is significantly higher than forwards (16.6%) and centres (14.7%) (5). It is therefore surprising to note that not all studies to date have shown guards to be significantly faster over the frequently used 20 m sprint test (35,41). This may be due to frequent use of rapid accelerations and short sprint distances over 5 m and 10 m performed basketball players across all playing positions during match play (5,28,81). Centres may also exhibit a longer stride length than guards given their increased height, thus reducing the impact of slower cadence over these short distances (61).

Physiological and performance measures in basketball players have typically focussed on field-based tests and their performance outcomes (6,59). The underlying power variables of these performance outcomes and how they can be used by strength and conditioning coaches to better train athletes remain unclear. The analysis of power production in basketball players has traditionally focused on Wingate (cycle ergometer) testing and vertical jump measures (35,41,73). While the Wingate 30s cycle ergometer test is a valid and reliable it can be argued that it has limited crossover to the sport-specific actions encountered in basketball. In contrast, the drop jump capacities of elite female basketball players have not been reported in the existing literature. The propulsive action of jumping may be a more suitable measure for evaluating explosive characteristics of basketball players through the use of a linear position transducer (77,118). Vertical jump performance has been extensively studied in basketball players as an indicator of lower limb power, with the primary differences in jumping ability seen in skill levels of the players, with more elite players recording greater jump heights (55,116). The effect of playing position on jumping ability is small particularly in females where the majority of studies have focused on junior or sub elite players (11,35,56). An understanding of the jumping ability in elite senior basketball players may assist basketball coaches in their development of players from junior to senior squads.

Analysis of jump performances and kinetics of female basketball players has primarily focused on countermovement jump (CMJ) characteristics particularly slow stretch shortening cycle (SSC) muscle contractions of greater than 0.25s (43,67). In this investigation, drop jump (DJ) assessment was also used to provide information regarding fast SSC muscle contractions (<0.25sec) (67). Drop jump testing is an appropriate method for assessing basketball players as sprinting speed, agility and repeat rebounding ability are all linked to SCC capacity (8,28,99). Drop jumps also provide greater insight into the neuromuscular system of the players and their capacity to produce force rapidly, with the potential to improve agility through DJ and CMJ training alone (8).

The aim of the study was to quantify the effect of playing position in international representative female basketball players and determine if common performance markers of aerobic capacity, sprint times or jumping performance substantially differ between positions. Whilst the morphological differences between playing positions is well established, the performance markers between these playing positions remains unclear. Selected studies have shown reactive strength, aerobic and anaerobic power to differ according to player position however these results remain inconclusive with differences more noticeable between sub elite players of varying skill levels (17,34,93). Therefore it is hypothesized that a) there would be clear morphological differences between playing positions and b) physiological variables and jump kinetics would differ substantially between the different positions in particular power based variables such as concentric peak power (W/kg) and concentric peak velocity (m/s) would show substantial differences between the playing positions. Greater clarity of the performance markers linked to positional play will facilitate more targeted strength and conditioning programs for elite level players.

3.2 Methods

3.2.1 Experimental Approach to the Problem

Twenty six Women's Australian national team basketball players were categorized into playing position (guards, forwards and centres) and anthropometric and physiological measures were assessed. Anthropometric measurements included sum of seven skinfolds (mm) standing height (cm) and body mass (kg). Physiological testing consisted of a 20m sprint test, the YoYo Intermittent Recovery Level 1 test, countermovement jumps (CMJ) and depth jumps. Countermovement jump data was collected with each subject performing 5 trials, with a small pause between each trial. Athletes were encouraged to reach a maximum jump height with every trial in an attempt to maximize power output. Drop jump data was collected for each athlete with 5 trials completed stepping down from a 30 cm box with hands placed on hips. Contact time (s), jump height (m) and flight time(s) were recorded, with the reactive strength index of each player calculated as jump height/ground contact time.

3.2.2 Subjects

Australian female representative basketball players (age (y) 24.1 ± 3.6) participated in this study (n=25). According to positional roles players were categorized as guards (n=9), forwards (n=5) and centres (n=11). Physiological and anthropometric measurements were assessed during the final preparation period for international tournaments assuring players were in good condition. All players were tested as part of their normal athletic training program during afternoon training sessions and informed consent was granted from all participants with ethics approval through the Australian Institute of Sport Ethics Committee. Players were excluded from field testing if they were not currently completing a full training load for basketball due to injury or illness (centres n=4, forwards n =1). Each subject completed all of the tests on one occasion.

3.2.3 Procedures

Anthropometric and Physiological Measures. Body fat was determined with the sum of seven skinfolds (mm) taken at the following sites using a calibrated set of Harpenden skinfold callipers (Lange, Cambridge, MA, USA); biceps, triceps, subscapular, suprailiac, abdomen, thigh and calf. Skinfold sites were marked in accordance with ISAK guidelines. Standing height (cm) was measured using a wall-mounted stadiometer (Holtain Ltd, Crymych, UK) and body mass (kg) determined to the nearest 0.1kg with AND HW standing scales (AND Industries, Melbourne, Australia).

Field Tests. A 20 m sprint test was implemented to measure acceleration and running speed as a measure of anaerobic power. A single-beam infrared light gate system (Smartspeed, Fusion Sport, Brisbane, Australia) was used to measure 5 m, 10 m, and 20 m sprint times. Subjects were required to complete 3 maximal effort sprints over the full distance of 20 m. All trials were recorded but only the best result over 20 m was retained for data analysis across all gate measures.

The YoYo Intermittent Recovery Level 1 test was used to determine aerobic fitness. The endurance test was completed 10 min after sprint testing on the same indoor court. The test consisted of repeated 2 × 20 m runs at a progressively increased speed controlled by an MP3 player. Between each running bout, players have a 10-s rest period. The test result is recorded as the distance covered at the point when a participant has failed twice to reach the finishing line in the allocated time.

Jump Tests. Countermovement jump (CMJ) data was collected with a Gymaware™ optical encoder (50Hz sample period with data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia). The Gymaware™ optical encoder was attached via a tether to the right side of a wooden bar. Bar placement on the back for each subject was between the superior portion of the scapula and vertebra C7. The stance for each subject was constrained to within 15 cm of the lateral portion of the individual's deltoid as specified by McBride (82). Subjects initiated the jump squat via a downward countermovement to a self-selected depth, followed immediately by a vertical jump. Participants were instructed to keep constant downward pressure on the barbell throughout the jump and encouraged to reach a maximum jump height with every trial in an attempt to maximize power output. Participants were encouraged and reminded between trials to "jump high" & "jump fast". Each subject performed 5 trials, with a small pause between each trial to steady themselves and stand tall.

Drop jump data was collected with a Swift Speed Mat (Swift Performance Equipment, Brisbane, Queensland), and analyzed via the commercially available Swift Speed-Light software v2. Contact time (s), jump height (m) and flight time(s) were recorded, with the reactive strength index of each player calculated as jump height/ground contact time. Each athlete completed five trials stepping down from a 30 cm box with hands placed on hips with the mean of the 5 jumps recorded. Athletes could choose which leg they used to initiate stepping off the box. Athletes were encouraged to rebound from the ground as quickly as possible and jump as high as possible.

Prior to jump testing, all athletes completed the same 5-10 min warm up consisting of dynamic flexibility work followed by a specific warm-up for the testing comprising 10 bodyweight squats, 3 bodyweight CMJ at 60% maximal effort and 3 bodyweight CMJ at 90% maximal effort. All athletes had previously conducted this type of jump testing as part of their normal training. Each athlete completed one set of both CMJ and drop jump prior to testing to familiarize themselves with the test protocol. A minimum of 2 min rest was taken between the familiarization trials and testing as well as between CMJ tests and drop jump testing.

3.2.4 Statistical Analyses

SPSS Version 21 Software (IBM, Corporation, Armonk, NY, USA) was used for the statistical analyses procedures. The mean and standard deviation values were calculated for the whole group and each subgroup (centres, forwards and guards).

A 1-way analysis of variance (ANOVA) was conducted to test for mean differences across playing positions for all anthropometric and performance variables tested with a post-hoc Tukey significance held at $p<0.05$. Reliability measures were assessed by using the coefficient of variation (CV) with greater than 15% considered an large change with most variables covariance falling below this (9). Precision of estimation was indicated with 95% confidence limits.

3.3 Results

Table 1 shows the anthropometric characteristics of the Australian women's basketball squad as well as the positional breakdown of these variables. Centres and forwards were significantly taller and heavier than guards ($p < 0.05$) with an average difference of 11 kg and 17 cm respectively. There was no significant difference between positional groups in any of the field test performance markers for the members of this squad with the exception that guards produced faster times than forwards and centres over 5 m, 10 m, and 20m.

Table 1- Physical characteristics and field test performance markers for the Australian women's basketball squad, with effect of playing position.

Values are expressed as mean ± SD.

Anthropometric characteristics	Centres (n = 11)	Forwards (n = 5)	Guards (n = 9)	All Players (n = 25)
Body mass (kg)	78.66 ± 7.16ɨ	77.03 ± 4.16*	67.01 ± 6.11*ɨ	73.45 ± 8.14
Height (cm)	190.09 ± 4.19ɨ	184.95 ± 5.39*	173.93 ± 6.52*ɨ	181.88 ± 8.98
Sum of 7 skinfolds (mm)	83.97 ± 19.29	78.33 ± 14.71	73.68 ± 14.88	78.65 ± 16.05
Field test performance markers	Centres (n = 7)	Forwards (n = 4)	Guards (n = 9)	Overall mean (n = 20)
5m (sec)	1.22 ± 0.10	1.17 ± 0.16	1.16 ± 0.05	1.20 ± 0.10
10m (sec)	2.04 ± 0.15	1.97 ± 0.20	1.96 ± 0.08	2.00 ± 0.13
20m (sec)	3.46 ± 0.21	3.34 ± 0.26	3.33 ± 0.11	3.39 ± 0.18
YoYo (level)	16.47 ± 0.82	18.20 ± 0.10	17.64 ± 0.97	17.26 ± 1.04
YoYo (metres)	1268.57 ± 252.68	1800 ± 40	1631.11 ± 310.34	1510.00 ± 326.22

*Significant difference between guards and forwards, $p < 0.05$
ɨSignificant difference between guards and centres, $p < 0.05$
‡Significant difference between forwards and centres, $p < 0.05$

Table 2 shows the countermovement (CMJ) jump performances of the subjects. All subjects' single set means were collated and analysed to characterize overall means as well as position-specific means for each variable. Centres had significantly greater peak force (N) 2641.36 ± 864.27 than guards 2113.57 ± 134.74 $p<0.05$. Although not significant centres did have higher concentric peak power (W) and relative concentric peak power (W/kg) than forwards and guards

Table 2- Jump characteristics of countermovement jump for the Australian women's basketball squad, with effect of playing position.

	Centres (n = 11)		Forwards (n = 5)		Guards (n = 9)		All Players (n = 25)	
	Mean ± SD	% CV	Mean ± SD	% CV	Mean ± SD	% CV	Mean ± SD	% CV
Conc Peak Power (W)	4917.42 ± 1046.04	21.27	4487.94 ± 688.00	15.33	4030.48 ± 463.08	11.49	4512.22 ± 1190.80	26.47
Conc Peak Power W/Kg	59.29 ± 7.89	13.31	58.32 ± 10.26	17.59	58.9383 ± 5.35	8.99	59.17 ± 8.23	14.20
Conc Peak Force (N)	2641.36 ± 864.29ɨ	32.72	2350.82 ± 213.82	9.10	2113.57 ± 134.75ɨ	6.38	2393.25 ± 907.42	36.70
Conc Peak Velocity (m/s)	2.96 ± 0.26	8.63	3.04 ± 0.22	7.10	3.03 ±0.14	4.71	3.00 ± 0.21	7.27
Height (cm)	36.00 ± 4.00	10.29	37.00 ± 1.00	3.31	35.00 ± 1.00	3.70	38.00 ± 0.03	7.84
Conc Mean Power (W)	3053.28 ± 705.92	23.12	2835.03 ± 387.56	13.67	2540.59 ± 266.54	10.49	2825.06 ± 768.43	27.25

ɨSignificant difference between guards and centres, $p > 0.05$

Table 3 shows the drop jump (DJ) performances of the subjects. All subjects' single set means were collated and analysed to achieve group overall means as well as position specific means for each variable. Mean contact times were similar across playing position (s) 0.19 ± 0.03 with a CV of 12.9%. Jump height had a similar mean across the playing positons (cm) 25 ± 5 however the CV was large 19.6%.

Table 3- Drop jump characteristics of the Australian women's basketball squad, with effect of playing position.

	Centres (n = 11)		Forwards (n = 5)		Guards (n = 9)		All Players (n = 25)	
	Mean ± SD	% CV	Mean ± SD	% CV	Mean ± SD	% CV	Mean ± SD	% CV
DJ Contact Time (s)	0.19 ± 0.02	8	0.19 ± 0.02	13	0.20 ± 0.03	17	0.19 ± 0.03	13
Height (cm)	24.0 ± 4.0	18	25.0 ± 7.0	27	26.0 ± 5.0	18	25.0 ± 5.0	20
RSI	1.24 ± 0.30	24	1.41 ± 0.52	37	1.31 ± 0.32	25	1.30 ± 0.35	27

Body mass was moderately correlated with sprint time over 5 m (r=0.45), 10 m (r=0.44) and 20m (r=.46) respectively p > 0.05. There was a small negative correlation between peak power relative to body mass and sprint time over 5m (-0.158,), 10m (-0.148) and 20m (-0.183) p > 0.05.

3.4 Discussion

This study represents the first analyses of jump power characteristics in international standard female basketball players. This study has shown that in elite players there are differences between height, mass and concentric peak force in jumping with no significant differences shown in other variables. This suggests that skills may play a larger role in determining international success once baseline performance markers have been achieved.

The performance markers seen within this study align with previous research of basketball players and illustrate the requirement of numerous physical attributes to be successful (35,41,72,98). The results of this study indicated a significant relationship between playing position and the anthropometric characteristics of female basketball players. These results mirror previous findings with centres significantly heavier and taller than guards with an average difference of 11kg and 17cm respectively. (21,35,72). Centres were also characterized in this study as having higher skinfolds than both forwards and guards although not significantly so. It has been theorized that this result may be due to the varying physical demands and skills required for these positions (28,93). Guards are expected to carry the ball up the floor and subsequently utilize a lighter frame whereas centres experience greater levels of physical contact around the post.

This study found a small negative correlation between peak power relative to body mass and sprint time over 5 m, 10 m and 20 m. This outcome is in contrast to Shalfawi et al. who showed a significant relationship between peak power relative to body weight and sprint times over 10 ($r=0.44$) and 20m ($r=0.49$) (103). The differences in these studies could be due to the use of male participants in Shalfawi's investigation who are typically stronger and have greater muscle mass. The speed of the squad over 20m was slightly faster than those already reported in the literature (3.50 – 3.76) with an average of 3.39 ± 0.18s (40,98). In this study, guards and forwards recorded faster 20m times than centres; however these results were not significant, matching the previous findings of other female basketball players (35). It should be noted however that previous research into female basketball players has utilised players at a lower representative level and junior athletes (35,41).

Basketball players time on court is consistently correlated with the anaerobic parameters of vertical jump height, speed and agility (59). The ability to produce force efficiently is essential for jumping ability for basketball players with the propulsive action considered an acceptable measure for evaluating explosive characteristics (77,118). The ability of the athletes in this investigation to consistently obtain jump height is evident with only small intra-set variability (CV 7.84%) seen in this measure for countermovement jumps. It is interesting to note that concentric peak force had greater intra-set variability then jump height and concentric peak velocity suggesting that CMJ performance may be improved within this squad by reducing variability of lower body force production (32,112). The peak velocity of the players in this investigation (3.00 ± 0.21m/s) is comparable to other sports with examinations of women's football (3.00 ± 0.20m/s) and netball (2.80 ± 0.20m/s) reporting similar values (113). It could therefore be interpreted that the strength levels within this squad need to be improved for greater jump performance as the ability to generate speed is less variable (CV 7.24%) with the squad however force production variation was large (CV 36.7%). The link between maximal strength levels and power production has been well established (101,109) but requires further investigation with this cohort of athletes as strength testing was not conducted. Centres had marginally lower velocities and higher absolute peak forces compared to the guards indicating they are could be more reliant on force generation through strength to perform the jumps, opposed to a potentially more energy efficient and coordinated jumping pattern of the guards.

The assessment of drop jumps were used in this investigation to provide information regarding fast SSC muscle contractions (<0.25s). The squad mean contact time of 0.19 ± 0.02s indicated that a fast SSC was used by all athletes. This ground contact time was similar to those recorded in female sprinters and hurdlers (0.19 ± 0.02 s) by Hennessy and Kilty (55). The results for this squad suggest a low reactive strength ability (1.32 ± 0.37) as drop jump height (25.2 ± 5.6 cm) was less than countermovement jump height (36.0 ± 2.5 cm). This shortcoming has been associated with inadequate maximal relative leg strength as a performance limiter for drop jumps (14,91). The contact times in the current study indicate that the athletes are landing with the desired stiffness desirable to train the fast SSC however the subsequent jump heights were low yielding a low RSI (43,114). This sequence of events may indicate that muscular-tendon compliance, the subsequent velocity of the tendon recoil and the muscular rate of force development has not been effectively utilised. While CMJ height is considered a key performance indicator among basketball coaches these findings indicate that reactive strength may be an area of training which has the potential to further enhance performance in many basketball-specific movements such as sprinting (34,119). Furthermore whilst a fast SSC was used by the athletes in this squad to complete the drop jumps the contact times would not be considered by most strength and conditioning coaches as fast and are an area in which this squad could improve.

Aerobic fitness was assessed using the Intermittent recovery Level 1 Yo-Yo test which is considered a reliable and valid measure of basketball-specific endurance (22). No previous research of elite female basketball players Yo-Yo scores could be found however the metres covered for this subject group (1510 ± 326) were higher than the scores found in elite female handball players (1436 ± 222m) which displays similar aerobic requirements (85). Whilst a large variations (CV 22%) was present for this cohort such variations are not considered unusual in team sports (12). A well-developed aerobic capacity is important for basketball athletes to recover from intense actions of the game as well as preserve performance within training sessions and training blocks. Forwards had the best results in the aerobic testing with the smallest variability (1800 ± 40m), which may be indicative of the court coverage required in this position.

3.5 Practical Application**s**

This study provides insight into the physical requirements required to play elite level female basketball. It is clear that basketball players must possess high aerobic and anaerobic capacities comparable to other elite female athlete cohorts to compete at the highest level. While there were few statistically significant differences in physiological characteristics between playing position guards and forwards exhibited higher peak velocities in their CMJ and faster sprint times over 20m suggesting this may be an important performance factor for these positions. There was also a clear anthropometric difference between the playing positions with centres significantly taller and heavier than guards and forwards. International success in female basketball appears to be dependent on acquiring at least the baseline of performance markers outlined in this study complemented with superior skills.

CHAPTER 4: VARIABILITY OF JUMP KINETICS RELATED TO TRAINING LOAD IN ELITE FEMALE BASKETBALL

4.1 Introduction

Vertical jump performance has been studied extensively in male basketball players as an indicator of lower limb power, with more elite players recording greater jump heights (119). Time on court correlates highly with the anaerobic performance of vertical jump height, speed and agility indicating that physical capabilities play a strong role in team selection (59). The countermovement jump (CMJ) is considered a practical assessment tool in elite sports to examine kinetic and or kinematic performance variables (26,112).

The ability to produce force is essential for jumping ability in basketball players, with jumping considered an acceptable measure for evaluating the stretch shortening cycle (SCC) (77,118). Muscle function and the ability to quickly transition from eccentric to concentric contractions via the SCC is critical to many offensive and defensive manoeuvres performed in basketball including rebounding, shooting and sprinting. Analysis of an athlete's SCC can also be useful in monitoring the effects of fatigue on performance. This type of analysis has not been conducted previously on elite female basketball players across a competition season.

The use of a linear positon transducer (LPT) by high performance coaches and their support staff to measure CMJ performance is increasingly common. A LPT provides a portable and effective method of analysing displacement of the bar or body (31). Kinematic data from LPTs is differentiated to estimate force and power when subject mass is factored in, with strong relative validity compared with a force plate (31,32). Until recently, analysis of CMJ data has been limited to values relating to the concentric phase of the jump such as jump height and peak power. However, the importance of monitoring eccentric jump variables as a result of altered jumping mechanics after training adaptations or fatigue is now recognized (29,49). CMJ testing can also provide valuable insights into neuromuscular fatigue, response to training loads and subsequent recovery in high performance sport environments (112).

Countermovement jump analysis can provide worthwhile information, however, it is imperative that coaches understand the typical variation or repeatability of the testing. It is critical for coaches to understand where a meaningful change in performance has occurred or whether the magnitude of changes lie within the normal reproducibility of the outcome variable (jump performance) known as the typical error (60). The level of expertise an athlete has acquired in the performance skill will affect reliability, with elite athletes having a demonstrated ability to perform more consistently (102). This is in contrast to dynamical systems theory and coordination profiling that proposes that as an athlete's skill level and expertise improves the motor system variability will increase to achieve consistent performance outcomes (33). These theories propose that skilled performers adapt to their surroundings and any unique restraints (environmental, task and personal) to achieve stable task execution through movement variability. This adaptation mechanism may only be applicable to open sport skills such as shooting in basketball when under pressure from an opposing player rather than the closed skill of a CMJ, particularly in developing athletes (25,62). Consequently whilst kinetic variability is likely to be relatively stable in a CMJ this remains unknown.

Acceptable within-subject reliability for force-related measures of the CMJ has been defined as a coefficient of variation (%CV) between 2.8 to 9.5% for single trials and 0.8 and 6.2% when 6 trials are used (27,112). The error rate for a six jump protocol is estimated between 1.1-3.2% for most kinetic and kinematic variables, except for rate of force development which may be as high as 13-16% (112). While studies have focused on the magnitude of training interventions (7,29), the changes in within-subject reliability of the kinetic profile from the CMJ in an elite female basketball players across the course of a training period is unclear. Research is required to determine if kinetic variability can be decreased as a function of improved performance in basketball players.

The purpose of this study was to quantify the pattern of within-subject variability in jump height, and kinetic variables in elite female basketball players over the course of a competitive season. This investigation also sought to determine if performance increases in jump height and kinetic variables were evident within the 10 week in-season training period. This information should provide valuable insight to coaches by highlighting the specific areas athletes can target in training to improve power production and jump performance. We hypothesized that while jump performance may not improve substantially in-season, the within-subject variability of SSC parameters would likely decrease as a result of structured training throughout the competition phase.

4.2 Methods

4.2.1 Experimental Approach to the Problem

Ten female Basketball Australia Centre of Excellence scholarship holders completed a ten week in-season strength and conditioning program to improve jump technique and performance. A single group longitudinal assessment was employed over the competition season. Kinetic variables were recorded from the CMJ at three different time points across the season (pre-, mid- and post-season) with within-subject and between-subject reliability analysis undertaken to assess kinetic variability.

4.2.2 Subjects

Australian female junior and senior representative basketball players (n=10) aged 18 ± 2 y, height 184.7 ± 9.0 cm, mass 75.2 ± 7.2 kg, sum of seven skinfolds 82.6 ± 13.9 mm (mean ± SD) participated in this study (n = 10). All players performed jump testing as part of their usual athletic training program during a designated afternoon training session. Informed consent was given by all subjects with ethics approval granted through the Australian Institute of Sport Ethics Committee. Players were excluded from individual testing sessions if they were not currently completing a full training load for basketball due to injury, fatigue or illness. All subjects had a minimum of 12 months resistance training experience and up to 6 years.

4.2.3 Procedures

Resistance Training and Training Load. Athletes were required to complete their usual periodized resistance training sessions consisting of 2-3 full body sessions per week (depending on scheduling of games). The distribution of exercise selection and consequent loading across each training week was stability and control 20%, power 30-40%, and strength 40-50%. Mean weekly training load consisted of three full team on-court training sessions of 2-2.5 h duration, two individual high intensity on-court training sessions of 30 min duration, and two low-intensity 60 min shooting sessions. This load was elevated at the mid-season point during an intensive training camp of 5 days duration to a mean of 4 h of court-based team training daily – approximately a 2-fold increase (doubling) in duration. Rating of perceived exertion was collected following each training session on the Borg 10 point scale (18). Athletes were required to identify the RPE for each session and this was multiplied by the session duration. The total training load using the session-RPE method for each week was calculated as the total load sum of sessional data for each athlete aggregated as a group mean.

Jump Tests. Countermovement jump data was collected with a Gymaware™ optical encoder (50 Hz sample period with data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia). The Gymaware™ optical encoder was attached via a tether to the right side of a 0.3 kg wooden bar. Bar placement on the back for each subject was between the superior portion of the scapula and vertebra C7. The stance for each subject was constrained to within 15 cm of the lateral portion of the individual's deltoid as specified by McBride et al. (82). Subjects initiated the CMJ via a downward countermovement to a self-selected depth, followed immediately by a maximal effort vertical jump. Subjects were instructed to keep constant downward pressure on the bar throughout the jump and encouraged to reach a maximum jump height with every trial in an attempt to maximize power output. Subjects were encouraged and reminded between trials to "jump high" & "jump fast". Each subject performed 5 trials, with a small pause between each trial to steady themselves and stand tall.

Prior to jump testing, all athletes completed the same 10 min warm up consisting of dynamic flexibility work followed by 10 bodyweight squats, three bodyweight CMJ's at 60% maximal effort and three bodyweight CMJ's at 90% maximal effort. All athletes had previously completed this type of jump testing as part of their regular training for at least 4 weeks prior to the investigation.

4.2.4 Statistical Analyses

Mean and standard deviation (SD) were calculated for the kinetic and kinematic variables at pre-season, mid-season and post season. Independent variables were the time point of the testing (pre / mid /post) while the dependant variables were power, velocity, force, jump height and dip. The effect of training on jump performance was quantified by determining the mean change in test scores over the 10 week training period using an independent student's t-test. Precision of estimation was expressed as the 90% confidence limits. A standardized mean effect was used to characterize the magnitude of change. Magnitudes of standardized effects were interpreted against the following criteria: trivial 0.0, small 0.2, moderate 0.6 and large 1.0 (58). An effect was deemed unclear if its confidence limits simultaneously overlapped the thresholds for a substantially positive and negative change.

To examine the mean within-subject variability in jump performance and kinetics at baseline and changes in variability across the season we computed the %coefficient of variation (%CV). To compare the magnitude of change in variation for phase of the season we divided the %CV for consecutive pairs of testing sessions. Ratios within a range of 0.87 to 1.15 were considered trivial; a ratio> 1.15 indicates that CMJ performance was substantially more variable, whereas a ratio <0.87 indicate test results were substantially less variable (36).

To examine the mean between-subject variability in jump performance and kinetics at baseline and changes in variability across the season we calculated an interclass correlation coefficient (ICC). We interpreted the magnitude of the correlation using the thresholds of 0.20 (low), 0.50 (moderate), 0.75 (high), 0.90 (very high) and 0.99 (extremely high) consistency (60). A difference > 0.10 in the correlation coefficient between time points across the season was deemed substantial.

4.3 Results

No substantial changes in jump performance occurred from pre- to post-season (Table 4), with jump height performance measures stable at all measurement points across the season. A moderate reduction in Watts/kg and a small reduction in concentric mean power was evident from the pre-season to mid-season. These effects were reversed however by the end of the season with a moderate and small increase in these measures from the mid-season to post season. There were decreased values for %CV, suggesting more consistent jumping, from the beginning of the season to mid-season (which coincides with the period of the highest training loads) in all variables except jump height.

Table 4- Changes in within-subject lower body power characteristics in junior women's basketball players across a season using a countermovement jump.

%CV coefficient of variation; pre-season; mid-season, post-season; X change in the mean, mod moderate, Ecc Eccentric, Conc Concentric.

	Pre-season		Mid-Season		change (pre v mid)		Post-Season		change (pre v post)		change (mid v post)	
	Mean	%CV	Mean	%CV	X	Effect size	Mean	%CV	X	Effect Size	X	Effect Size
Mass (kg)	76.2 ± 7.6		76.3 ± 8.3				76.4 ± 7.8					
Watts/kg	43.0 ± 5.1	12	41.1 ± 4.4	11	-2.0	-0.36 mod	43.2 ± 7.2	17	0.17	0.00 trivial	2.13	0.35 mod
Peak Power	5130 ± 862	17	5160 ± 651	13	30	0.06 trivial	5039 ± 889	18	-91	-0.10 trivial	-121	-0.16 trivial
Peak Watts	67.2 ± 9.6	14	67.8 ± 6.8	10	0.18	0.05 trivial	66.3 ± 12.2	18	-2.0	-0.17 trivial	-1.5	-0.22 small
Conc Mean Power	3275 ± 592	18	3129 ± 422	14	-171	-0.26 small	3269 ± 499	15	-30	-0.03 trivial	140	0.23 small
Conc Peak Velocity	3.22 ± 0.25	8	3.23 ± 0.19	6	-0.02	-0.05 trivial	3.23 ± 0.24	7	-0.02	-0.08 trivial	0.01	-0.03 trivial
Height	0.39 ± 0.05	13	0.40 ± 0.07	17	0.004	0.00 trivial	0.39 ± 0.06	15	-0.01	-0.18 trivial	-0.01	-0.18 trivial
Dip	0.43 ± 0.11	27	0.46 ± 0.11	25	0.013	0.26 small	0.44 ± 0.12	29	-0.004	-0.02 trivial	-0.02	-0.21 small
Ecc Peak Velocity	1.0 ± 0.2	23	0.9 ± 0.2	19	-0.07	-0.09 trivial	1.0 ± 0.2	22	-0.05	-0.04 trivial	0.02	0.05 trivial

Table 5 details the inter-set reliability across the season, with mid-season showing the highest variation in executing five CMJ in all variables except eccentric peak velocity, dip and height which remained stable. Eccentric peak velocity also had a large increase in variability in the post-season testing exhibited a within-set %CV of 46% - however this change was deemed unclear. There were substantial improvements in within-set reliability for Mean W/kg and mean power from pre-season to post season testing. Concentric peak velocity, jump height and dip showed the greatest consistency from pre- to post-season with the CV ranging from 6-10%. However concentric peak velocity was less reliable mid-season with an increase in CV% and a substantial reduction in reliability from moderate to low.

Table 5- Inter-set reliability of performing five counter movement jumps (CMJ) at each time point presented as %CV, 90% confidence interval, and the intraclass correlation coefficient (ICC).

	Pre-Season	Mid-Season	Post-Season
Mean W/kg	12, 9 – 22 0.46	14, 11 – 27 0.29	9, 7 - 17 0.69
Peak Power	15, 11 – 27 0.62	18, 14 – 34 0.22	15, 12 – 28 0.50
Peak Watts	15. 11 – 27 0.45	18, 14 – 34 0.05	15, 12 – 28 0.54
Mean Power	12, 9 – 22 0.64	14, 11 – 27 0.46	9, 7 - 17 0.69
Conc Peak Velocity	6, 5 – 11 0.62	8, 6 – 15 0.17	6, 4 – 10 0.60
Height	7, 5 – 11 0.79	8, 6 - 15 0.84	6, 5 – 11 0.87
Dip	9, 7 – 15 0.93	10, 7 – 17 0.89	7, 5 – 12 0.94
Eccentric Peak Velocity	27, 24 - 67 0.58	22, 18 - 50 0.59	46, 43 – 138 0.43

Thresholds for ICC: 0.20 (low), 0.50 (moderate), 0.75 (high), 0.90 (very high) and 0.99 (extremely high) consistency

Group training loads were recorded to be the following: pre-season 3195 ± 1083 (arbitrary units; mean ± SD), mid-season 4344 ± 1376 and post season 2161 ± 1043. The groups training loads were markedly higher during mid-season, corresponding with high reported RPE values.

4.4 Discussion

A ten week in-season competition phase did not elicit substantial changes in jump performance in a cohort of elite Australian representative female population. While kinetic performance of relative (moderate) and mean (small) concentric power declined from pre- to mid-season, these measures were restored by the post-season. Consistency of jumping (reliability) in context of performing the standard five jump CMJ protocol was improved across the course of the season for mean Watts/kg, mean power, concentric peak velocity, jump height and dip. These outcomes indicate that while performance markers such as height and power did not improve, consistency of jump performance improved as a result of a structured training program throughout the competition phase. Within-subject variation decreased across the season in mean power and dip whereas height and concentric peak velocity remained steady, demonstrating increased reliability as well as consistency in the primary performance outcomes.

The ability to produce force efficiently is essential for jumping ability for basketball players, with the propulsive action considered an acceptable measure for evaluating explosive characteristics (77,118). In the protocols used in this investigation (i.e. restricting arm swing), jump height values are lower than those reported in other investigations that permitted a more natural jumping action. Concentric peak velocity, jump height and dip showed the greatest consistency from pre- to post-season with the CV ranging from 6-10%, which may be attributed to the established relationship between jump height and velocity (50). The concentric peak velocity of the players in the pre-season of this investigation (3.22 ± 0.25 m/s) was comparable to other sports of similar age and performance (women's football 3.00 ± 0.20m/s and netball 2.80 ± 0.20 m/s) (113). Concentric peak velocity was less reliable mid-season with an increase in the CV% and a marked reduction in the intra-set consistency from moderate to low reliability. This reduction may relate to altered jumping mechanics of the athletes during this fatigued training period as dip was increased to maintain jump height despite more variable velocity measures. The altered jumping mechanics may also explain the large changes in the power characteristics observed in the peak power, peak watts and concentric mean power as the athletes modified their jump in order to achieve the performance outcome of jump height.

The improved consistency of jumping in this squad may be attributed to improvements in coordination, control and skill as the season progressed. The likely explanation is improvement in jumping motor patterns. Given the limited experience of strength training in the majority of the squad, motor learning as described by Newell would most likely have occurred throughout the competition phase (90). Strength and power levels can increase significantly for athletes trained in a supervised environment, when compared to those training in an unsupervised environment (30). An increase in motor control and coordination of jumping skills would be anticipated in athletes training for the first time within a centralized training environment under direct coaching and supervision (117). It is likely that the athletes in this investigation were beginning to master the skill of jumping as demonstrated by the ability to perform more consistently (102). This outcome follows traditional motor learning principles that once skilled performance has been acquired there is likely a concomitant reduction in coordination variability. However the changed dip patterns seen in this squad following fatigue raises the question of whether coordination variability in athletes is influenced by both adaptation and fatigue.

With increased training loads during mid-season (4344 ± 1376) compared to pre-season (3195 ± 1083), the magnitude of the dip was increased across the squad suggesting that the athletes were completing a deeper squat prior to commencing the jump, to generate the necessary power to achieve a similar jump height. This outcome may be explained by the concept that skilled performers are able to demonstrate increased movement variability and altered movement strategies to achieve consistent performance outcomes (49,77). Impulse was likely to have been altered in this fatigued state with time under the force-time curve increased (68). This effect is likely related to athletes inherently trying to generate more force through increased eccentric loading when in a fatigued state, although only a trivial positive increase in peak power and peak watts was observed from pre to mid-season. Elite snowboard cross athletes exhibited a similar change in jump mechanics when athletes were fatigued with increased dip in an effort to maintain jump height (49). While neuromuscular fatigue appears to have altered the biomechanics of the CMJ through increased dip measures in both Gathercole's research and this investigation, no significant decreases in capacity were evident (49). This outcome may be explained by the motor learning concept that in well-learned movements, consistent performance outcome is often associated with high intra-limb joint coordination variability whereby the movement pattern an athlete uses may appear different but the end result is the same (88).

When training loads based on RPE were at their highest point (mid-season), the within group variation in selected kinetic variables was reduced. It might be the case that neuromuscular fatigue limits the jumping capacity of the best overall jumpers and bringing them to similar levels of lesser skilled jumpers within the group. Neural control as demonstrated through coordination could be compromised following fatigue and affect the strength available for optimal jump performance (97). The change in mean scores of peak power was increased mid-season in this squad along with small (-0.36 & -0.26) decrements of the within subject strength-based variables of relative peak watts (W/kg) and concentric mean power. This study was not able to collect strength markers at the midpoint of the season however these results are likely related to a reduction in maximum strength driven by NM fatigue. A reduction in strength has been linked to decreased jumping ability in numerous sports (82,108).

This investigation did not show any significant changes in jump performance within the 10 week in-season training block. This stability in jumping is in contrast a earlier report detailing accumulating fatigue and reduced CMJ performance across a 7 week in-season competition phase for junior male rugby league players (92). Reductions in CMJ performance was also reported in division 1 collegiate male soccer players who exhibited a 13.8% reduction in vertical jump across an 11 week season (69). While fatigue was evident in this investigation at the mid-season point as demonstrated by impaired jump mechanics, recovery was sufficient throughout the season to avoid any significant decreases in jump performance.

4.5 Practical Applications

During the course of a competitive season basketball players are exposed to a combination of the rigors of games, and training demands both on the court and in the weight room. Strength and conditioning coaches should consider monitoring movement variability of the CMJ to assess training effects as well as NM fatigue. This investigation showed increased movement variability in the CMJ when training loads were at their peak along with increased fatigue. While the commonly investigated performance marker of jump height appears stable even when players are in a fatigued state, strength and conditioning coaches can monitor eccentric jump variables for signs of overtraining or overreaching. An increase in eccentric duration has the potential to negatively affect sport outcomes. For example, a longer duration spent achieving maximal push off on the basketball court could lead to a missed pass or rebound. Given the importance of movement speed and mechanical efficiency these results could affect the training load prescribed to athletes during a competition season.

CHAPTER 5: SYNOPSIS

The purpose of these studies was to assess the physical characteristics of female basketball players and to determine the impact of seasonal load on power and movement variability. The vast majority of research to date has focused on the physiological requirements of male players with the assumption that similar qualities are required in female athletes. The limited research that has previously been conducted to examine the physiological capacities of female players has investigated junior level athletes. This study also sought to determine if jumping performance or variability could be improved in well trained female basketball players' in-season. Previous research has reported increases in vertical jump from pre to post season in junior basketball players of approximately 10% (20,80). It was unclear however if a competitive season and associated fatigue affected this capacity in national level players (20,80).

The first study highlighted the physical attributes required to be successful in female international standard basketball. It is evident that basketball players must possess high aerobic and anaerobic capacities to compete at the highest level. It was interesting to note that this study showed few statistically significant differences in the physiological characteristics between playing positions. This is contrary to the research of male players that clearly aligns physical attributes such as aerobic capacity and anaerobic power to playing position (93,99). In this study, guards and forwards exhibited higher peak velocities in their CMJ and faster sprint times over 20m than centres, suggesting this may be an important performance factor for these positions however the results were not significant. This may be due to the small sample size of athletes per playing position in the Australian squad.

The results of the first study indicated a significant ($p < 0.05$) differences between playing position and the anthropometric characteristics of players. Centres were significantly heavier and taller than guards with an average difference of 11kg and 17cm respectively. Centres were also characterized as having higher skinfolds (83.97 ± 19.29mm) than both forwards (78.33 ± 14.71mm) and guards (73.68 ± 14.88mm) although not significantly. Therefore while anthropometrical differences exist, differences in physical performance were minimal. This suggests that players who wish to be competitive in international standard women's basketball must possess a standard baseline of physical parameters regardless of playing position. These physical performance markers are then complemented with the requisite basketball skills required to be world class.

Although no previous research on Yo-Yo scores could be found in elite female basketball populations, the metres covered by this subject group (1510 ± 326m) were higher than the scores found in elite female handball players (1436 ± 222m) who display similar aerobic requirements (85). Research by Klusemann et al. (65) demonstrated that youth elite male basketball players have mean playing and break periods of 1.5 and 1 minute respectively in conjunction with high mean heart-rate values (84.3 ± 1.8% of maximal heart rate) during active in-season play. Research of this nature has not been conducted with female players to date and is an interesting area for future study. Assuming similar qualities are required of female players a well-developed aerobic capacity would be essential for basketball athletes to ensure recovery from intense actions of the game as well as preserve performance within training sessions and training blocks.

The assessment of DJ were used to provide information regarding fast SSC muscle contractions (<0.25s). The mean contact time of 0.19 ± 0.02 s indicated that a fast SSC was completed by all subjects however the squad had low RSI scores (1.32 ± 0.37) and drop jump height (25.2 ± 5.6 cm) was less than CMJ height (36.0 ± 2.5 cm) highlighting poor reactive strength qualities. The contact times indicate that landings occurred with the desired stiffness to train fast SSC, however the subsequent jump heights were low resulting in low RSI values (43,114). This ground contact time was similar to those recorded in female sprinters and hurdlers (0.19 ± 0.02s) however jump height was lower for the squad (33.8 ± 3.8cm) resulting in lower RSI values. A low performance in DJ to CMJ is associated with inadequate maximal relative leg strength resulting in a reduced jump height performance (9,14). A limitation of this study is that strength testing was not conducted and it therefore cannot be confirmed that poor strength led to the low DJ height performances. Due to the timing of the investigation (within a national squad training camp and prior to an international tour) the national coach used his discretion to exclude strength testing from the program to minimise injury risk and delayed onset muscle soreness for players vying for tour selection.

It should also be noted that whilst contact times exhibited in this study were fast according to the literature description of <0.25sec, the squad average of 0.19 ± 0.02 s would anecdotally be considered slow by many strength and conditioning coaches, who would aim to improve this contact time through targeted training programs. A twelve month investigation of elite male volleyball players found improved depth jump ability was strongly associated ($r = 0.865$; $p<0.001$) with significant increases in CMJ height (104). These findings support research in male professional basketball players that illustrate the strong link between reactive strength profile and CMJ jump height (79). Thus, reactive strength training has the potential to enhance performance in many basketball-specific movements such as CMJ, sprinting and rebounding (34,119).

In the second study it was found that a ten week in-season competition phase did not elicit substantial changes in jump performance in a cohort of elite Australian representative female basketball players. These findings are similar to those of in-season netball players who exhibited no significant improvements during a competition phase (84). This implies that in-season schedules in female court sports impede jumping performance. Jump height measures were stable at all data collection time points throughout the season, again reflecting similar findings to those of netball athletes who exhibited unclear changes in jump height over the course of an 18 week training period (84). Whilst strength and conditioning coaches aim to increase physical parameters throughout the year competition demands often limit positive adaptations and as such maintenance of these qualities can be seen as a positive.

Basketball coaches consider CMJ height as a key performance indicator, and subjects in this study were able to consistently obtain jump heights throughout the season (38.00 ± 0.03cm) with only small intra-set variability (CV 7.84%). Investigations into elite female rugby, male youth rugby union players, AFL and soccer have all shown decrements in CMJ performance via increased NM fatigue whilst in-season, suggesting that maintenance of the qualities in-season may be an above average result (26,48,69,92). Peak velocity during the CMJ (3.00 ± 0.21m/s) was comparable to other sports with reviews of women’s football (3.00 ± 0.20m/s) and netball (2.80 ± 0.20m/s) reporting similar values (113). Concentric peak force had greater intra-set variability (36.70%) than jump height (7.84%) and concentric peak velocity (7.27%) suggesting that CMJ performance may be improved within this squad by reducing variability of lower body force production.

It has previously been determined that maximum vertical jump height is dictated by muscle strength, however, performance is dependent on the coordinative control of muscle properties (15). It is therefore imperative for strength and conditioning coaches to address movement technique to improve jump performance. It is consequently not surprising then that research has shown that a combination of strength and plyometric training is the most effective method to improve the intramuscular coordination of the SSC in the CMJ as well as force production capacities (42,43). Strength and conditioning coaches should also be mindful of how they teach jumping technique as research has recently demonstrated the effects of feedback on performance outcomes (63,116). An investigation by Wulf & Dufek (116) concluded that the instructions and feedback provided to athletes dramatically influenced their CMJ performance. The use of an external focus of attention (EF) such as jumping as high as possible to touch a suspended object resulted in greater CMJ performance than an internal focus of attention (IF) such as focusing on the extension of the legs (116). Interestingly, when athletes were provided augmented feedback such as visual displays of jump height immediately post jumping, this instantaneously led to improvements in motor performance (63). It is not yet known if augmented feedback could help in providing motivation as well as an external focus of attention via performance measures, to assist well trained athletes to maintain jump performance throughout a competition season. This is an area that requires further research and may have the potential to reduce variability particularly when combined with proven performance enhancement methods of strength and plyometric training.

A key finding of the second study was increased movement variability in the CMJ when training loads were at their peak (mid-season) coinciding with increased fatigue. An investigation by Cormack (26) found NM fatigue peaked in AFL players following several in-season games prior to a bye. It has been theorised that athletes involved in high-level weekly team sport competition may have a threshold capacity to cope with repetitive loading, however when this is breached they enter a phase of NM overreaching (87). Given effective periodisation and rest this has the potential to lead to positive training adaptations, however in many professional sports this recovery phase is restricted in-season. As a result strength training is often the first training component to be modified with decreased volumes and duration for in-season athletes to assist with recovery between games.

While performance markers such as jump height and power did not improve over the season, consistency of jump performance improved as a result of a structured training program throughout the competition phase. Within-subject variation decreased across the season in mean power and dip, whereas height and concentric peak velocity remained steady. This was demonstrated through increased reliability as well as consistency in the primary performance outcomes. The results may be explained by dynamic systems theory and the description by Bosch (19) of movement technique whereby parts of the technique are stable economical components (attractors) and others are unstable high energy components (fluctuators). A combination of attractors and fluctuators are required for fluid human movement and are important in creating robust athletes with numerous neuromuscular strategies to utilise (19). This is potentially exhibited in the results of this study whereby within-subject variation of the fluctuators of dip and mean power were decreased across the season and the attractors of height and concentric peak velocity remained steady.

The improved consistency of jumping seen in this study may be attributed to improvements in coordination, control and skill as the season progressed resulting in enhanced jumping motor patterns. Given the low resistance training age in the majority of the squad, motor learning as described by Newell would most likely have occurred throughout the competition phase (90). As jump performance became more consistent it is likely that the athletes in this study were beginning to master the skill of jumping (102) This outcome follows traditional motor learning principles that propose once skilled performance has been acquired there is likely a concomitant reduction in coordination variability in key variables.

Given the established relationship between jump height and velocity it is unsurprising that concentric peak velocity, jump height and dip showed the greatest consistency from pre- to post-season with the CV ranging from 6-10% (50). The concentric peak velocity of the players in the pre-season (3.22 ± 0.25 m/s) was comparable to those players in other sports of similar age and performance (women's football 3.00 ± 0.20m/s and netball 2.80 ± 0.20 m/s) (113). Concentric peak velocity was less reliable mid-season with an increase in the CV% and a marked reduction in the intra-set consistency from moderate to low reliability. This reduction may relate to altered jumping mechanics of the athletes during this fatigued training period, as compensatory mechanisms in the form of increased dip were executed to maintain jump height.

Trivial positive changes in the power characteristics of peak power and peak watts were observed as dip patterns were changed following fatigue at mid-season. Whilst not measured in this study it is probable that impulse would have been altered with time under the force curve increased (29). The mechanism for this is not completely understood but may be due to decreased reflex sensitivity that occurs following fatiguing exercise (10). This acts to protect muscle fibres from further damage by effecting eccentric function (10). The increased dip duration may also be due to subjects inherently trying to generate more force through increased eccentric loading when in a fatigued state (49). It is therefore suggested that strength and conditioning coaches should monitor eccentric jump variables for signs of overtraining or overreaching. It also raises the question of whether coordination variability in athletes is influenced by both adaptation and fatigue.

This study provides valuable insight into some of the physical requirements required to play elite level female basketball. It is clear that basketball players must possess high aerobic and anaerobic capacities to compete at the highest level. Physiological characteristics were not statistically different between playing positions in female basketballers however, there were clear anthropometric differences between playing positions with centres significantly taller and heavier than guards and forwards. International success in female basketball appears to be dependent on acquiring at least the performance markers outlined in this study and complementing them with superior basketball specific skills.

This study showed increased movement variability in the CMJ when training loads were at their peak along with increased fatigue. Strength and conditioning coaches should be cognisant of monitoring movement variability of the CMJ to assess training effects as well as NM fatigue. Throughout the course of a competitive season basketball players are exposed to a combination of the physical demands of games, and training demands both on the court and in the weights room. Monitoring of eccentric jump variables for increases in eccentric duration has the potential to flag signs of overtraining or overreaching in athletes. Given the importance of movement speed and mechanical efficiency the methods used to monitor CMJ variables in this study have the capacity to affect the training load prescribed to athletes during a competition season.

In the Chapter 3 investigation the following hypotheses were proven to be correct;

- Centres and forwards were significantly ($p>0.05$) taller and heavier than guards.
- Whilst centres did exhibit the highest concentric peak power (W/kg) (59.29 ± 7.89) although this was not significantly greater than the forwards (58.32 ± 10.26) or guards (58.94 ± 5.35).
- Jump height measures neither increased nor decreased over the course of the season.

In the Chapter 4 investigation the following hypotheses were proven to be incorrect;

- Guards did not exhibit the highest jump height (cm) in the CMJ. Guards had the lowest average jump heights of the squad (35 ± 1.00) when compared to centres (36 ± 4.00) and forwards (37 ± 1.00)
- Guards did not exhibit higher concentric peak velocity measures than forwards and centres in the CMJ. There were no significant differences between positions with centres (2.94 ± 0.26m/s) forwards (3.04 ± 0.22m/s) and guards (3.03 ± 0.14) all recording similar values.
- The variability of SSC parameters did not decrease as a result of a structured training environment. This investigation found increased variability of SSC parameters in particular dip at the mid-season timepoint. These qualities were restored by the end of the season and seem to be dependent on fatigue.

5.1 Recommendations

Based on the findings from this study it is recommended that strength and conditioning coaches use the aerobic and anaerobic markers outlined in this investigation as baseline performance targets for speed, CMJ and aerobic capacity. As playing position did not influence the physiological capacities of the players it is suggested that female basketballer's must possess all the aforementioned physical traits in order to compete at the highest level. It is suggested however, that improving the reactive strength qualities in this athletic population would lead to improvement in the CMJ and faster sprinting speeds. Jump height was maintained in this study even when in-season training loads were at their highest point and thus jump height alone does not indicate fatigue. It is therefore recommended that coaches monitor eccentric duration and dip in the CMJ for signs of fatigue. Coaches can utilise jump testing at least 3 x season to monitor the performance of their athletes but may find benefit from more frequent weekly testing to observe any peaks or troughs in jumping ability.

5.2 Future Research

The continued growth and professionalism of women's basketball provides researchers with opportunities to increase the depth of knowledge relating to the physiological characteristics of international standard players. Further research into women's basketball is needed to assess the strength qualities of female players and to determine if this influences on-court performance in athletes of this calibre. There is also the potential that strength could limit the effects of high in-season training loads on movement variability in the CMJ. An increased understanding of the role of strength in women's basketball would allow strength and conditioning coaches to target their programs effectively throughout the year to ensure positive adaptations and greater performance outcomes.

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APPENDICES

APPENDIX A

STUDY 1 – INFORMED CONSENT (MINOR)

Project Title: **Counter-movement and jump drop characteristics of Australian elite female basketball players.**

Principal Researchers: **Jan Legg**

This is to certify that I, ______________________ hereby agree to give permission to have my child participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Jan Legg.

The investigation and my child's part in the investigation have been defined and fully explained to me by Jan Legg and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions my child or myself may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that my child is free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that my child is free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage.
- I understand that my child is free to withdraw his/her data from analysis without disadvantage.
- I understand that any data or answers to questions will remain confidential with regard to my child's identity.
- I certify to the best of my knowledge and belief, my child has no physical or mental illness or weakness that would increase the risk to me (him/her) of participating in this investigation.
- My child is participating in this project of my (his/her) own free will and My child has) not been coerced in any way to participate.

Signature of Participant: _________________________________ Date: ___/___/___

Signature of Parent or Guardian of minor: (under 18 years) _______________________Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: _______________________________ Date: ___/___/___

APPENDIX B

STUDY 1 – INFORMED CONSENT (Adult)

Project Title: **Counter-movement and jump drop characteristics of Australian elite female basketball players.**

Principal Researchers: **Jan Legg**

This is to certify that I, ______________________ hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Jan Legg.

The investigation and my part in the investigation have been defined and fully explained to me by Jan Legg and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.
- I understand that I am free to withdraw my data from analysis without disadvantage to myself.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participating in this investigation.
- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ________________________________ Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________ Date: ___/___/___

APPENDIX C

STUDY 2 – INFORMED CONSENT (MINOR)

Project Title: **Counter-movement jump characteristics of in-season Australian elite female basketball players.**

Principal Researchers: **Jan Legg**

This is to certify that I, ______________________ hereby agree to give permission to have my child participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Jan Legg.

The investigation and my child's part in the investigation have been defined and fully explained to me by Jan Legg and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions my child or myself may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that my child is free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that my child is free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage.
- I understand that my child is free to withdraw his/her data from analysis without disadvantage.
- I understand that any data or answers to questions will remain confidential with regard to my child's identity.
- I certify to the best of my knowledge and belief, my child has no physical or mental illness or weakness that would increase the risk to me (him/her) of participating in this investigation.
- My child is participating in this project of my (his/her) own free will and My child has) not been coerced in any way to participate.

Signature of Participant: ________________________________ Date: ___/___/___

Signature of Parent or Guardian of minor: (under 18 years) ______________________Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________ Date: ___/___/___

APPENDIX D

STUDY 2 – INFORMED CONSENT (ADULT)

Project Title: **Counter-movement and jump drop characteristics of in-season Australian elite female basketball players.**

Principal Researchers: **Jan Legg**

This is to certify that I, ______________________ hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Jan Legg.

The investigation and my part in the investigation have been defined and fully explained to me by Jan Legg and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.
- I understand that I am free to withdraw my data from analysis without disadvantage to myself.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participating in this investigation.
- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ________________________________ Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________ Date: ___/___/___

APPENDIX E

FORM E: DECLARATION OF CO-AUTHORED PUBLICATION CHAPTER

Declaration for Thesis Chapter 3

Declaration by candidate,

In the case of Chapter 3, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Primary researcher and author of manuscript	80%

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Contributor is also a student at UC Y/N**
Kym Williams	Assistant in data collection	Y
David Pyne	Assistance in data collection and statistical analyses	N
Stuart Semple	Editorial assistance (supervisor)	N
Nick Ball	Editorial assistance (primary supervisor)	N

Candidate's Signature		**Date** 27/01/2017

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Australian Institute of Sport, Strength and Conditioning**

Signature 1		**Date** **27/01/2017**
Signature 2		
Signature 3		