Ground Reaction Force Profiles of Specific Jump-Landing Tasks in Females:

Development of a systematic and progressive jump-landing model

Guy Mothersole:

A thesis submitted to the
Auckland University of Technology
in fulfillment of the requirements for the degree of
Master of Sport and Exercise (MSpEx)

2013
Faculty of Health and Environmental Sciences

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Guy Mothersole

21st September 2013

CO-AUTHORED WORKS

The following three manuscripts have been accepted or are in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis.

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

Mothersole, G. M., Cronin, J., and Harris, N. (2013). Jump-landing program for females: development of a systematic progression model. *(Target journal – Strength and Conditioning Journal)*

Mothersole, G. M., Cronin, J., and Harris, N. (2013). Ground reaction forces associated with different landing tasks in females. *(Targeted journal - Journal of Strength and Conditioning Research)*

ACKNOWLEDGEMENTS

Firstly I would like to extend my gratitude to my primary supervisor Professor John Cronin. Your encouragement and guidance during this process has been invaluable, and your ability to challenge me has had a profound impact on the quality of this thesis. Your passion for learning has inspired me to continue my quest for knowledge.

Nigel Harris, your diligence has played a crucial role in this process, and thus I also consider you a primary supervisor. You've been outstanding in leading me through the thesis procedure and your critical eye has been much appreciated.

I would also like to acknowledge Netball New Zealand, and especially Megan Crockett for providing me with the opportunity to complete this research. Your patience and prompt support have been greatly valued. Also, thank you also for providing me with enthusiastic subjects from each of the regions I travelled to.

Furthermore I would like to acknowledge Stephanie Vague for your personal and professional support. Thank you for investing your time to read what at times must have been tedious and wearisome. I know that you have read my work with just as much enthusiasm as I have put into writing it. Your critical lens has greatly enhanced the readability of this manuscript.

Finally to my partner Pippa. I believe you are the only person who truly understands what this means to me. Thank you for your attention and support in all areas of my life. You've provided me with the opportunity to realise and appreciate what I have achieved, and it means so much more to me to experience this with you.

INTELLECTUAL PROPERTY RIGHTS

ETHICAL APPROVAL

Ethical approval for the commencement of participant involvement for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). Ethics Application Number 10/164: Date if approval 15 June 2011.

NOTE TO THE READER

Excluding chapter one and five, this thesis is presented as a series of chapters in publication submission format, which in some instances, due to the chosen submission format, there may be some repetition. Furthermore there may be a difference in writing style between the chapters so as to make them appropriate for the specific targeted journals. This thesis fulfils the AUT University Master of Sport and Exercise guidelines by conducting an applied research investigation in a relevant area. These pieces of research critique previous literature relevant to the topic and provide experimental application to the growing body of knowledge.

Dedicated to anyone who has the

courage to continually learn

ABSTRACT

During dynamic fast paced sports, such as netball, volleyball and basketball the body is exposed to high ground reaction forces (GRF), contributing to lower body injury occurrence during landing. A certain amount of conditioning and/or technique training to effectively mitigate injury risk and improve performance is particularly important amongst a female population. Therefore the initial aim of this thesis was to systematically review the literature on jump-landing progressions. This incorporated an in-depth discussion of the prerequisite factors which were thought critical when progressing jump-landing stimuli during training.

Following the review of literature a systematic model aimed at progressing jump-landing proficiency was presented, which targeted training components for effective program implementation. This model addressed the issues of incorrect landing technique, insufficient muscular strength and lack of balance and neuromuscular control. Each of these concerns are integrated into specific phases and training components aimed at progressively overloading the subject during landing.

Understanding the magnitude of the GRF associated with various jump-landing patterns was the aim for the final part of this thesis. Presented as a cross sectional experimental study, this section quantified the GRFs experienced during progressive drop-landing tasks. This study informed the exercise prescription for Phase 2 of the training model developed in the previous chapter. Twenty-one netball players from the National Talent Development squad volunteered to participate in a study to quantify the vertical (VGRF), horizontal (HGRF) and lateral (LGRF) GRFs when jump height and distance were systematically increased across bilateral and unilateral landings. Three different heights (15, 30 and 45 cm), distances (40, 80 and 120 cm) and landing strategies (bilateral forward, unilateral forward and unilateral lateral) were used to create 27 jump-

landing conditions. Two-way analysis of variance was used to analyse the effects of drop height and jumping distance for each landing strategy. It would appear that increasing height and distance significantly increased VGRF (mean = 18.1%) for all landing strategies. HGRF was more dependent on changes in height for forward landings, while increases in both drop height and/or jump distance were shown to be effective methods of increasing LGRF (mean = 36.2%) for single leg landings. These results can be used to systematically overload jump-landing exercises, which may therefore enhance training prescription to improve performance and decrease injury.

CHAPTER 1

INTRODUCTION

Netball has one of the highest injury rates per participant of any sport (25). Research statistics regarding specific netball injuries observed 70% were GRF related, of which, 44% were directly linked to incorrect or poor landing patterns (38). Furthermore 66% of injuries that are lower extremity related, 26% occur at the ankle and 18% are derived from the knee (56). Netball is a sport that is characterized by many multidirectional landing patterns which have been deemed as potential injury hazards of the lower limbs (33). Statistics from accident compensation corporation (ACC) and NetballSmart (1) reveal that in New Zealand in 2010 alone there were 23,825 accepted netball related ACC claims which amounted to a total cost of $13,343,000. What makes these statistics more alarming is that out of the 23,825 claims, 14,575 were landing related and were responsible for a total cost of $10,911,00. These statistics are accumulated using information regarding injuries related to the hip, upper leg, thigh, knee, lower leg, and ankle and toe region, all of which are associated with landing performance.

Various studies have explored the relationship between ground reaction forces (GRF) and different physical activities and movements. Research from Hagen, Hennig, & Stieldorf (27) studied the effect of walking, nordic walking and running at various velocities. GRF was measured and equated to participants body weight (BW) to make it a relative figure. The findings revealed that walking was shown to have the lowest GRF during each velocity, however there was a trend of increasing GRF as the velocity increased from 5.0kph to 8.5kph. Also, running at 8.0 and 8.5kph produced significantly larger GRF when compared to walking, 1.8 vs 2.3 (BW) at 8.0kph and 1.8 vs 2.5 (BW) at 8.5kph respectively. A similar study explored the GRF of slow walking, brisk walking, running, and landing from a jump 30.5cm high (41). It was observed that GRF increased in a linear fashion; slow walking 1.2BW, brisk walking 1.5BW, running 2.3BW, and landing 3.5BW. Whilst the forces associated with walking and running have been shown to be relatively high, landing movements have the potential to produce much greater forces (see figure 1); therefore the focus for this thesis is landing forces.

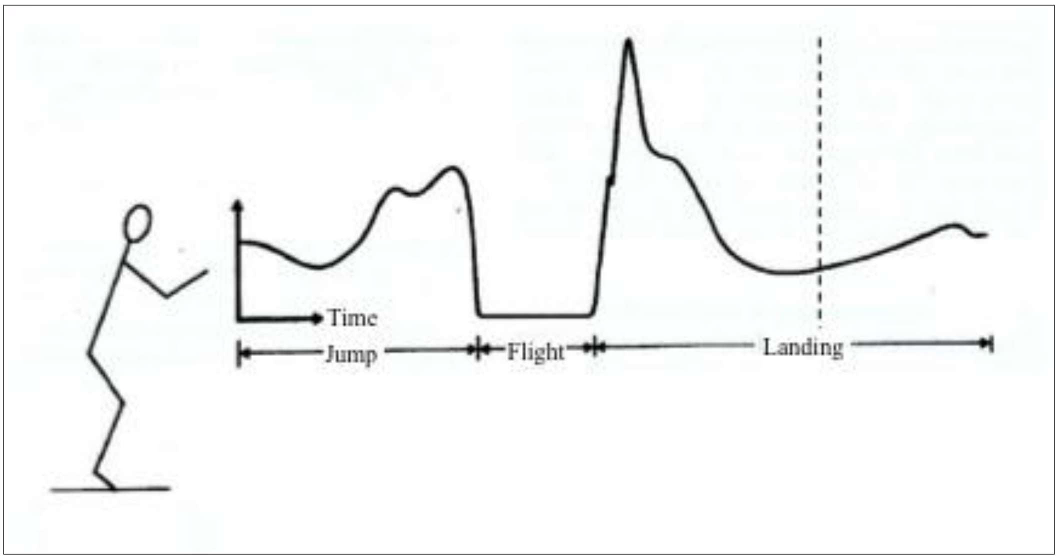

Figure 1: Typical GRF profile of a simple jump-landing sequence depicting the prominent force spike during landing.

When analysing a typical landing force profile it is common to witness two peaks in vertical force (see Figure 2). The first peak (F1) represents the initial contact of the toe and the second more pronounced peak (F2) belongs to the contact of the heel (55). It is during this heel contact that the body is under the highest eccentric load, therefore it is logical to assume that this phase of landing has the most influential effect on injury or adaptation. Although there are a multitude of kinematic and kinetic variables to consider when landing, essentially a successful landing is performed when the joints involved are able to resist collapsing by producing enough force to decelerate the body's downward momentum under control whist avoiding injury.

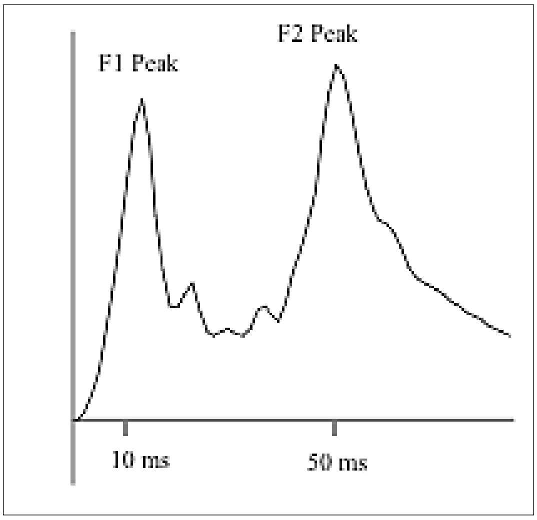

Figure 2: First and second force peaks recorded during landing.

During landing, the body is exposed to high external and internal forces which are a product of the high velocities as well as the technique utilised during the landing movement (58). The GRFs that are produced during landings in netball have been shown to be substantial for both unilateral and bilateral jump-landings. Studies have reported landing forces of between 3.3 and 6.8 times body mass (36, 63, 78). It has been proposed that GRFs produced during landing can be utilised as an accurate measure of exercise intensity as there is an association between GRF and compressive strain on the bones and surrounding musculature (84). It is also known that peak landing forces are influenced by height (landing velocity), distance (angular momentum) and technique (landing with one or two feet), however the relationship between these parameters is not clearly established (32).

The ability of a netball player to safely attenuate the forces experienced during landing may be compromised by the lack of strength and in particular eccentric strength exhibited by the musculotendinous unit which can cause weak neuromuscular control prior to contact (33). Muscle strength is thought to play a fundamental role in lower extremity biomechanics relevant to functional movement. Greater eccentric muscle activation of the hamstring muscles has been shown to produce increased flexion at the knee joint during landing, which created a better position to absorb impact forces (31).

McNitty-Gray (58) proposed that the joint motion and activity of the contracting muscles are important throughout landing as they help decrease the impact forces and increase joint stability. Although decreasing the impact forces upon landing may be recommended to decrease GRFs, there is evidence that increased muscle activity may lead to increased stresses in tissue, causing injury (58). The previous point magnifies the importance of systematically progressive jump landing conditioning programs, which aim at preparing the musculotendinous unit for the stresses experienced through netball specific jump landings.

Research from Hewett, Myer, & Ford (29) has demonstrated that biomechanical and neuromuscular differences exist between males and females during landing. The female subjects in the above study measured noticeable imbalances through ligament and muscular dominance, which has the potential to limit lower limb stability while performing dynamic tasks. When compared to male performance, it is plausible to suggest that female athletes rely on bone and passive capsuloligamentous structures to dissipate landing forces (9). It has also been shown that females tend to land in a more erect position during ground contact, which subsequently decreases hamstring activation as opposed to their male counterparts (18). However, they compensated for the high forces due to their erect initial contact position, by producing more knee and plantar flexion through the ankle. Given the various gender differences, it is important to note that inclusion or discussion of male kinematics and kinetics during landing performance is outside the scope of this thesis.

Landing movements which are characterised as plyometric exercises are often utilised by various athletes as a means of enhancing performance and also preventing injury (4, 7, 20). Intensity in plyometric exercise is defined as the amount of stress placed on the muscles, joints, and connective tissues involved in the movement (4). However, an exact way of quantifying the intensity of plyometric exercises does not currently exist. At present the variables that are being used to quantify the relative intensity are foot contacts, speed of the movement, height of drops, and the participant’s weight (4). Whilst these are deemed practical and logical, they are not a true representation of the actual stresses experienced during the execution of plyometric exercises (85).

When developing a sport specific jump-landing programme, special consideration must be given to the intensities of movement patterns specific to an activity or the sport. Various netball related studies have gone some way to identifying the intensities during competition (68), landing after receiving a jump pass (78), effect of surface on landing (80), and effects of taping and bracing the ankle during landing (36). However, there is a distinct lack of literature regarding the quantification of the movement patterns specific to netball in a manner which can be systematically and progressively overloaded. The main mechanistic culprits of lower body injuries in netball are thought to involve abrupt decelerations, in particular those experienced whilst landing from a jump (68, 71). Therefore quantifying the intensities of various jump-landings specific to netball is an effective starting point for designing a progressive netball jump-landing programme.

This thesis will present itself as three separate chapters, written as individual studies prepared for journal submission. Chapter two reviews the literature on systematically progressing jump-landing. This review incorporates an in-depth discussion of the prerequisite factors which are important to systematic progression of jump-landings.

Subsequently, chapter three presents a systematic progression model for the development of jump-landing proficiency. This model includes specific phases and training components aimed at progressively overloading the stimulus subjected upon the body during landing. Chapter 4 is a cross sectional experimental study which examines the intensity of jumps-landings during different drop-landing tasks. This is in an effort to provide exact impact force quantification. Data is presented and the trends and differences between jump-landing conditions are analysed.

PURPOSE STATEMENT

The purpose of this thesis is to: 1) explore the prerequisite factors important among systematic progressions of jump-landings; 2) develop a systematic progressive jump-landing training model; and 3) quantify ground reaction force profiles of various drop-landings specific to female performance.

SIGNIFICANCE OF THE RESEARCH

From previous netball related research (50), the different types of jumps per position are well documented. Therefore there is a need to design a landing programme that can be systematically progressed to ensure safe and clinically sound neuromuscular adaptation is achieved. It needs to have vertical, horizontal and lateral components, as well as bilateral and unilateral aspects, as these are the common jump-landing characteristics known to netball performance. More importantly, landing with control and balance requires a great deal of eccentric strength; therefore there is a need to quantify the eccentric or landing forces involved with netball specific landings.

Whilst conventional methods of quantifying jump-landing intensity are viewed as practical and logical, they are not a true representation of the actual stresses experienced during the jump-landing sequence. The landing forces experienced throughout netball are influenced by height, distance and landing technique, however the relationship between these parameters is not clearly established. A manipulation of these factors, which methodically increases task demands during landings, will help to provide information concerning the magnitude of the loads which can be safely accommodated by netball players.

Statistical findings from ACC & NetballSmart (1) show that players within the netball community aged between 10 to 15 years are responsible for the most accident injury claims which is closely followed by those between the ages of 15 to 19 years of age. Once above the age of 20 the amount of claims starts to dissipate, which may well be due to a drop in participation numbers. However one may speculate this decline in claims, or injuries, is due to the development of the muscular system as the female body matures. This shows that there is a prime opportunity to enhance both muscular and neural adaptation during this susceptible stage of development.

The study will also benefit physicians, strength and conditioning staff and coaches by providing details of prognostic and diagnostic value. Furthermore, few studies have examined the relationship between height, distance and landing strategy simultaneously and reported the subsequent effects.

LIMITATIONS

- Given that this study was cross sectional, the ground reaction forces witnessed throughout the landing conditions were merely an insight into measures on the particular testing day.
- The results from this research may not be generalised to other populations or sports.
- It is difficult to simulate performance at competition level; therefore the ground reaction forces compiled may not mimic exactly game-related situations.

DELIMITATIONS

- This study did not include the participation of subjects with a history of lower body injury within the last three months.
- All participants included in this research were female netball players from the New Zealand talent development programme. All participants were between the ages of 16 and 18 years.

CHAPTER 2

KEY PREREQUISITE FACTORS INFLUENCING LANDING FORCES IN NETBALL

INTRODUCTION

Landing is a fundamental skill of many movements performed during netball. Given that running with ball in hand is a rule violation, players often perform leaps and bounds to evade opposition in order to receive a pass. These explosive jumps combined with abrupt landing decelerations impose hazardously high ground reaction forces (GRF) on the lower body (68). As such these GRFs coupled with incorrect landing technique have been suggested as a primary cause of lower body injuries among female netball players (34, 76, 78).

A number of studies have investigated factors that influence the magnitude of landing forces. Notably drop height (10, 26, 54, 64, 70), jumping distance (21, 73, 74) and the particular skills being performed (16, 63, 75) provide varying degrees of impact upon GRF during landing. These factors can also potentially dictate the landing technique adopted by influencing knee angle (19, 21, 22) and foot placement (43, 63) depending on the landing strategy utilised. The literature suggests that adopting fundamental landing mechanics supplemented with appropriate training strategies may help to minimise injury occurrence and enhance landing performance.

In light of this information a logical step is to develop an understanding of the components that influence landing forces within netball. This article first explores the movement patterns within netball and the typical GRFs associated with various netball landings. A template of factors that may influence subsequent GRF whilst performing a successful landing ensues, and finally an overview of an “ideal” landing sequence is provided along with identified training strategies to enhance landing proficiency.

NETBALL MOVEMENT PATTERNS

Despite netball’s international popularity, there is a paucity of research identifying different patterns of landing movements with methodical consistency. The few studies that have attempted to quantify specific movements have used time motion analysis to establish patterns such as walking, jogging, and rest periods (67, 77), whilst others have captured a comparatively limited sample of landing characteristics during match play (35, 50, 79).

Lavipour (50) event coded two premier league netball games during match play with reference to jump-landing performance. All players were investigated during the two games representing four teams, 28 players and seven different player positions. Player jump movement patterns were coded as vertical, forward, or lateral in terms of direction as well as unilateral or bilateral in terms of the landing strategy. A summary of the results from this analysis can be observed in Table 1.

Table 1: Average number of jump-landings for netball during match play adapted from Lavipour (50).

Position	Average number of jumps per game	Jump Direction			Landing Type	
		Vertical	Forward	Lateral	Unilateral	Bilateral
Attack	63	23	25	15	43	21
Mid-court	69	14	33	22	44	25
Defence	42	23	13	7	28	15
Average	**58**	**20**	**24**	**14**	**38**	**20**

The average number of jump-landings recorded across all positions was 58 per game which equated to approximately one jump per minute (50). From a total of 416 analysed jump-landings, on average 42% were forward, 32% were vertical, and 26% were classed as laterally domininant, per game. Despite similar jump-landing totals, Hopper et al (35) reported 11%, 50%, and 38% for forward, vertical and laterally dominated jump-landings respectively. In addition 1% of jumps were classified as backwards however this movement was not reported in Lavipour's anaylsis.

Interestingly, with respect to landing type, regardless of jump-landing movement differentiation both Hopper et al (35) and Lavipour (50) reported that players landed unilaterally 65% and bilaterally 35% of the time (collectively). In addition, the defensive positions were significantly less likely to land on both feet (14%) as opposed to unilaterally (86%) when compared to mid-court and attacking players who landed bilaterally 44% (35). Furthermore, jumps in the vertical direction showed an equal number of unilateral and bilateral landings as opposed to a unilateral landing tendency for jumps in the forward and lateral direction (35, 50).

Lavipour's study (50) also investigated jump-landings with a 180 degree turn mid-flight along with landings that were immediately followed by another jump or explosive movement. The majority of jumps analyzed did not turn whilst in-flight except for the wing attack position, reporting a turn 66% of the time. Performing a subsequent jump after landing was more prevalent among attacking positions (32%), as opposed to defence positions (16%). It was proposed that jumps with turns mid-flight were indicitive of attacking play (50).

In summary, from the limited research on specific jump-landing charateristics witnessed during match-play, different directions and jump-landing types are associated with positional demands. Despite the inconsistent findings it should be noted that jump-landings are influenced by the inclusion of a ball, technical skill and the style of play. It is apparent that all players are exposed to each landing situation although each position demands varying degrees of jump-landing styles and strategies.

GROUND REACTION FORCES IN NETBALL

Although the action of landing remains similar for various sporting codes, how the body reacts to the landing can significantly differ. Athletes can develop specific adaptations within the body due to the demands of the activity or stresses they are subjected to (58). Therefore it is important to review netball related GRF research to gain an insight into the potential stresses that are encountered during netball performance (Table 2). The resultant GRF may be expressed as vertical (VGRF), horizontal (HGRF) and lateral (LGRF).

Steele and Milburn (79) investigated the effects of four different types of footwear and the GRFs produced by landing on one foot after performing a classic netball attacking manoeuvre. The fifteen elite netball athletes produced GRF ranges of 3.9 to 4.3 times their body weight (BW) for VGRF and 4.2 to 4.6BW for HGRF. The authors concluded that reducing GRF is more effective through alterations in landing mechanics as opposed to the specific shoe worn. Furthermore this study only used centre position players therefore the GRFs associated with other positions/movement patterns were not identified.

A follow on study by Steele and Milburn (80) examined the influence of twelve different synthetic sport surfaces on GRFs in netball landing. Ten skilled netball players performed an attacking movement involving acceleration from a standing position, an abrupt stop onto a force platform, receiving a pass and then off-loading the ball to another player. For all twelve surface conditions, the mean peak VGRF and HGRF across all subjects for dominant foot landings were 3.8BW and 3.4BW respectively.

Table 2: Quantification of various GRFs from Netball players

Study	Subjects	Movement Researched	Description	VGRF –BW (Average ± SD)	HGRF –BW (Average ± SD)
Steel and Milburn (79)	15 Elite Netball players (Centre position)	A typical netball landing manoeuvre with either barefoot (BF) or shod (S)	Each subject performed 3 trials per foot condition	BF = 4.3 S = 3.9	BF = 4.6 S = 4.2
Steel and Milburn (80)	10 skilled Netball players	An attacking movement involving acceleration from a standing position, an abrupt stop onto a force platform, receiving a pass and then offloading the ball to another player	Each subject performed 3 trials per surface condition	3.8 ± 0.8	3.4 ± 0.9
Steele and Lafortune (78)	10 skilled Netball players	The entire movement included running forward, evading a defender, leaping to receive a pass, and landing on their dominant leg	Subjects were instructed to land either on their forefoot (FF) or heel (H)	FF = 5.7 ± 1.1 H = 5.3 ± 0.9	FF = 2.0 ± 0.3 H = 3.3 ± 0.6
Hopper, McNair and Elliot (36)	15 Elite Netball players	Single leg forward jump 1.25 x their leg length	Each subject performed 3 trials for the jump	3.4 ± 0.1	N/A
Otago (68)	14 U21 Netball players	Land & step (LS) Land & pivot (LP) 2 foot land & step (2LS) Land & step & step (LSS) Land & step & pivot (LSP)	Subjects were asked to perform these tasks and land on a force plate	LS = 4.0 ± 0.1 LP = 4.3 ± 0.1 2LS = 5.7 ± 0.1 LSS = 3.5 ± 0.1 LSP = 3.7 ± 0.1	LS = 1.4 ± 0.03 LP = 1.1 ± 0.03 2LS = 1.8 ± 0.03 LSS = 0.8± 0.02 LSP = 0.9 ± 0.02

Another study utilizing match specific manoeuvres compared the GRF produced by either a forefoot or heel dominated landing (78). The classification of the landing was determined by post hoc analysis of the landing examining centre of pressure data. Ten competent netball players performed a standard netball-attacking task where they had to catch a high pass. The entire movement included running forward, evading a defender, leaping to receive a pass, and then landing on their dominant leg. Mean peak VGRF for the heel and forefoot patterns during single leg landing conditions were 5.3 and 5.7BW while HGRF were recorded at 3.3 and 2.0BW.

Hopper, McNair and Elliott (36) investigated fifteen elite level netball players executing a forward jump on to a force plate. Each subject was instructed to land on their dominant foot only. The distance jumped was calculated to be 1.25 times the subject's leg length, which was representative of a typical distance that a player may jump during a netball game, based on pilot testing. Mean peak VGRF of 3.3BW were reported.

One comparatively recent piece of research investigated the GRF of various netball landings (68). The purpose of the study was to establish whether or not an extra step upon landing would significantly alter the forces acting upon the body. The data was compiled using eighteen netball players completing five different landing conditions at two pass heights, either above the head or shoulder height. Peak VGRF across the five different landing conditions ranged from 3.5 to 5.7BW, whilst the HGRFs ranged from 0.8 to 1.8BW.

In summary, upon landing the body is exposed to substantial vertical and horizontal GRFs. The vertical component appears the larger of the two forces, with mean peak values of 5.7BW compared to 4.6BW for HGRF. Also apparent is that netball specific research quantifying the GRFs associated with bilateral landings is scarce, with the majority of the studies incorporating single leg dominant foot landings. Depending on landing condition, and with an average of approximately 60 powerful jump-landing movements per game (50), a typical netball player can experience an enormous accumulative load through the lower extremities. In addition to this load are the impact forces accumulated with walking, jogging and running between jump movements, which are indicative of natural play.

FACTORS THAT INFLUENCE LANDING KINETICS

Influental factors identified in the literature include: drop height, as this can impact on landing velocity; jump distance, which dictates angular momentum; and landing strategy, as landing with one or two feet requires differing muscular recruitment patterns and balance strategies. Auxiliary factors such as foot placement, knee angle during initial ground contact and the particular netball skill being performed during landing have also been shown to contribute a significant influence upon GRF during landing (see Table 3).

Table 3: Landing factors and subsequent effects on GRF

GRF modifiers	**Low ← Effect on Force Production**	**→ High**
Landing Height	Low Height	High Height
Jumping Distance	Short Distance	Long Distance
Landing Strategy	Bilateral	Unilateral
Foot Placement	Forefoot	Heel
Knee Angle	Soft (Bent Knees)	Stiff (Straight Knees)
Pass Delivery (VGRF)	Chest Height and Below	Above Head Height
Pass Delivery (HGRF)	Above Head Height	Chest Height and Below

Landing Height

The relationship between drop height and GRF upon landing is well documented. Caster (10) investigated the effects of increasing drop height on landing kinetics during bilateral drop landings. VGRF ranges of 3.9 to 6.6BW were reported with the authors concluding that impact forces were found to increase with height. Research with similar drop heights examined muscle activation patterns and subsequent VGRF in female volleyball players during drop jumps (26). These authors observed significant overall increases in VGRF of 49.0% ranging from 1.5 to 2.3BW as a direct result of increasing the height of the jump.

Research from Makaruk and Sacewicz (54) investigated the effects of increasing drop height on landing impact during bilateral drop jumps. A significant increase in VGRF ($p<0.01$) as a result of increasing height was reported observing VGRFs of 4.5, 5.8, and 6.5BW for 20, 40, and 60cm heights. Slightly lower VGRF ranges of 2.0 to 3.8BW were derived during drop landings from the same height increments among physically active males and females (70). However, in contrast to Makaruk's (54) findings, Peng (70) observed VGRF produced from 60cm heights were not significantly different compared to the 40cm height.

To our knowledge, only one study has investigated the effects of differing heights on all force components (64). Using bilateral drop landings from heights of 32, 52 and 72cm GRFs ranged from 3.1 to 5.3BW for VGRF, 0.6 to 1.1BW for HGRF and 0.3 to 0.5BW for LGRF. It was found that only VGRF and HGRF indicated significant differences across all three heights ($p<0.05$).

Landing Distance

The effects of incremental jump distance on GRF have not received the same attention in the literature as drop height. Simpson and Cronin (74) used a unilateral horizontal jump and explored propulsive GRF production from jump distances of 80, 120, and 160% of subject's leg length. An increase in distance had a minimum effect on the landing forces, with GRF ranging from 2.4 to 2.7BW for VGRF and a 0.6 to 0.7BW for HGRF. It was interesting to note that the lowest HGRF was generated from the furthest distance (160% leg length), and the greatest HGRF originated from the closest distance (74). It was speculated that this was due to the landing technique adopted as a result of the subject's perception of task difficulty. When landing from the shortest distance as opposed to the furthest, the subject's may have landed with less control given the perception that the landing task provided minimal risk of injury, thus landing more suddenly and producing greater HGRFs.

Another study investigating the effects of increasing jump distance on lower body kinetics explored jumps at 30, 60 and 90% of subject's leg length (73). The horizontal jumps in their study from the six female subjects equated to average distances of 43, 86, and 129 cm. Observed forces ranged from 1.4 to 2.8 BW for VGRF and 0.2 to 1.0 BW for HGRF. HGRF were different across all three heights ($p<0.05$) however only distance between 30% and 90% were found to be significant for VGRF, which were in contrast to the findings from Simpson and Cronin (74) who reported HGRFs increased as a result of increased jump distance. These differences are most likely due to the different tasks that were utilised in the two studies, Simpson and Cronin (74) reported GRFs from jumps whereas Simpson (73) reported GRFs from landings.

Research from Dufek and Bates (21) set out to develop a predictive template for impact landing forces through the use of various regression models. Jump distances of 40, 70 and 100cm produced 4.1, 4.4 and 4.5BW during bilateral landings with varying degrees of knee flexion. This equated to a total increase of 9.7% across all distances, concluding that impact forces were found to increase with distance.

LANDING STRATEGY

Many different types of landing strategies are possible when playing netball (35, 50). These range from landing with one or two feet, having to land from various directions, and deciding on a mixture of force absorption/dissipation strategies. This can be classed as the type of footfall patterns used along with the degree of knee and hip flexion present during foot contact.

BILATERAL VS. UNILATERAL

While it is well documented that injuries can occur during bilateral landings, the general consensus is that landing unilaterally carries more vulnerability to injury (52, 69, 87). This generalisation stems from the fact that unilateral landings have a decreased base of support which reduces stability and potentially increases muscle activation, creating a more abrupt landing (87).

The kinematics and kinetics between bilateral and unilateral landings were explored by Weinhandl et al. (87). It was observed that unilateral landings compared to bilateral increase VGRF by 44% along with an increase in total energy absorption of 11%. In agreement with the previous study Pappas et al. (69) observed an 18.8% increase in VGRF from unilateral drop landings in comparison to bilateral at a height of 40cm.

Both studies (69, 87) concluded that unilateral landings were accompanied by larger joint angles upon impact. It was speculated that insufficient levels of leg strength are responsible for greater joint angles (51). Lephart and colleagues (51) observed that females with increased leg strength through resistance training significantly decreased initial hip and peak knee angle during landing, thus adopting a mechanically more efficient landing style, congruent with lower landing forces.

Foot Placement

Foot placement is also referred to as a footfall pattern. Landing with the heel as opposed to the forefoot seemed to be the preferred style of landing among netball players (79, 80), although this can become problematic as heel landings have the potential to generate larger GRFs. Netball players have been reported to produce significantly greater VGRF during heel landings as compared to forefoot (7.3 vs. 2.7BW), whilst receiving a pass at chest height (63). These findings were supported by Kovacs and colleagues (43) concluding the heel landings produced 3.4 times greater peak VGRFs compared to forefoot landings from a 40cm drop height.

In contrast, Steele and Lafortune (78) reported no significant differences in VGRF between heel (5.3BW) and forefoot (5.7BW) landings during a typical single leg netball manoeuvre. However HGRF produced by forefoot landings in this same study were 39.4% lower compared to heel landings. Steele (75) also reported that foot placement was influenced by the particular pass type received. Subjects receiving a high pass had a tendency to land in a forefoot position, as opposed to a heel foot placement. Hopper and colleagues (35) agreed, reporting 88% forefoot landing occurring from an overhead pass as opposed to 62% from chest height and 26% from below waist pass height.

Despite the research trends, footfall patterns within netball are often dependant on the activity being performed prior to landing and the subsequent manoeuvre being executed. If the aim is to decelerate the body as fast as possible then heel landings would prove superior with respect to halting horizontal momentum in contrast to forefoot landing.

Knee Angle

The amount of knee flexion present during landing determines either stiff or soft landing characterisation (19, 21, 22). Devita and Skelly (19) have classified knee angles during landing of greater than 90° as stiff landings, and less than 90° as soft landings.

Research from Dufet and Bates (21) further categorised landings into three varying degrees of stiffness; angles less than 75° as fully flexed (FF) between 110° and 75° as slightly stiff (SL) and greater than 110° as stiff (ST).

Dufek and Bates (21) assessed the dynamic loading of height, distance and knee angle during bilateral landings. It was observed that an increase in knee angle significantly increased VGRF reporting 3.6, 4.0 and 5.4BW for FF, SL and ST knee angles. This was also supported by Devita and Skelly (19), who reported that 23% larger forces occurred during stiff landings as opposed to soft landings. It was also observed that the hip and knee muscular structures absorbed 19% more kinetic energy during the soft landings, illustrating how landing technique has the potential to decrease impact forces through selective GRF dissipation (19).

PASS DELIVERY

Specific netball skills such as catching a pass can place the body in vulnerable positions, which can negatively affect the force attenuation capabilities of the lower extremities. Cowling and Steele (16) observed the act of catching a ball at chest height whilst in flight has the potential to alter the kinematics of the hip and trunk. This is supported by research from Steele (75) who explored the effect of pass height on GRF among netball players. Subjects were required to land on a force plate after receiving either a pass at chest height, or at heights above the head. It was noted that delivering a higher pass, the receiver reduced their HGRF upon landing by 13.0% from 3.1 to 2.7BW; however this led to an increase in VGRF of 20.0% from 4.5 to 5.4BW. These findings were supported by Neal and Sydney-Smith (63) reporting an average HGRF of 2.5BW for chest height passes and 1.9BW for passes above head height.

In summary, it seems that increasing both jump height and distance can have an effect on landing GRF. Athletes who jump higher or drop from a higher point will potentially experience greater impact forces due to the effect of gravity and associated velocity on impact. With respect to jump distance, greater propulsive forces upon take off must be applied to achieve further distance (24). This effectively increases both vertical and horizontal centre of mass velocity, thus acting in the same fashion as the effect of height. Unilateral landings are associated with larger hip and knee angles upon initial ground contact. The suggested cause is a deficiency in lower body strength as larger angles require less muscular force to maintain due to smaller joint moments. Larger knee angles imply that the forces are transferred and absorbed by the passive structures, which may create a more susceptible environment for lower body injury (21). Regarding foot placement, landing in a forefoot to heel pattern allows the body to absorb forces over a longer period of time. This may help to decrease the musculoskeletal stress present upon impact. Finally, by attempting to receive an above head pass the body has converted horizontal momentum into vertical propulsion in order to initiate a vertical jump to catch the ball. This process supports GRF reductions by adopting a more suitable position to increase knee flexion and initiate forefoot landings (46).

FUNDAMENTAL LANDING PRINCIPLES

The aforementioned described netball performance involving a variety of jump-landing sequences, which are often reliant on opposition movement and allocated court space. It is also apparent that a diverse range of factors, including aspects that are outside the control of the athlete can influence landing forces. Consequently it is misleading to talk of developing a perfect landing model. A more appropriate strategy is to articulate a set of fundamental landing principles which can be applied to the diverse landing conditions performed throughout competition. A set of suggested landing principles derived from existing literature (32, 43, 78) can be observed in Table 4

Table 4: Suggested landing principles, instructional cues and common faults (32, 43, 78).

Landing Cue	Common Fault
• Head upright • Shoulders level • Trunk strong, upright and controlled • Feet shoulder width apart • Bend at the hips and knees 45° • Knees in line with toes • Soft landing	• Looking down • Shoulders asymmetrical • Weight distribution forward • Feet too narrow • Insufficient bend at hips and knees • Knees not in line with toes • Heavy landing

Essentially a successful landing decelerates the body's projected momentum under control whist avoiding injury (19). Steele and Lafortune (78) explored the relationship between kinematic factors and landing GRF whilst performing a common attacking movement in netball. Using 3-dimensional cinematography, they correlated certain landing movements with GRF recordings to create a set of suggested landing fundamentals. It is proposed that an effective landing displays adequate flexion of the hips, knees and ankles (Figure 3) as this helps to dissipate the majority of the energy (78). Absorbing the impact forces over a greater time period reduces the sudden effects of landing by subtly lowering the body's centre of mass. Also the chest is encouraged to be above knees with shoulders and hips aligned. In addition knees should avoid excessive adduction or abduction as equal distribution of impact forces across both the medial and lateral compartments of the knee may reduce the impact stress (32). With respect to foot placement, a forefoot to heel ground contact pattern is advocated as this helps to disperse forces more evenly throughout the foot (43). This pattern also acts like a shock absorber for the leg. Adopting these fundamental landing principles may help to reduce both the rate and magnitude of GRF during impact.

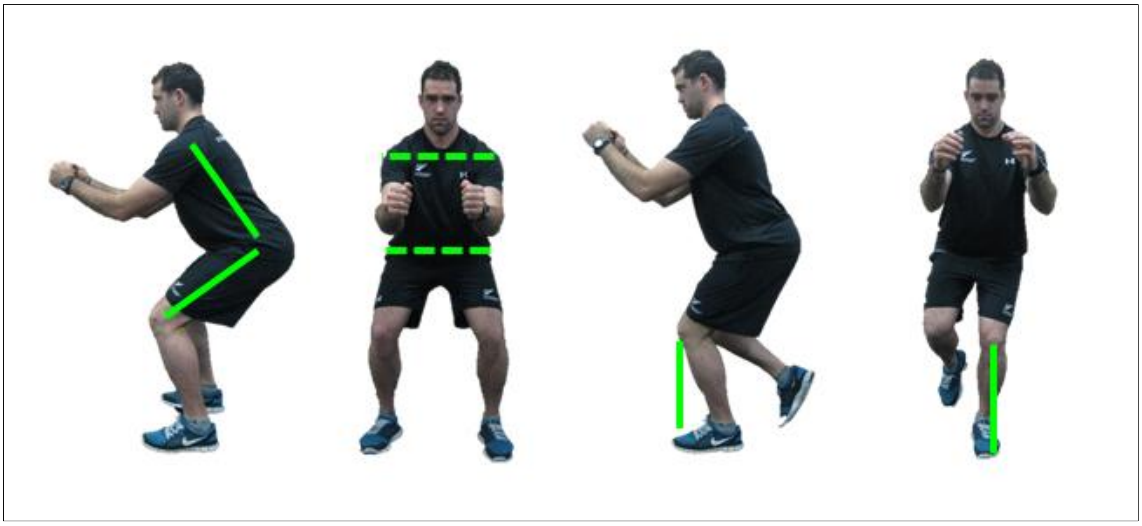

Figure 3: Suggested landing technique for bilateral and unilateral landings

Although the concept of soft landings is ideal for attenuating impact forces they may become detrimental towards performance. Deliberately absorbing landing forces through increased ranges of joint flexion slows down the execution of subsequent movements. This is due to the fact that, in netball, landings are often met by additional jumps, which require the leg to be somewhat extended upon landing (50). A logical approach is to implement the appropriate training strategies to enhance performance by increasing the lower body's ability to withstand greater impacts.

Research suggests that a combination of training components has the most advantageous effect on reducing landing force as well as conditioning the body to effectively withstand these repetitive impacts. The four most promising components appear to be 1) teaching correct landing fundamental principles, landing mechanics and force dissipation strategies; 2) improving balance and dynamic stability, specifically surrounding the ankle and hip joint; 3) increasing muscular strength through resistance training, particularly the muscles of the posterior chain; and 4) heightening neural drive through plyometric type exercises, as this can strengthen specific muscle recruitment and synchronicity aiding the skill of landing. For the reader's reference two review articles (2, 31) provide an in-depth discussion on each of the identified training strategies with specifics on intervention details.

In order to promote fundamental landing training, progressively overloading landing intensity is advocated. Through systematic progression of task specific intensity, the body has the ability to effectively adapt to the stresses experienced during netball match play. These progressions in task difficulty are not solely for injury prevention, as the concept of load intensification supports the notion of enhanced transfer to on-court performance, thus bridging the gap between training and competition.

CONCLUSION AND PRACTICAL APPLICATION

It is widely acknowledged that research has quantified the GRFs surrounding typical netball movements and manoeuvres involving landing. This article was designed in an effort to develop an understanding of the components that impact upon landing forces during landing. Evidently these forces are associated with lower body injury occurrence, through sudden force application along with accumulative impacts which are indicative of natural play. Based on a fundamental understanding of landing biomechanics and a review of observed research, a number of jump-landing kinetic modifiers have been detailed (Table 3). Accepting that landing is a multifaceted task, it is essential to acknowledge the identified modifiers during landing performance.

It is important to remember that it is unrealistic to execute perfect jump-landing form every time during a game. Implementing fundamental landing principles may help to reduce injury, both in an acute and chronic sense. This is achieved by effectively dissipating the impact forces through the appropriate structures of the body. In addition selective strength and conditioning strategies may help by providing the best platform to prepare athletes for landing activities during competition. Future research may want to explore all GRFs during landing tasks relevant to netball that progress in intensity.

CHAPTER 3

JUMP-LANDING PROGRAM FOR FEMALES: DEVELOPMENT OF A SYSTEMATIC PROGRESSION MODEL

INTRODUCTION

Many sports such as netball, basketball and volleyball are typified by a variety of jump-landing tasks that are often critical to success and winning performance. Typically high ground reaction forces (GRF) are experienced by athletes in these sports given the dynamic and explosive nature of movement especially during jump-landings in training and competition. These high GRFs are considered as potentially injurious for the lower limbs (33, 35, 50). Although players may have the capability to absorb these high forces upon impact, incorrect landing technique (17, 66), insufficient muscular strength (28, 31, 52), a lack of balance (37, 61) and deficiencies in neuromuscular control (30) increase the likelihood of lower extremities injury.

In order to physically condition the body to withstand high impact forces during training and competition, it is essential to systematically progress jump-landing intensity throughout training. This can be achieved by gradually increasing the stress imposed upon the body in an effort to develop a high GRF tolerance. This systematic increase in stimulus is important for continual adaptation and a pre-requisite for injury prevention and athletic improvement (44).

Given the previous information, the need for an appropriately designed jump-landing program integrating correct landing principles and progressive conditioning of the lower limb is apparent. This article introduces a systematic progression model for the development of jump-landing proficiency incorporating recommended design methods and targeted training components for effective program implementation.

JUMP-LANDING PROGRESSION MODEL

The majority of studies investigating interventions aimed at improving landing performance and injury prevention utilise a variety of training methods e.g. strength and plyometric training. It is therefore difficult to decipher the degree of influence certain programmes have on the training outcomes, although the major adaptations derived from a particular training modality are generally well known. Nonetheless, it would seem that a combination of training strategies has the most advantageous effect on landing mechanics, GRF dissipation and physical conditioning of the lower body. The most promising training components appear to be teaching fundamental exercise techniques and landing principles with the appropriate feedback; improving balance and stability with specific focus surrounding the ankle and hip joint; increasing muscular strength, with particular emphasis on the muscles of the posterior chain; and, heightening neural drive and neuromuscular control through plyometric type exercises.

The ultimate goal of a jump-landing program is to not only improve performance but to prevent injury. In order for this to occur the program must systematically progress in intensity, so that the body can appropriately adapt to the given training stimulus. The most influential barriers that impede the advancement of jump-landing performance are injury and training plateaus, however the correct application of progressive overload can potentially reduce the effects of these barriers (44). In this regard we propose a model that addresses this progression and the integration of various training methods. The model is a derivative of that proposed by Kritz et al. (48) where athletes are loaded according to their ability to perform an exercise and as such athletes are progressed through assisted, body weight, resisted, eccentric and plyometric exercises. This model incorporates four phases, which increase in load intensity and movement complexity (see Table 5). The four phases focus on specific outcomes and include: 1) technique and general strength; 2) eccentric strength, stability and alignment; 3) stretch-shorten cycle (SSC) propulsive power and landing ability; and, 4) sport-specific jump-landing ability.

Table 5: Jump-landing Training Progression Model

Phase and Training Focus	**1) Technique and General Strength**	**2) Eccentric Strength, Stability and Alignment**	**3) Stretch-Shorten Cycle Propulsive Power and Landing Ability**	**4) Sport-Specific Jump-Landing Ability**
Strength Training	***Strength Endurance*** Assisted, bodyweight or resisted exercises e.g. squats, single leg squats, lunges	***Maximal Strength*** Resisted exercises, increased load and decrease stability e.g. barbell lunges and lateral crossover step ups	***Relative Maximal Strength*** Resisted exercises, increased load and speed of movement e.g. single leg hip thrusts, kettle bell swings	***Relative Maximal Strength – Power*** Resisted exercises, increased load, fast explosive exercises if strong enough e.g. Olympic lifts (Power Clean, Snatch)
Balance Training	***Proprioception*** Static balance drills, eye open/closed, stable/unstable e.g. single leg balance drills, swings	***Dynamically Static*** Static and dynamic drills in place e.g. single leg medicine ball catch and throw, swings	***Dynamic*** Dynamic drills in motion e.g. drills that step or jump onto unstable surfaces, swings	***Perturbed Dynamic*** Perturbed and dynamic drills e.g. medicine ball catch and throw standing on unstable surfaces, swings
Plyometric Training	***Long Response*** Single jump-landings in place, single plane, bilateral e.g. jumps onto box, vertical jumps and drop and stick exercises	***Eccentric Response*** Drop-landings, multiple plane, bilateral/unilateral drop and stick exercises, using progressive heights and distances	***Short Response*** Multiple jump-landings, take-off and landing focus, bilateral/unilateral e.g. continue hop, bound and stick exercises	***Shock Response*** Multiple jump-landings, multidirectional, unanticipated and perturbed landing focus e.g. reaction cutting, 3 step jump-landing with turn during flight

It needs to be acknowledged that each phase has a focus and builds upon the previous but the focus is not exclusive to that phase. For, example, good technique is a pre-requisite for advancement in any phase, and the strength and conditioning coach will be observing the eccentric strength, stability and alignment of landings in phases three and four even though it is a focus for phase two. With regards to the proposed model, the reader needs to be cognizant that some examples are given for each of the training modalities utilized in each phase. However, there are a myriad of exercises and combinations that can be used, the menu only limited by the imagination and experience of the strength and conditioning coach. Finally through each of the phases, it is recommended that the coach has a camera or other electronic devices to use for video recording purposes to provide feedback to the athlete, as this will be invaluable and likely enable a more rapid progression through the phases.

PHASE 1: TECHNIQUE AND GENERAL STRENGTH

This first stage should focus on exercises and techniques aimed at developing competent movement patterns and strength endurance. In this phase exercises are chosen that aim at optimizing movement efficiency, laying the foundation for more complex and explosive movement patterns typical of the latter phases. Optimal movement has been described as pain free motion involving correct posture, muscle coordination and joint alignment (13). Typically fundamental movement patterns, such as squats, lunges, push, pull, bend and twist patterns form the basis of much of the training.

This type of movement education is typically linked to the strength training and is progressed through an assisted, body weight or resisted paradigm (see Figure 4). For example, the athlete is asked to perform a body weight squat with good technique (see Kritz et al. (47)) and if the athlete cannot perform an acceptable squat then it is recommended that the athlete performs assisted squat training until squat technique is perfected. Thereafter this athlete will progress to body weight squat training and when ready resisted squat training.

Figure 4: Squat progressions: assisted squat; body weight squat; resisted squat

Once training has progressed to loading the athlete, strength training during this phase needs to use light loads initially (~15RM – strength endurance) with an emphasis on good technique. Progression to heavier loads (~10RM) during this phase should be a goal. Once good technique using these heavier loads is achieved then progression to Phase 2 strength training is recommended.

It is well documented that the particular technique utilized during landing has a profound effect on the forces that are produced (21, 22). An effective landing demonstrates adequate flexion of the hips, knees and ankles as this helps to dissipate the majority of GRF present during impact (78). The suggested position of the chest is above knees with shoulders and hips aligned. In addition the knees should be in line with feet and a forefoot foot to heel placement pattern is advocated (43). Given this information, ensuring that athletes show proficiency and strength in primary movements such as the bilateral and unilateral squat is essential.

Females have a tendency to adopt an erect trunk position during landing (40), which can subsequently reduce flexion of the knee (6). It is speculated that this upright positioning of the trunk is due to weak gluteal and hamstring muscles, given their function as hip extensors and trunk stabilisers (9). In reality, all of the muscles of the posterior side of the lower extremities need to work in unison, to effectively withstand the GRF imposed upon landing impact (31). By strengthening these muscles, and mimicking suggested landing mechanics, the body has a considerable mechanical advantage by simulating a safer landing position (58).

It is also documented that female athletes are inclined to utilize their quadriceps muscles to a greater extent to stabilise during landing, whilst underutilizing their hamstring muscles (31, 32, 39). Particularly for the knee, the co-activation of the hamstrings and quadriceps may provide injury protection during landing by resisting anterior and lateral tibial translation along with transverse tibial rotations (53). Greater activation of the hamstring muscles allows the knee to produce increased flexion which creates a better position to absorb impact forces (31). Improvement in technique and an increase in general strength especially of the posterior chain muscles during this phase may help to facilitate greater levels of pre-activation and co-activation of the musculature involved throughout successful jump-landing.

With regards to balance training, basic balance and stability exercises are initially static with limited movement. The objective of this is to concentrate on proprioceptive information being received to maintain stability. This also effectively develops the ability to activate the stabiliser muscles. Static balance exercises can be manipulated by opening and closing eyes, changing the arm position as well as progressing from stable ground through to unstable surfaces (see Figure 5) (60). The use of unstable surfaces accelerates the transference of joint stability through the development of synergistic muscle recruitment and activation patterns (59).

Figure 5: Static balance exercises: left to right – single leg floor; bilateral wobble board; single leg bosu ball

It needs to be acknowledged that strength and balance training do not necessarily need to be viewed in isolation. For example, exercises such as single leg squats, split squats and lunges will also challenge balance ability. Conversely exercises such as swings will challenge functional ankle stability as well as strengthening the gluteal muscles. Swings (Phase 1) involve the athlete balancing on one leg flat footed, whilst swinging the airborne leg forward and back, laterally in front and laterally behind. A typical set would involve 10 reps on the left leg, left forward and back then change to the right leg; this is immediately followed by 10 reps on the left leg, swinging the leg laterally in front of the body and then change to the right leg; and, finally 10 reps on the left leg, swinging the leg laterally behind the body and then change to the right leg (see Figure 6). The aim for the athlete is to perform all 60 reps without touching the ground. Once they can achieve this then the exercise is progressed by increasing the number of reps, the magnitude of the swings or progress the athlete to Phase 2 swings. Cueing the torso to be strong and tall is important and you will find that the gluteals of the stance leg will be working hard to stabilise the body. Furthermore, integrating swings into the warm-up can maximise training efficiency.

Figure 6: Swing exercise

Plyometric training during Phase 1 has been termed “long response” in that the propulsion and landing are typified by adequate hip, knee and ankle flexion as well as alignment upon impact. That is, the propulsive and landing phases are deeper than other phases, reducing particularly the landing forces (i.e. soft landings), which become a greater focus in Phase 2. Plyometric exercises should initially be performed bilaterally with a progression to single leg landings once correct landing mechanics are regularly demonstrated.

Box jump exercises are effective during this phase as they develop basic jump-landing ability in a controlled environment. Jumping onto a box effectively develops jumping actions without the accentuated landing impact caused by gravity through reducing the descent to the ground (see Figure 7). These types of jump-landings can be progressed within this phase by increasing the height of the box and advancing to single landings as this increases the stability required to maintain a balanced landing.

Figure 7: Jump exercises: left to right – box jumps; stair jumps

Another option is to have athletes jump up sets of steps (see Figure 7); again the landing forces will be attenuated. They can be progressed to jumping up 2-4 steps at a time. As an adjunct to the plyometric training and a precursor to Phase 2 training you can ask the athletes to descend the steps in a very slow and controlled manner accentuating eccentric strength, control and alignment (see Figure 8). This can be progressed from descending 1-3 steps at a time depending on athletic ability and step height. It is at the discretion of the strength and conditioning specialist to progress the athlete to Phase 2 once proficient technique and movement competency has regularly been demonstrated. Competent performance in this phase is critical to the development of jump-landing ability in the latter stages of this progressive model.

Figure 8: Athlete decsending down stairs with good form

In terms of the general loading parameters it is assumed that this type of training will occur in the off-season and therefore 2-3 sessions will be performed weekly. Decisions throughout the program will have to be made about maximising training efficiency. Furthermore decisions about performing different modes of training whilst fresh or fatigued will have to be made. For example, a tri-set such as a squat (15 RM), box jumps (10 reps) and single leg balance (30 secs) would maximise training efficiency by eliciting strength endurance, power and balance within 90-120 secs. By the time power and balance training begins there might be fatigue which affects power and balance ability. This can be a deliberate training goal to simulate game like conditions i.e. to challenge power and balance under fatigue. Conversely power and balance training might be trained in isolation whilst the athlete is unfatigued for a different training effect.

PHASE 2: ECCENTRIC STRENGTH, STABILITY AND ALIGNMENT

The emphasis of Phase 2 is to develop eccentric leg strength along with enhancing balance, stability and control of joint alignment. The landing component is the primary focus throughout this phase with exercises and drills projected towards improving the body's ability to land controlled and aligned. Consistent feedback which modifies faulty movement and reinforces correct technique should be applied in the beginning until the athlete can effectively demonstrate good landing form. It is also important to cease all landings if the desired landing technique diminishes so that incorrect landing behaviour is not learnt. Table 6 offers a set of suggested landing cues for the recommended use throughout training to amend faulty movement patterns and reinforce correct technique.

Table 6: Suggested landing cues

Landing Cues
• Head upright • Chest above knees • Shoulders and hips level • Bend at the hips and knees 45° • Knees in line with toes • Feet shoulder width apart (Bilateral) • Foot underneath centre of mass (unilateral) • Forefoot to heel foot placement

Receiving feedback is an essential part of modifying movement patterns as it is a key component of acquiring new motor programs (17). Herman and colleagues (28) examined the use of strength training and feedback on lower body biomechanics during a jump task. They concluded that with the exclusion of proper instruction on technique, athletes may not effectively integrate the benefits of their increased strength into their movement patterns. Onate and colleagues (66) explored how different types of video feedback affected the instruction of jump-landing technique. In this study four training groups were tested. The first group viewed a video of an expert model trained in proper landing technique as their feedback, group two viewed a video of their own landing trials, group three observed both the expert model video plus their own performance and the last group was a control group who received no feedback at all. All feedback groups reported significant reductions in VGRF during landing (-25.8%) however the use of self or combining expert modelling with self-observation was more effective than expert-only modelling for reducing risk of injury (66).

Research exploring the effects of verbal feedback on volleyball spike jump–landing technique showed that a single session of augmented feedback significantly reduced VGRF by -23% (17). Similar conclusions were drawn from McNair, Prapavessis, and Callender (57), demonstrating that precise kinematic instruction (feedback on knee flexion angle at initial ground contact), can mediate decreases in landing GRF by -13%. This body of knowledge reinforces the need for appropriate feedback and how it should be fundamental to all phases.

During landing, the most prominent forces are present when the involved musculature is contracting eccentrically (12). Therefore the body must possess adequate levels of eccentric strength in order to control the body's movements and accomplish safe jump-landing form (28). If the involved musculature displays insufficient strength during landing then the muscles ability to absorb the GRF diminishes. This in turn leads to the forces being diverted to the bones and ligaments, which amplifies the expected risk of ligament ruptures (31).

Once competent movement patterns have been acquired and the solid base of muscular endurance has been established during Phase 1, the resistance training emphasis during Phase 2 should move towards developing maximal absolute strength of the athlete. In terms of specific exercises the emphasis should continue to progress squatting strength and competence in addition to exercises that focus on single leg strength development (see Figure 9). Incorporating single leg exercises will help to develop the athlete's ability to express strength in an unstable environment as well as eccentrically loading the lower extremities in a safe manner.

Figure 9: Single leg exercises: left to right – lateral cross over step up (start position), lateral cross over step up (finish position); bulgarian squat

Effective sporting manoeuvres such as evading opponents or finding clear space on court can require powerful jump-landings. These jump-landings can be enhanced by taking advantage of stored elastic energy primarily held within the tendons; however for this elastic energy to be optimally used, the impact load upon landing must be within the eccentric strength limits of the athlete (83). This reinforces that importance of developing adequate eccentric strength before advancing to Phase 3.

Balance drills in Phase 2 should transition towards more dynamic stability exercises however should still be performed in a stationary position (see Figure 10) as the focus is stability and alignment. The particular drills in Figure 10 are effective as they allow the athlete to manoeuvre their centre of mass (COM) while continuing to stabilize on their stance leg, which is consistent with landing performance. These types of exercises have been coined “dynamically static”. The swing exercise can progress to swinging movements whilst moving to toes, using the same loading parameters detailed in Phase 1. This effectively decreases the base of support, creates a higher COM and challenges the ability to stabilise to a greater extent. Once balance can be maintained during these exercises then a progression to Phase 3 can commence, in which dynamic moving stability drills are performed.

Figure 10: Dynamic balance exercises in place

For the plyometric component a progression to accentuated landings begins in order to strengthen eccentric landing ability i.e. thus termed eccentric response training (see Table 5). It is recommended that exercises such as drop-landings off a box (see Figure 11) are used in this phase. Drop-landing exercises, such as dropping off a box and performing a stick landing, are particularly important as they allow the body to adapt to high eccentric force loads in a controlled manner (68). Advancing these exercises within this phase can be achieved by increasing box drop height and/or jumping distance. Also the number of unilateral landings should increase to challenge the need to stabilise and balance.

Figure 11: Single leg drop landing finish position

In addition, advancement within this phase should be based upon an analysis of movement quality and should not involve performing advanced exercises until adequate form is observed. Athletes must demonstrate correct landing mechanics during single leg drop landings with stability and control before proceeding to Phase 3, as this validates the required eccentric strength is present to safely advance intensity.

This phase would presumably be performed in a preseason phase of a periodized training plan therefore the general loading parameters may involve 2-3 sessions weekly. Again, similar to Phase 1, decisions surrounding the most appropriate method to maximise training efficiency is dependent on the intended aim of the training phase and the particular conditioning response the strength and conditioning coach is envisioning.

For example, given that the aim of the resistance training component is to develop maximum absolute strength it would be recommended to perform exercises in a relatively unfatigued state with repetition ranges of 6-10 RM with 2-5 minutes rest. Likewise, plyometric exercises such as box drop landings involve high GRFs and may best be performed in isolation to maximise the adaptation response upon the body. With this being said balance exercises and drills could be utilized as part of a warm-up circuit or employed as prehabilitation training at the start or end of either a power or strength workout. This could be effectively administrated by performing 3-5 balance exercises (15-20 reps) with 30-60 secs rest between each exercise.

Phase 3: SSC Propulsive Power and Landing Ability

Phase 3 of this progression model should focus on exercises and techniques aimed at developing propulsive power and landing ability. The impact forces experienced during jump-landings are inherently larger and have more degrees of freedom than the previous drop landing program. For example, because the landing is preceded by a jump there is likely to be greater horizontal and/or lateral momentum to arrest or control when jumping for distance.

The goal of the resistance training throughout Phase 3 is to develop or at least maintain maximal relative strength of the athlete, given that power is the product of force and velocity. The amount of jump-landing training the athlete performs during training and competition is high velocity in nature and therefore will preserve or develop the athlete's velocity capability. However, if force decreases during this phase the net effect could be reduced leg power. Furthermore, for injury prevention purposes it is important that the strength of the involved musculature is developed or at the very least maintained. Finally, given that most sports necessitate the athlete to possess certain amounts of strength endurance and power, maximal strength is an optimal quality to develop given its strong relationship to both these strength qualities. Therefore it is recommended that the athlete's lift 1-6 RM loads that aim to increase strength whilst minimising changes in body mass i.e. maintaining or increasing strength/force and power capability per kg of body mass. As intimated previously, there is likely to be greater horizontal and/or lateral momentum to arrest or control during this phase due to the inclusion of the propulsive/jump phase, so the strength training needs to become multiplanar in focus. That is, exercises that strengthen the musculature in the vertical as well as horizontal and lateral planes are fundamental to this phase. Some examples of relevant exercises for this phase, which aim at increasing horizontal and lateral force capability, are the hip thrust (see Figure 12) and forward/lateral lunges.

With respect to balance, in order to demonstrate fundamental landing mechanics, the body's centre of mass should be positioned over the base of support which requires a certain amount of balance and stability. The location of the upper body's COM has been shown to affect the final position of the knee during landing (65). This is of particular importance during single leg landings. Whilst landing, balance is achieved primarily through the ankle and or hip (23). Stability is maintained through the ankle when the body is static or when there is limited disturbance as seen during the end recovery phase of a landing, due to the joints small range of motion (42). The ankle achieves this stability mainly in the anterior-posterior plane. In contrast when landing is projected from a mediolateral direction, or when landing from a perturbed jump, balance is maintained through the hip joint (42). This is evidently due to the hip joint's larger ranges of motion, which is achieved in both the medial-lateral and anterior-posterior planes (5). This type of balance is termed "dynamic" as the body endeavours to stabilize whilst simultaneously performing movement.

Figure 12: Hip thrust exercise

It is recommended that balance training exercises during Phase 3 challenge stability in a dynamic fashion. That is, a landing will be preceded by a pre-movement such as a lateral jump. This can be progressed by jumping onto an unstable surface (see Figure 13). To continue the progression of swing drills the strength and conditioning coach should add a jump and land with each swing rep. These exercises are designed to develop functional stability whilst also continuing to improve technique in both landing and take-off positions.

Figure 13: Dynamic balance exercise: left to right – lunge onto wobble board; jump onto bosu ball

With regards to the jump training, this phase should involve a wide variety of movements that are dynamic in nature with an overriding objective of enhancing the SSC and landing ability of athletes (68). Movements and ground contact times are typically quicker during this phase thus the emphasis has been termed "short response". Essentially this phase emphasises development of neuromuscular control, particularly aiming to stabilise the working joints through unconscious activation of the surrounding musculature (3). Unconscious muscle recruitment, co-activation and coordination have been found to be critical factors involved in successful jumping-landing in females (30).

Researchers have reported that following a growth spurt, adolescent females do not appear to develop the neuromuscular system at the same rate as the musculoskeletal system (29). This is suggested to reduce the amount of neuromuscular control of the knee during landing, causing landing techniques which are associated with injury. Various studies utilizing plyometric type training have been able to correct this imbalance in neuromuscular control (10, 11, 51, 59, 62). The strength and conditioning coach needs to be aware of this reduced control throughout the neuromuscular system during periods of rapid growth, thus paying particular focus towards the development of Phases 1 and 2. The importance of developing Phase 3 is amplified as the impact forces during landing occur too rapidly to be modified by a reaction response from the neuromuscular system (19). To effectively prevent unwarranted injury during jump-landing it is essential to pre-activate the involved musculature prior to ground contact (30, 71).

Muscle activation strategies and their subsequent effect after plyometric training was explored by Chimera and co-authors (26). This study observed significantly different muscle activation patterns from the adductor muscles with pre-activation occurring earlier, in conjunction with greater activation magnitude before landing. Furthermore significant increases in adductor and abductor muscle co-activation were found, suggesting that the muscles were working in concert to balance joint forces during jump-landing propulsive exercises. This is important as equal distribution of impact forces across both the medial and lateral compartments of the knee may reduce the impact stress during landing (32).

The ability to perform the jump-landing movements with good technique drives progression through this phase. If faulty technique is observed during the propulsive phase, the athlete could benefit from further “Phase 1” training or a less intense plyometric exercise. If faulty technique was observed during the landing phase, then further Phase 2 training may be prescribed. This movement efficiency could be assessed via multiple single leg jumps. For example, the athlete could perform continuous hop and stick exercises with a focus on jumping and landing execution. This can be progressed into sub-maximal triple or quintuple bounding jumps (see Figure 14), with the coach observing their single leg propulsive and landing ability (alignment and stability) when there are increasing motor control demands associated with increased horizontal and vertical momentum. It is suggested that the coach has a camera or other electronic device to use for video recording purposes, as this type of jump-landing occurs rather rapidly and would benefit from frame by frame analysis.

Figure 14: Bounding jump-landings

Plyometric exercises in this phase should be short response activities which demand quicker propulsive phases and stiffer, more abrupt landings. Short response movements are more sport-specific and a systematic progression into the sport-specific exercises of Phase 4. To progress to the final Phase 4 it is recommended that fundamental jump-landing mechanics along with control and posture are maintained during exercises utilising multiple jump-landing efforts. Athletes who can successfully perform short response jump-landing activities will demonstrate the capability to effectively train these movements in a sport-specific context.

Phase 4: Sport-Specific Jump-Landing Ability

The objective of the final phase is to develop propulsive power production and landing ability specific to the sport or activity the athlete is engaged in, which should optimize the transfer of conditioning activities to the performance demands of the sport.

The strength training component for this phase is similar to Phase 3 i.e. relative maximal strength focus. Maximum relative strength needs to be maintained during this phase as it is quite likely that the athlete resistance training will be reduced to one session a week given the training requirements of the sport. Therefore lifting heavy (1-6 RM) at least once a week is recommended so as force capability is preserved (4). As with all phases, exercise selection should complement the nature of jump-landing actions and should be specific to the athlete's particular weaknesses. However, if an athlete has developed the required levels of relative strength for their specific position and/or movement requirements, as ascertained by the strength and conditioning coach, it is suggested that resistance training could progress to fast explosive movements such as Olympic weightlifting derivatives.

Olympic weightlifting exercises such as the power clean (see Figure 15) are an effective means of developing power (45, 81). The movement patterns utilized in these types of exercises are similar to movement witnessed in jumping-landing patterns (8). In addition, the skill and muscle coordination required to execute these exercises may help to foster neuromuscular adaptations that are transferred to sports performance (82). Another effective set of exercises which can be utilized to develop muscular power for jump-landing proficiency are resisted jump squat variations (14). Jump squats involve the exact action of jump-landing in addition to providing similar neuromuscular benefits as Olympic weightlifting exercises (15).

Figure 15: Power clean exercise

Exercises and drills throughout this phase should utilize unanticipated cutting actions and perturbed movements, as this helps to integrate safe levels of sport-specific landing technique. Adaptations from this specific form of stimulus has been shown to reduce injury prevalence and improve performance during multidirectional sporting activities (32). Specifically for balance and stability training, the ultimate aim during Phase 4 is to advance the athletes ability to maintain steadiness and regain stability whilst resisting external forces (see Figure 16). During this phase there is an introduction to exercises such as “Phase 4 swings” which incorporate the same initial swing movement process from Phase 1; however, this exercise is overloaded by jumping and landing diagonally, laterally, horizontally or backwards after every swing. The preceding swings can also integrate jumping with ball in hand in addition to perturbed or disrupted flight. This final progression of the swing exercise allows the body to attempt to stabilise in a sport specific dynamic fashion.

Figure 16: Medicine ball catch while standing on a wobble board

Phase 4 plyometric training, concentrates on “shock training” as well as jumps that are sport-specific. Shock training refers to plyometric movements that accentuate the eccentric loading phase followed by a powerful concentric action. An example of this is a depth jump exercise in which an athlete descends from a height to the ground, thus overloading the eccentric phase, and performing a concentric action such as a maximum vertical jump immediately after the landing. This is an effective modality of training as it allows the body to simulate similar loading stimulus experienced during competition.

Intra and inter-muscle activation patterns are sensitive to specific landing movements (72) therefore it is important to stimulate the musculature with jump-landing activities related to actual performance. Once the appropriate jump-landing technique and position have been demonstrated during multiple jump-landing tasks, the plyometric component can introduce unanticipated landings drills to enhance the pre-activation of muscles thus increasing the ability to dynamically stabilize during unplanned landings.

This is an important aspect to develop as many competition sporting actions involve reactive unexpected jump-landings. These can be effectively administrated using verbal and/or visual directional prompt drills or perturbing the athlete (see Figure 17). Reducing the reaction time for the athlete to perform the directional demand will help to progress this type of activity.

Figure 17: Directional cue jumping exercises: left to right – (Visual) after completing a ladder sequence the athlete looks at the strength and conditioning coach just before jumping either left or right depending on the direction of the coache's hand; (Verbal) with the athlete initially standing outside the large hurdles the strength and conditioning coach says a color, the athlete then jumps inside with the correlating color between their feet with the body facing the middle of the colored cross

The final progression among the plyometric component is to introduce game-related drills and exercise situations that demand multidirectional, unanticipated, perturbed jump-landings. Examples of these situations are; repetitive rebound blocks in volleyball, 3 step jump shot at goal in handball and/or reacting to the movement of a thrown ball in netball (see Figure 18). Landing technique cues via feedback is important during this stage to ensure that fundamental movement patterns are maintained during potentially unsafe jump-landing sequences.

Figure 18: Reaction jump-landing drill – the athlete starts with a 180° turn and then reacts and attempts to catch a thrown ball. The athlete can also be instructed to land on a certain foot.

Both Phase 3 and 4 would typically be performed during a pre-competition or in-season training phase of a periodized training plan. During these training periods the majority of athlete's focus is directed towards on court performance and therefore the general loading parameters will likely involve 1-2 sessions performed weekly, which often supplement technical and tactical skill trainings. With this in mind it may be beneficial to combine training modalities in order to train components to prevent detraining. For example, utilizing balance and stability type training as a warm up routine, similar to Phase 2 and then performing contrast strength and power workouts. An effective method of executing contrast training is to perform a superset i.e. a lunge strength exercise (6 reps) and then perform plyometric bounding exercises (6 reps) as this would concurrently build strength while also developing muscular power. Alternatively exercise routines can isolate the training focus within the same workout. For example, the beginning may be dedicated to power and plyometric exercises while the latter stages of the workout could involve strength exercises. At the end of the session when the body has fatigued would be a prime time to challenge balance through a variety of stability drills and exercises (10-15 reps) with 60-90 secs rest between each exercise.

During this final phase, the advancement to unpredictable game simulated movements requires the integration of all training components to be performed to a high standard. It is therefore critical that each phase is progressed only after jump-landing proficiency is continually demonstrated.

CONCLUSION

It is evident that an effective jump-landing program involves various components which address the diverse demands of landing that is implicit during competition. Identified strategies targeted towards perfecting landing technique, improving balance, increasing strength and plyometric ability, may accumulatively enhance landing performance and reduce injury prevalence. Additionally, in order to optimise athlete compliance, program design should focus on performance and injury prevention simultaneously. Most importantly training regimes must systematically progress task specific intensity at an individualized rate for optimal adaptation, hence the development of this four phase program. Within each of these phases there is still much research to be performed in terms of improving practice. For example, quantifying the GRFs associated with various jump-landing tasks, which can be tabled into a program that progressively overloads the athlete, would be invaluable to the strength and conditioning coach in terms of training prescription.

CHAPTER 4

GROUND REACTION FORCES ASSOCIATED WITH DIFFERENT LANDING TASKS IN FEMALES

INTRODUCTION

Landing from multidirectional movement patterns in sport, particularly in games such as volleyball, basketball and netball, are generally considered as potentially injurious for the lower limbs given the forces experienced during impact (33, 35, 50). The resultant ground reaction force (GRF) attained through landings may be expressed as vertical (VGRF), horizontal (HGRF) and lateral (LGRF) which are dependent on various factors such as drop height (58, 64, 83, 86), horizontal distance travelled during flight (73, 74) and landing strategy (69, 87). For instance Caster (83) investigated the effects of 15, 30, 45 and 60 cm drop heights on post landing kinetics during bilateral drop landings. With VGRF ranging from 3.89 to 6.62 bodyweights (BW), it was concluded the GRF increased with drop height (83). GRF of gymnasts and recreational athletes during drop landings from different heights were profiled by McNitt-Gray (58). Significant increases in VGRF ($p<0.05$) followed height increases, reporting ranges of 3.9 to 11.0 BW for drop heights ranging from 32 to 128 cm. This theme was continued by Wang (88) with significant increases in VGRF as a result of increased height, observing ranges of 1.52 to 2.09 BW for drop height from 40 to 80 cm.

To the knowledge of the author only one research has explored the effects of differing heights on all GRFs (64). Forces ranging from 3.09 to 5.26 BW for VGRF, 0.62 to 1.08 BW for HGRF and 0.34 to 0.45 BW for LGRF during drop landings from 32, 52 and 72 cm drop heights were reported. In terms of bilateral and unilateral landing strategies, unilateral landings have been shown to increase VGRF by 44% and increase total energy absorption by 11% as compared to bilateral landings (87). Pappas and colleagues (69) reported that unilateral landings from a 40 cm drop height resulted in an 18.8% increase in VGRF (3.20 vs. 2.70BW) compared to bilateral landings. Surprisingly only two studies have explored the interaction between drop height and jump distance with different landing techniques on VGRF (21, 22). Each study aimed to develop a predictive template for impact landing forces by manipulating drop height, jump distance and landing technique via specific knee angle. Drop height and jump distance ranged from 40 to 100 cm producing VGRF of 3.00 to 6.04 BW in the research of Dufek and Bates (21, 22). Drop height and landing technique were identified as significant variables for all subjects when predicting VGRF during landing.

Athletes exposed to such forces often participate in strength and conditioning programs centred on preparing the involved musculature to withstand the stresses experienced. Among the various training modalities available, plyometric drop landings are one of the most popular techniques used to deliver effective conditioning for landing proficiency. Drop landings are important as they help to develop eccentric strength, alignment and stability in the lower extremities, which are considered critical components of performing successful sporting actions that involve the stretch-shorten cycle (SSC) (49).

With the association between injury risk and high GRFs created by landing (21), profiling all the landing forces (vertical, horizontal and lateral) associated with various drop landing tasks may help clarify the forces potentially linked with lower limb injury as well as performance. However, the interaction between height, distance and landing strategy on landing GRF has received little attention among the literature. Such information is fundamental to exercise prescription and systematic progressive overload. Therefore the purpose of this study was to quantify the landing VGRF, HGRF and LGRF experienced by female athletes when drop height and jump distance were systematically increased during bilateral and unilateral landings.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

This study utilized a repeated measure experimental design to investigate if differences in landing GRFs existed between varying jump-landing conditions. Three different heights (15, 30 and 45 cm), distances (40, 80 and 120 cm) and landing strategies (bilateral forward, unilateral forward and unilateral lateral) were used to create 27 jump-landing conditions, which were the independent variables of interest. The dependent variables were VGRF, HGRF and LGRF. To determine the relationship between landing forces and landing strategy, each participant performed 2 trials for each separate jump-landing condition. Mean peak GRFs were quantified to establish a GRF profile for each task, which were compared between conditions.

SUBJECTS

Twenty-one female netball players from the New Zealand Talent Development Programme squad volunteered to participate in this study. Subject average (± SD) age, height and weight were 17.1 ± 0.6 years, 173.0 ± 5.2 cm and 68.7 ± 5.9 kg, respectively. Subjects were asked to refrain from strenuous exercise 24-hours prior to testing. Subjects were excluded if they had received a lower body injury within three months prior to testing. Prior to involvement all subjects were informed of the study requirements, risks and benefits, and were required to provide the appropriate informed consent. Ethical approval was granted from the Human Research Ethics Committee of AUT University.

PROCEDURE

Each subject was tested for each jump condition during a single testing session. Before testing the subject's weight, height and age were recorded. Each subject performed a standardized warm up consisting of light aerobic exercise and dynamic stretches. The testing began after a 5-minute rest following the warm-up. The landing procedure order was fixed for all subjects and commenced with the lowest height (15 cm), closest distance (40 cm) and landing with two feet. This procedure was implemented to allow an increased warm-up as the task difficulty increased along with minimizing the risk of injury (21). Once two successful trials were completed for the given landing task, the landing condition then progressed to the next jump condition. Each jump condition consisted of a specified drop height from a box (15, 30 and 45 cm), jump distance away from the force plate (40, 80 and 120 cm), and landing style; either bilateral forward (BF), unilateral forward (UF) or unilateral lateral (UL) landing. Each landing was performed onto a force plate in order to record the different GRF components (see Figure 19). Two trials were completed for each jump condition for every subject with 20-30 seconds rest between each trial. All unilateral landings were performed with the dominant leg. The mean values from the two drop landing trials from each landing condition were used for further statistical analysis.

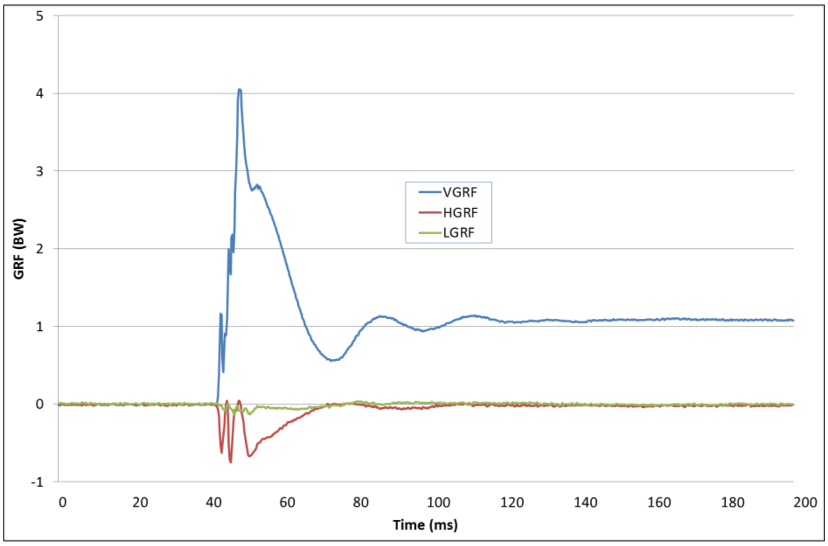

Figure 19: Representative VGRF, HGRF and LGRF curve

DATA ANALYSIS

A portable tri-axial force plate (Accupower model, 76 × 102 cm, AMTI, Watertown, MA) was used to measure the GRFs at a sampling rate of 500 Hz. The force plate was calibrated as instructed by the manufacturer. The force plate was reset immediately before each jump and the three force components, VGRF, HGRF and LGRF were recorded when the subject contacted the force plate. The force plate interfaced directly to a computer with a data acquisition package via a USB connection. VGRF, HGRF, and LGRF for each jump-landing condition were quantified for each subject. Stored GRF data were normalized to subject's body weight (BW) and the results expressed in units of BW. This was achieved with the following formula: N/(bodymass*9.81). This normalisation process is typical when assessing GRF and allows comparisons between subjects and previous research. Finally, means and standard deviations for peak VGRF, HGRF and LGRF for each jump-landing condition were calculated. The data was grouped by landing condition then further categorised by force component (VGRF, HGRF, or LGRF).

Statistical Analysis

The data was analyzed using Statistical Package for Social Sciences (SPSS) version 18.0. Prior to all statistical analyses data was analyzed descriptively to ensure there were no extreme outliers and that the data was distributed normally. Two-way ANOVA (general linear model with repeated measures; factors height × distance) was conducted to determine whether significant differences existed between jump-landing conditions. If significant differences were reported then post hoc pairwise comparisons were analyzed to establish any significant differences among means. The alpha level was set at $p<0.05$ for all statistical tests.

RESULTS

The effect of height for each landing strategy ranged from 2.67 to 4.45 BW for VGRF, 0.03 to 0.13 BW for HGRF and 0.13 to 0.61 BW for LGRF (see Table 7). Increases in drop height significantly increased all VGRFs for all landings strategies. HGRF for bilateral and unilateral forward landings significantly increased with increases in drop height in addition to significant increases in all unilateral landings (forward and lateral) for LGRF. The largest increase (98.1%) occurred during a BF landing between 30 and 45cm for LGRF.

Table 7: The effect of drop height on GRFs for BF, UF and UL landings (mean ± SD)

Landing Strategy	**Landing Height**	**VGRF** (BW)	**HGRF** (BW)	**LGRF** (BW)
	15cm	3.07 ± 0.54	0.06 ± 0.04	0.18 ± 0.08
BL	**30cm**	3.72 ± 0.64 ǂ	0.09 ± 0.07 ǂ	0.18 ± 0.07
	45cm	4.32 ± 0.82 ǂ¶	0.13 ± 0.09 ǂ¶	0.36 ± 0.14 ǂ¶
	15cm	2.83 ± 0.56	0.03 ± 0.02	0.13 ± 0.03
UF	**30cm**	3.73 ± 0.78 ǂ	0.05 ± 0.04 ǂ	0.15 ± 0.04 ǂ
	45cm	4.45 ± 0.81 ǂ¶	0.09 ± 0.05 ǂ¶	0.19 ± 0.05 ǂ¶
	15cm	2.67 ± 0.49	0.03 ± 0.02	0.29 ± 0.16
UL	**30cm**	3.51 ± 0.75 ǂ	0.03 ± 0.02	0.50 ± 0.24 ǂ
	45cm	4.15 ± 0.59 ǂ¶	0.04 ± 0.03	0.61 ± 0.24 ǂ¶

ǂ = Significantly different from 15cm
¶ = Significantly different from 30cm ($p < 0.05$)

The effect of distance for each landing strategy is presented in Table 8. GRFs ranged from 2.96 to 4.26 BW for VGRF, 0.03 to 0.16 BW for HGRF and 0.12 to 0.64 BW for LGRF. As distance increased from 40 to 80 cm a significant increase (15.0%) in VGRF for UL landings was observed along with significant increases in LGRF of 152, 33.3 and 53.9% for BF, UF and UL landings respectively. Significant reductions in HGRF were observed between 40 and 80cm distances of -58.3 and -40.0% for BF and UF landings. As the jump distance increased from 80 to 120 cm VGRF for BF, UF and UL increased significantly by 19.8, 22.6 and 17.0% respectively. LGRF also significantly increased by 18.8 and 40.1% for UF and UL landings between the 80 and 120 cm distance, whilst the BL landing strategy resulted in a significant -27.7% decrease in LGRF.

Table 8: The effect of jump distance on GRFs for BF, UF and UL landings (mean ± SD)

Landing Strategy	**Jumping Distance**	**VGRF** (BW)	**HGRF** (BW)	**LGRF** (BW)
BF	**40cm**	3.53 ± 0.54	0.16 ± 0.11	0.13 ± 0.05
	80cm	3.45 ± 0.55	0.07 ± 0.05 [ǂ]	0.34 ± 0.15 [ǂ]
	120cm	4.13 ± 0.91 [ǂ¶]	0.05 ± 0.05 [ǂ]	0.24 ± 0.10 [ǂ¶]
UF	**40cm**	3.27 ± 0.49	0.08 ± 0.05	0.12 ± 0.03
	80cm	3.48 ± 0.62	0.05 ± 0.03 [ǂ]	0.16 ± 0.04 [ǂ]
	120cm	4.26 ± 1.04 [ǂ¶]	0.04 ± 0.03 [ǂ]	0.19 ± 0.05 [ǂ¶]
UL	**40cm**	2.96 ± 0.53	0.03 ± 0.02	0.30 ± 0.16
	80cm	3.40 ± 0.63 [ǂ]	0.04 ± 0.03	0.46 ± 0.22 [ǂ]
	120cm	3.98 ± 0.67 [ǂ¶]	0.03 ± 0.02	0.64 ± 0.27 [ǂ¶]

[ǂ] = Significantly different from 40cm
[¶] = Significantly different from 80cm ($p < 0.05$)

The GRF associated with BF landings ranged from 2.91 to 4.91 BW for VGRF, 0.03 to 0.27 BW for HGRF and 0.12 to 0.65 BW for LGRF (see Table 9). The interaction between drop height and jump distance was significant for all profiled forces. As the drop height increased from 30 to 45 cm (40 cm jump distance) significant increases in HGRF (125%) and LGRF (33.3%) were observed. Furthermore, for the same drop height (30 to 45 cm) an 80 cm jump distance produced a 261% significant increase in LGRF.

Table 9: VGRF, HGRF and LGRF for BF landings from different drop heights with different jump distances (mean ± SD)

Ground Reaction Force	Drop Height	Jump Distance		
		40cm	**80cm**	**120cm**
Vertical (BW)	**15cm**	3.07 ± 0.52	2.91 ± 0.49	3.23 ± 0.62
	30cm	3.43 ± 0.46 [ǂ]	3.46 ± 0.53 [ǂ]	4.26 ± 0.92 [ǂab]
	45cm	4.08 ± 0.64 [ǂ¶]	3.97 ± 0.62 [ǂ¶]	4.91 ± 1.20 [ǂ¶ab]
Horizontal (BW)	**15cm**	0.09 ± 0.06	0.07 ± 0.05	0.03 ± 0.02 [ab]
	30cm	0.12 ± 0.09	0.08 ± 0.05	0.07 ± 0.07 [ǂa]
	45cm	0.27 ± 0.19 [ǂ¶]	0.05 ± 0.04 [a]	0.06 ± 0.05 [ǂa]
Lateral (BW)	**15cm**	0.12 ± 0.04	0.18 ± 0.10 [a]	0.23 ± 0.11 [a]
	30cm	0.12 ± 0.04	0.18 ± 0.08 [a]	0.24 ± 0.08 [ab]
	45cm	0.16 ± 0.07 [ǂ¶]	0.65 ± 0.26 [ǂ¶a]	0.23 ± 0.10 [ab]

[ǂ] = Significantly different from 15cm height
[¶] = Significantly different from 30cm height
[a] = Significantly different from 40cm distance
[b] = Significantly different from 80cm distance ($p < 0.05$)

UF landing GRFs ranged from 2.58 to 5.13 BW for VGRF, 0.03 to 0.15 BW for HGRF and 0.09 to 0.23 BW for LGRF (see Table 10). The only significant interaction between drop height and jump distance observed was for HGRF. At a drop height of 45 cm a reduction in HGRF was observed when distance increased from 40 to 80 cm (-53.3%) and 80 to 120 cm (-42.9%). The total reduction in HGRF from the shortest (40 cm) to furthest distance (120 cm) was -73.3%; however, no significant differences between distances were observed at 15 and 30 cm drop heights. In addition, from a jump distance of 40 cm HGRF significantly increased with increments of height from 15 to 30 cm (133%) and 30 to 45 cm (114%). This equated to total increases of HGRF from the smallest (15 cm) to highest drop height (45 cm) of (400%). This trend was not replicated at distances of 80 and 120 cm.

Table 10: VGRF, HGRF and LGRF for UF landings from different drop heights with different jump distances (mean ± SD)

Ground Reaction Force	Drop Height	Jump Distance		
		40cm	**80cm**	**120cm**
Vertical (BW)	**15cm**	2.58 ± 0.56	2.63 ± 0.37	3.27 ± 0.75 [ab]
	30cm	3.25 ± 0.41 [ǂ]	3.55 ± 0.69 [ǂ]	4.39 ± 1.23 [ǂab]
	45cm	3.97 ± 0.49 [ǂ¶]	4.25 ± 0.79 [ǂ¶]	5.13 ± 1.15 [ǂ¶ab]
Horizontal (BW)	**15cm**	0.03 ± 0.02	0.04 ± 0.02	0.03 ± 0.02
	30cm	0.07 ± 0.06 [ǂ]	0.04 ± 0.02	0.05 ± 0.04
	45cm	0.15 ± 0.07 [ǂ¶]	0.07 ± 0.05 [¶ a]	0.04 ± 0.02 [ab]
Lateral (BW)	**15cm**	0.09 ± 0.02	0.14 ± 0.04 [a]	0.17 ± 0.05 [ab]
	30cm	0.11 ± 0.02 [ǂ]	0.15 ± 0.04 [a]	0.20 ± 0.06 [ǂab]
	45cm	0.16 ± 0.04 [ǂ¶]	0.20 ± 0.07 [ǂ¶a]	0.23 ± 0.06 [ǂa]

[ǂ] = Significantly different from 15cm height
[¶] = Significantly different from 30cm height
[**a**] = Significantly different from 40cm distance
[b] = Significantly different from 80cm distance ($p < 0.05$)

UL landing GRFs ranged from 2.36 to 4.75 BW for VGRF, 0.02 to 0.05 BW for HGRF, and 0.17 to 0.77 BW for LGRF (see Table 11). A significant interaction between drop height and jump distance was observed for VGRF and LGRF. As drop height increased from 15 to 30 cm (120 cm jump distance) the largest increase in VGRF (41.8 %) was observed compared to 24.6 and 26.5% from 40 and 80 cm distances respectively. As drop height increased from 30 to 45 cm (120 cm jump distance) the smallest increase in VGRF (12.8%) was reported compared to 21.4 and 21.8% from 40 and 80 cm distances respectively. All increases were found to be significant. With regards to the LGRF, an increase in drop height from 30 to 45 cm resulted in a significant increase in GRF of 48.3 and 47.3% at jump distances of 40 and 80 cm respectively. Furthermore, for the same drop height (30 to 45 cm), LGRF produced at a 120 cm jump distance were not significantly different compared to the 80 cm jump distance.

Table 11: VGRF, HGRF and LGRF for UL landings from different drop heights with different jump distances (mean ± SD)

Ground Reaction Force	Drop Height	Jump Distance		
		40cm	**80cm**	**120cm**
	15cm	2.36 ± 0.44	2.68 ± 0.46 [a]	2.97 ± 0.56 [ab]
Vertical (BW)	**30cm**	2.94 ± 0.65 [ǂ]	3.39 ± 0.77 [ǂa]	4.21 ± 0.84 [ǂab]
	45cm	3.57 ± 0.50 [ǂ¶]	4.13 ± 0.66 [ǂ¶a]	4.75 ± 0.62 [ǂ¶ab]
	15cm	0.02 ± 0.01	0.04 ± 0.02 [a]	0.03 ± 0.02
Horizontal (BW)	**30cm**	0.03 ± 0.02	0.03 ± 0.02	0.03 ± 0.03
	45cm	0.04 ± 0.02 [ǂ]	0.05 ± 0.04 [¶]	0.03 ± 0.02 [b]
	15cm	0.17 ± 0.10	0.28 ± 0.15 [a]	0.41 ± 0.21 [ab]
Lateral (BW)	**30cm**	0.29 ± 0.17 [ǂ]	0.44 ± 0.22 [ǂa]	0.77 ± 0.34 [ǂab]
	45cm	0.43 ± 0.21 [ǂ¶]	0.65 ± 0.28 [ǂ¶a]	0.74 ± 0.23 [ǂa]

[ǂ] = Significantly different from 15cm height
[¶] = Significantly different from 30cm height
[a] = Significantly different from 40cm distance
[b] = Significantly different from 80cm distance ($p < 0.05$)

DISCUSSION

The primary purpose of this study was to quantify the GRF experienced when drop height and jump distance were systematically increased during various jump-landing strategies. The main effect of height was to increase all VGRFs for all jump-landing strategies, which aligns with previous research findings (58, 64, 83, 86). The VGRF values in this study for each drop height were higher (109%) than the observed forces reported by Wang (86), however they were somewhat lower (-12.4, -43.2 and -84.3%) than Niu et al. (64), Caster (83) and McNitt-Gray's (58) findings respectively. Lower GRFs in this study can be explained by the lower jump heights of this study. Furthermore, McNitt-Gray's (58) study involved gymnasts who were instructed to land similar to competition guidelines, which created naturally greater impact GRFs.

Increase in drop height also significantly increased HGRF for both bilateral (41.4%) and unilateral landings (61.3%) in a forward direction. Previously reported HGRFs for bilateral landings (64) were over eight times greater compared to the findings of the current study, which most likely can be attributed to the larger (60%) drop heights. However, the increase in HGRF between drop heights observed in this study for bilateral landings were on average 46.3% larger than that reported by Niu et al. (64). Furthermore, the increase in drop height resulted in significant increases (18.4 to 74.4%) in LGRF for all unilateral landings (forward and lateral). It would seem that increasing jump height challenges all components of landing GRFs. Given the effects of gravity on associated velocity during landing impact, it is logical to assume that larger drop heights yield greater GRFs. However, it needs to be noted that increased landing GRFs may also originate from incorrect landing mechanics.

The main effect of distance was to significantly increase all VGRF (15 to 22.6%) and LGRFs (18.8 to 53.9%) for all unilateral landings (forward and lateral). The VGRFs observed for bilateral landings in this study for each jump distance were marginally lower (-14.5%) than values reported by Dufek and Bates (21). The longest distance in the current investigation was 20 cm longer and may account for the 77.1% increase in VGRF from the shortest to furthest distance in comparison to findings from Dufet and Bates (21).

In contrast, an increase in distance resulted in significant reductions in HGRF for both bilateral (-39.2%) and unilateral forward landings (-30%). Such a finding is difficult to explain. It has been speculated that an athlete's perception of task difficulty might cause GRF discrepancies (68), which may account for the decreasing HGRF patterns observed in the present study. Subjects landing from the shortest distance (40 cm) may have landed with less control given the perception that the landing task provided minimal risk of injury, thus landing more suddenly and producing greater HGRFs. Conversely, landing from a further projected distance (80 and 120 cm), subjects may have increased their vertical trajectory due to the task being perceived as hard to execute. A more pronounced vertical emphasis upon landing would make it easier to arrest the horizontal momentum of the body's centre of mass. Unfortunately no video footage was taken to verify this contention regarding task difficulty.

Another principle aim of this study was to investigate the influence of landing strategies on GRF magnitude. The landing strategies (BF, UF and UL) were selected to simulate landing characteristics identified during competitive sporting activities. Confounding height × distance interaction effects were found for all bilateral GRFs. Each peak GRF occurred at the largest drop height (45 cm). However, VGRF only significantly increased (23.9%) at a distance of 120 cm during drop heights greater than 30 cm. HGRF significantly increased (200%) as a result of drop height, but only at a distance of 40 cm. Furthermore, a jump distance of 120 cm appeared to reduce any effects of drop height upon LGRF. The present findings illustrate the importance of integrating variation in both height and distance to effectively overload targeted planar GRFs during drop landings.

Greater VGRFs were observed for UF (5.13 ± 1.15 BW) compared to BF (4.91 ± 1.20 BW) landings during increases of both drop height and jump distance. Larger impact forces originating from single leg landings in relation to bilateral type landings has been reported previously (69, 87). The greater VGRF magnitudes associated with UF landings may increase the likelihood of lower body injuries in female athletes. It would appear that adopting a bilateral landing strategy may potentially lessen impact, possibly reducing the likelihood of injury. Conversely, dedicated eccentric strengthening and progressive jump-landing programs are needed if single landings commonly occur within a sport specific context.

Increases in both drop height and jump distance led to significant increases in LGRF for unilateral forward (24.8%) and lateral (47.5%) landings, except for one condition (45 cm drop height with 120 cm jump distance). Increasing jump height and distance increased lateral landing GRF and therefore represents an increasing challenge for the muscles controlling lateral stability during forward and lateral landings. It is suggested that a drop height of 45 cm combined with a 120 cm jump distance may represent a threshold for unilateral landing LGRF production. This is of importance, as to our knowledge this is the only study exploring LGRF during systematic increases of drop height and jump distance during landing.

The drop landing task employed in this study was arguably not representative of what the body experiences during competition for the majority of athletes. Athletes seldom in competition land from a height without the effort of a jump to propel them to the height (e.g. drop landing). This may have reduced the amount of horizontal and lateral momentum upon impact, therefore substantiating the relatively small HGRF and LGRF recordings in each landing task. Whilst previous research has derived GRF data from more realistic landing movements, the inclusion of controlled landing conditions allows for higher consistency of GRF data when systematically progressing landing intensity. It is also noted that this study did not take into account subjects initial strength levels, nor were specific landing kinematics enforced. However, given these limitations it needs to be remembered that the current design was aimed at quantifying landing forces to inform loading parameters around progressive-jump landing programs, especially during the eccentric strengthening phase of conditioning.

PRACTICAL APPLICATIONS

There are many texts that detail the loading parameters associated with jump/plyometric programs. However, in most cases there is no quantitative detail around the forces associated with various jumps and more importantly landing, particularly in all three planes of motion (vertical, horizontal and lateral). This study described the landing forces associated with progressive drop landings and should be used for the development of eccentric strength, stability, alignment and control. It is suggested that this falls within Phase 2 (see Table 12) conditioning of the athlete, which is preceded by a phase that ensures baseline movement competency and overall (concentric/eccentric) strength. Phases 3 and 4 progress into more specific and sport-specific conditioning for the athlete exposed to high landing forces as a result of participation in their sport.

Table 12: Progressions for jump-landing training

→ Increasing complexity and intensity of movement task →				
Progression Phase	1	2	3	4
Goal of training	Technique and general strength	Eccentric strength, stability and alignment	SSC propulsive power and landing ability	Sport-specific jump-landing ability
Example exercise	Assisted, bodyweight or resisted squat or single leg squats	Drop landings from 45 cm height and 80 cm distance	Bounding drills	Three step approach to spike in volleyball

In summary, the main findings of this study and implications for strength and conditioning were: 1) VGRF was augmented by increases in drop height and jump distances for all landings strategies. Consequently, manipulating height and distance is an effective mode of progressing VGRF during landing. 2) HGRF appears to be more dependent on changes of height when landing in a forward direction and employing drop landings. Developing HGRF should concentrate on progressing height for both BF and UF landing strategies. 3) With respect to LGRF production, increases in both drop height and/or jump distance were found to be effective methods of progressing the GRFs for all landing strategies. Furthermore, it would appear that to overload LGRF the utilization of single leg landings is of fundamental importance. This is intuitive given the decreased base of support as compared to bilateral landings. In addition, there would seem little advantage to performing unilateral landings at a drop height of 45 cm and jump distance of 120 cm when progressing LGRF, as less demanding landing conditions elicit similar forces.

Finally, different landing strategies stress each GRF component differently, substantiating the necessity for training specificity. Strength and conditioning specialists who implement jump-landing training need to be aware that modification to certain parameters can influence landing kinematics and kinetics, and therefore neuromuscular adaptation. Further research quantifying the forces associated with specific (i.e. inclusion of progressive propulsive forces) and sport-specific landings is needed i.e. Phase 3 and 4. This would advance the understanding for the strength and conditioning coach specific to their sport, thus aiding the prescription of jump-landing exercises to improve jump-landing performance and decrease the likelihood of injury.

CHAPTER 5

SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS

SUMMARY

It is evident throughout the literature that dynamic fast paced sports, such as netball, volleyball and basketball expose the body to high GRFs which require a certain amount of conditioning and/or technique training to effectively mitigate injury risk and improve performance. Therefore the initial objective of this thesis was to explore and review the factors that influence GRFs commonly experienced in the game of netball to aid the development of a progressive jump-landing program (Chapter 2). The findings from the literature review were that drop height, jumping distance, landing strategy and specific landing kinematics (e.g. knee angle, foot placement and arm position) all have the potential to significantly influence landing GRF. In addition, absorption of these GRFs can be reduced by coaching fundamental landing principles. Incorporating these factors into general conditioning practice to develop best practice jump-landing programs is recommended.

Although the sport of Netball provided the primary focus of this thesis given the injury statistics and the National significance of this sport, the findings are of practical significance to many female ball-sport athletes. As a result the ensuing chapters were written with this in mind i.e. a broader female athlete focus.

Following Chapter 2 we introduced a systematic progressive training model, which aimed to guide strength and conditioning practice of females that utilise jump-landing movements in training and competition performance (Chapter 3). This model involved four progressive phases that increased in load intensity and movement complexity. The model included; Phase 1) teaching fundamental technique and building basic strength; Phase 2) developing eccentric strength, stability and alignment; Phase 3) building SSC propulsive power and landing ability; and finally, Phase 4) developing jump-landing ability in a sport specific manner. Each phase of this model incorporated three specific training components - balance, strength and plyometric training. These specific components were identified based on the development of specific movements and physical qualities that are demonstrated in dynamic explosive sporting situations. It was concluded that progressing through each specific phase should assist the strength and conditioning coach in the development of programs for jump-landing movements, which aim to prevent injury and improve competition performance.

It was evident from the literature reviewed that the impact forces presented during landings were greater than the propulsive forces and therefore are more likely to induce injury. Given this information the aim of the experimental study (Chapter 4) was to quantify the GRFs experienced during progressive drop-landing tasks, which was to inform exercise prescription for Phase 2 of the training model developed in Chapter 3. Drop-landing exercises are commonly used as a method of conditioning the lower extremities for landing. It was found that manipulating height and distance was an effective mode of progressively overloading the VGRFs during both bilateral and single leg landings. Progressing height during forward landings was found to be an effective means of systematically overloading HGRFs, while increases in both drop height and/or jump distance were shown to be effective methods of progressing LGRFs for single leg landings.

PRACTICAL APPLICATIONS

A new model of exercise prescription for jump-landing athletes has been proposed (Chapter 3). It involved four phases, which progress from relatively low intensity ground based non-explosive exercises to sport-specific explosive type activities. Most texts in this area focus on Phase 3 of the model (i.e. plyometric exercises) with little attention given to what type of exercises/training should precede and succeed plyometric activity. The model achieves this by detailing how to progressively overload strength, balance and plyometric training.

Given the breadth of the model, it was decided to focus on Phase 2 (eccentric ability), which is not well researched but is an important precursor to plyometric training for the experimental study. As the focus of Phase 2 was eccentric strength, stability and alignment, detailing exercises and the associated landing GRFs that develop these qualities provided the experimental focus. The findings of this study as outlined previously can be used to progressively overload the eccentric vertical, horizontal and lateral GRFs using a drop-landing programme. The practical applications of the findings integrated into the model proposed in Chapter 3.

RESEARCH DIRECTIONS

In order to effectively physically condition an athlete for the specific demands of their sport it is essential to accurately evaluate the movements that are fundamental to performance. Given the paucity of reseach regarding netball jump-landing movements, it is evident that there are inconsistencies when identifying the different patterns of jump-landing among netball performance. Future research may want to direct its attention towards longitudinal studies that observe competition netball jump-landing patterns to provide more consistent information concerning this area.

As mentioned previously, the majority of literature informs readers on the specifics of Phase 3 of the proposed model (i.e. plyometric exercises). It is important to acknowledge the significance of building a competent strength and technique base prior to performing high intensity plyometric activities. Strength and conditioning coaches need to prescribe exercises that align with the competence of the athlete to ensure safe and effective physical capabilities are developed, maintained and progressed. It is recommended that future studies quantify the forces associated with progressive jump-landing exercises specific to each phase of the presented jump-landing progression model in order to enhance the accuracy of exercise prescription.

Finally, while this thesis provides an insight into the various GRFs that are experienced among netball players, it must be remembered that the finding related to the subjects involved in this study should be generalised to a similar population. With this in mind future research may want to include subjects with elite or international playing status to determine whether the findings of this study are comparable to better-conditioned and more experienced athletes.

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