The effect of an eight week jump training program performed on indoor and sand surfaces on vertical jump performance in elite volleyball players.

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Statement of Authorship

I declare that the following thesis is a record of all original work conducted through-out the research process. It does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made in the text through-out the entire publication.

14 / 03 / 2014

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Contents

List of Figures

List of Data Tables

Abstract

Purpose – The main purpose of this study was to determine the effect of an 8-week jump training program, completed on either a hard or sand surface, on vertical jump performance in elite volleyball players. It was of major interest to determine if training on one surface yielded meaningful gains on the other surface. Further, this study sought to determine if the short term jump training program was effective for developing leg muscle function.

Method – Eighteen elite national and state volleyball players were split into two groups and trained on either a hard surface (HS, *n*=10) or a sand surface (SS, *n*=8). The participants completed 1380 jumps during the 8-week training program progressing from 120-jumps/week to 240-jumps/week. Participants were assessed on both a hard and a sand surface, pre and post training, on volleyball performance tests the block jump (BJ), spike jump (SPJ), as well as leg muscle function via ground reaction force (GRF) data collected during countermovement jump (CMJ), squat jump (SJ) and drop jump (DJ) performance.

Results – The HS group demonstrated significant gains in jump height for BJ on the hard surface (2.6%, p= 0.033) and sand surface (6.7%, p= 0.019) while the SS group only made significant gains in BJ on the sand surface (9.8%, p= 0.009). Neither group demonstrated significant ($p<0.05$) gains in SPJ performance. Strong correlations between pre intervention BJ and SPJ data suggested a level of consistency in the participants jumping ability regardless of the type of surface or skill (jump). GRF data demonstrated that leg muscle function predictors accounted for 86-89% of the variance associated with volleyball performance jump tests (BJ, SPJ).

Conclusion – The 8-week jump training program did not greatly improve the overall vertical jump performance of elite volleyball players. It appears surface does impact performance directly but any gains made from training on either surface are not necessarily isolated to performance on the same surface being trained on. Interestingly, SPJ performance did not demonstrate a strong link to DJ variables, in fact, within this study it appears that the skill of performing a BJ and SPJ are closely related, both rely heavily upon concentric power and this is part of why such strong correlations were seen between the two jump types.

Chapter 1

1.0 Introduction

The sport of volleyball can be played in either a controlled indoor environment (indoor volleyball) or an outdoor uncontrolled environment (beach volleyball); both have slight differences in court dimensions, player numbers and governing rules but ultimately are very similar and often athletes will play both, particularly early in their development. Both have two teams competing against one another on opposing sides of a net that separates the court into two halves (an indoor volleyball team has six athletes on the court while a beach volleyball team has only two athletes each side at any one time). The ball is served by one team over the net into the opposing team's half who then have three "touches" (the ball cannot be caught/held) to ensure the ball does not touch the ground in their half and then return it over the net to their opponents side. Typically the team returning the ball (the attacking team) will aim to "spike" the ball over the net on the third touch. To spike the ball an athlete will start well behind the ball and then generally use a three step approach and jump maximally up to the ball that has been "set" in the air aiming to hit the ball at the highest point with their hand. The ability to spike the ball well demands players be able to achieve high maximal jump reach height due to the need to hit a ball over a net height of 2.43m for men and 2.24m for women and within a court space measuring 9m x 9m (indoor) or 8m x 8m (beach). By having a high vertical jump reach height an attacking player will have improved hitting ("spiking") options and angles making it harder for the defending team to control the ball, avoid it hitting the ground in their half and then return it within their three allocated touches. The defending team can however attempt to "block" the attacking team's spike. Blocking requires the defender to stand as close to the net as possible and jump directly upward in front of the spiking attacker and use their arms to block the ball from crossing the net into their half. This skill also requires a maximal jump reach height as it will allow the defender to have better net penetration, resulting in reducing the attackers hitting options (angles) and potentially stopping the ball from landing in the defender's half off the block.

Due to the two critical skills identified above (spiking and blocking) and the general demands of the sport, volleyball athletes will tend to be tall in stature and have long arms as this leads to naturally high reach heights (Sheppard, Gabbett & Stanganelli

2009). There are important technical skill components that relate to correct and effective technique to be able to execute both skills effectively, which need to be coached. However, the role of a strength and conditioning coach working with volleyball athletes is to be able to develop training programmes that; ensure an athlete can physically perform the movements that are technically required by their coach, minimise the risk of injury due to poor physical preparation and identify training interventions that will develop and improve their vertical jump reach height.

The ability to maximise vertical jump reach height requires the body's centre of mass (COM) vertical displacement to be maximised, which requires maximal COM vertical velocity at the instant of take-off (Ham, Knez & Young 2007). A common approach to trying to improve the COM vertical velocity is to improve the power produced by the muscles involved in a vertical jump, the muscles of the lower-body. A frequent approach to increasing power is via resistance training to strengthen the musculature responsible for hip, knee and ankle extension to promote greater force production and or speed of muscle contraction (rate of force development) (Baker 1996; Ham et al. 2007). Another common method is to try and improve the maximal power of the muscles of the lower-body by developing and improving the contribution and efficiency of the stretch shortening cycle (SSC) (Ham et al. 2007). This type of training is called plyometric training and targets the muscle's ability to develop and use elastic energy created by the strain/tension developed in the muscle's connective tissue during a vertical jump. Some research has also assessed the improvements made when combining the two training modalities concurrently as opposed to the isolated training of each (e.g. strength training plus SSC training versus strength training on its own).

Plyometric training has been identified as effective for the athlete to develop and improve explosive power and in particular vertical jump performance. After a 6-week plyometric training program, Thomas, French and Hayes (2009) demonstrated significant improvement in the countermovement jump (CMJ) height of 12 semi-professional soccer players, as did Impellizzeri et al. (2008) who showed significant improvement across 37 soccer players in both CMJ and squat jump (SJ) but after only a 4-week training intervention. Campillo, Andrade and Izquierdo (2013) assessed not only the efficacy of plyometric training but also the difference in the volume of training and showed positive gains in both the CMJ and SJ for the varied training volumes and differing effect of surface. Plyometric training has been found to be an effective method of training vertical jump height for volleyball (Marques, van den Tillaar, Vescovi, González-Badillo 2008; Newton, Kraemer & Hakkinen 1999). Powers (1996) implemented a combination of plyometric drills that included rubber band resisted vertical jumps, box jumps and standing vertical jumps with a group of collegiate volleyball athletes and improved all except one athlete's standing vertical jump score. Other types of plyometric drills have been recommended as effective for training vertical jump reach height in volleyball athletes. Smith (1996) outlined multiple drills with varying degrees of complexity that target the SSC. While not typically described as plyometric exercises, it should be noted that the use of loaded squat jump drills to improve the performance of volleyball athletes also appears a popular choice of strength and conditioning coaches (Hori et al. 2009; Marques et al. 2008; Newton, Rogers, Volek, Hakkinen & Kraemer 2006). Even accentuated eccentric block jumps (Sheppard, McGuigan & Newton 2007) have been shown to positively influence vertical jump reach height. However, it appears a majority of studies that have investigated the effect of plyometric training on volleyball performance have purely been focussed on indoor volleyball and not beach volleyball. There appears to be a large gap within the literature on the effect plyometric training may have on performances on a sand surface and specifically volleyball specific jump types, the spike and block jump.

As mentioned previously, volleyball athletes may compete in both formats of the sport (indoor and beach), with indoor volleyball typically played on sprung wooden or rubberised surfaces while beach volleyball is played on sand. It is therefore critical that they are able to achieve maximal COM vertical displacement to achieve a maximal vertical jump reach height on both surfaces. In addition to this, beach volleyball is traditionally a summer sport with a majority of the peak international competition period being played during the warmer months of the northern hemisphere (May-August). As such, due to the seasonal nature of the sport, specialist beach volleyball athletes will spend a bulk of the colder winter months developing their physical capacities and abilities (like vertical jump) and often this is done indoors as a result of poor weather. If they cannot access an indoor sand facility, then their training may have to be completed on harder, less compliant surfaces than sand. It has been shown that vertical jump performance on sand is different to performance on less compliant surfaces (Bishop 2003; Giatsis, Kollias, Panoutsakpoulos & Papaikovou 2004; Muramatsu, Fukudome, Miyama, Arimoto, & Kijima 2006; Tilp, Wagner & Müller 2008). In addition to this, training studies that have performed training or one-off interventions on sand and other compliant surfaces have shown differences in training adaptations and outcomes (Campillo et al. 2013; Impellizzeri et al. 2008; Miyama and Nosaka 2004). The study completed by Impellizzeri et al. (2008) found that after a 4-week plyometric training period on either sand or a grass surface resulted in significant change in SJ for both training groups but only significant gains in CMJ performance was shown by the grass trained group. Further to this, the average reported muscle soreness was significantly lower for the sand group than the grass-trained group. These results suggest there is a different training stimulus and impact from performing plyometric training on sand compared to another surface. Therefore an important question is, "Will training for improvements in volleyball specific jump performance on a hard/non-compliant surface translate to improved performance on a soft/compliant surface like sand?" To this point the researcher has found no literature that has directly studied this topic, particularly with regard to elite volleyball athletes.

1.1 Statement of Problem

There appears to be a gap within the literature and a general lack of information identifying whether a vertical jump training program performed on a sand or hard surface, will enhance the performance of the volleyball specific spike jump and block jump on either surface, particularly with elite/semi elite volleyball athletes. In addition it is not known whether an 8-week jump training program can enhance leg muscle function and volleyball jumps over and above normal volleyball training in elite athletes.

1.2 Purpose of the Study

The focus and the purpose of this study, due to the apparent gap within the literature was to:

Investigate the efficacy of an eight week jump training program performed on indoor (hard) and sand surfaces on vertical jump performance in elite volleyball players. The project will constitute the implementation of a customised jump training program with pre and post intervention testing using both volleyball-specific and common vertical jump assessments.

1.3 Research Question/s

1. What is the effect on spike and block jump performance by completing a specific vertical jump training program on either a hard or sand surface?
2. What is the transfer of any gains made on one surface to another for volleyball specific jumps?
3. Are there any identifiable changes in leg muscle function contributing to any observed changes in performance?

1.4 Significance of Study

The significance of this study is to further the scientific body of knowledge in the field of applied strength and conditioning. It will allow coaches to be better informed about the effectiveness of an 8-week vertical jump training program to enhance spike and block jump performance on either sand or hard surfaces and any transfer between the two. The research collated on the block jump and spike jump, as well as the links to leg muscle function (particularly on a sand surface) is of great interest considering maximising vertical jump reach height is seen as a key to competition success. The sport specific nature of the project and the fact that the pool of participants are elite level athletes make this a novel study with the potential to impact coaching practices within the sport of volleyball.

1.5 Limitations

There were some limitations identified prior to commencement of the study that were unavoidable due to the nature of the elite-standard participants. One of these was the differing training schedule between participants from the Australian Institute of Sport (AIS) and South Australian Sports Institute (SASI) programs. The AIS had greater technical and physical training loads compared to those from the SASI group. Secondly due to the variations in competition and training schedules, the AIS-based subjects were not be able to undergo the jump program intervention at the same time as the SASI-based subjects (SASI athletes commenced 4-weeks after the AIS athletes). There was also a limited 10-week window of opportunity to implement the training study with the AIS athletes, again due to their training and competition schedules. Due to the subjects being elite athletes, there was a limited pool of participants to recruit and this resulted in small sample sizes (n=9), for both genders completing the intervention, a fact that may have resulted in the data for each gender lacking statistical power. The result of using participants that were elite athletes heightened the risk of injury due to other training and competition variables outside the researcher's control, and it was also ethically deemed not possible to include a control group.

Chapter 2

2.0 Literature Review

2.1 Prologue

Sports such as basketball, volleyball (indoor and beach) as well as individual non ball-focussed sports like gymnastics, and high jump require athletes to have the ability to jump as high as possible and this is a key contributing factor to their sporting success (Baker 1996; Campillo et al. 2013; Crowther Spinks, Leicht, & Spinks 2007; Markovic Jukic, Milanovic, & Metikos 2007; Reiser, Rocheford, & Armstrong 2006; Walsh, Bohm, Butterfield & Santhosam 2007; Young 1995). Due to the relationship between vertical jump heights with sporting success, various scientific studies have been conducted to identify key factors linked to performance, ways to maximise physical ability and also the best way to construct a training program that is sport-specific.

Reiser et al. (2007) identifies three core elements associated with maximising one's ability to touch the highest point possible above ground when jumping:

1. Raise the vertical velocity of your centre of mass (COM) as high as possible at take-off (projectile motion ensues once in the air). (p. 71)

2. Raise the vertical position of your centre of mass as high as practically possible at take-off (again projectile motion dictates centre of mass travel). (p. 71)

3. Once in the air, position the body in such a way that the reach hand is as far above the centre of mass as possible when it is at peak height. (p. 71)

With the above three principles in place, it is possible to begin identifying methods and processes of improving performance. However some consideration must also go towards the type or style of vertical jump that is to be improved. In the case of volleyball the two key jump types that are targeted are the spike jump and the block jump (Homberg and Papageorgiou 1995; Sheppard, Cronin, Gabbett et al. 2008). Sport specific jumps like the spike and block jump have a relatively high skill component as well as physical demands, so the ability to use these jumps to assess the vertical jump capacities of non-volleyball athletes can be flawed and misleading. Therefore there are some generic vertical jump types that are commonly used as assessment tools for lower body (leg) muscle function as they have a reduced skill element and sports specificity is less of an influence (McGuigan, Sheppard, Cormack & Taylor 2013). They are, the countermovement jump (CMJ) used as an assessment of power that includes an eccentric ("slow" stretch shortening cycle function) and a concentric component, the squat jump (SJ) an assessment of concentric-only power, and the drop jump (DJ) an assessment of the power/capacity of the "fast" stretch shortening cycle. All mentioned jump types will be discussed later in this chapter.

To perform a vertical jump requires an ability to coordinate multiple limb segments, related muscle groups and ensure that all components are working in the most harmonious way possible (Arabatzi, Kellis, & de Villarreal 2010; Young, Pryor and Wilson 1995). Due to the complexity of the task, a number of studies have attempted to quantify and assess various vertical jump actions using a range of methods. High speed cameras have been used to assess critical joint kinematics of the hip, knee and ankle measuring parameters such as joint range of motion, maximum joint angular velocity and acceleration. The use of force platforms has led to assessment of ground reaction force (GRF) and kinetic variables such as peak force, rate of force development and mean force. Electromyographic (EMG) equipment has been used to quantify muscle excitation/activation levels, as well as recruitment patterning and timing of muscle contraction. Another method is the development of mathematical models to calculate possible outcomes of a vertical jump by adjusting key variables (kinematic and kinetic). It should also be noted that on a number of occasions the above mentioned assessment methods are used in conjunction with one another to compliment any limitations each may have.

Based on the assessment of vertical jump techniques, key training strategies and methodologies that have been theorised, practically implemented and then scrutinised for their efficacy; resistance training and plyometric training appear to be the most common training strategies used, both separate to one another or in a combined format. In the following sections the researcher is aiming to identify and expand upon the key components required to perform and improve vertical jump ability and specifically volleyball relevant jump types.

2.2 Volleyball Specific Vertical Jumps (Block Jump and Spike Jump)

Within the sports of both indoor volleyball and beach volleyball there are two commonly identified performance jumps, the block jump (BJ) and the spike jump (SPJ). The BJ is associated with defensive play, the goal being to either directly stop the attacking opponent from hitting the ball back over the net and/or protecting a "zone" on the court to force the attacking hitter to hit in a direction away from the blocker/s. The SPJ is an attacking jump which is used to try and maximise the height at which the ball is hit ("spiked") from and returned over the net with maximum speed making it difficult for the defending team to control and therefore return. Due to the different dynamics and rules between indoor and beach volleyball, there are slight variations in the way both a block and spike jump are technically executed in competition, however the physical characteristics and mechanisms to train athletes of both sports is similar.

The block jump and spike jump appear to be the most prominent jump type in beach volleyball. Turpin, Cortell, Chinchilla, Cejuela & Suárez (2008) quantified the jump patterns across four matches of the European beach volleyball championships in Valencia (Spain) 2005 and showed on average the athletes competing performed 219.0 ± 7.4 vertical jumps per match, 44% of those being spike jumps and 39% being block jumps. Homberg and Papageorgiou (1995) calculated that during one hour of game play an elite German beach volleyball player executed on average 85 jumps (39 spiking, 26 blocking and 20 serving), while Giatsis et al. (2004) had similar findings, identifying that the skill of blocking accounted for 27% of the total jumps within a game of beach volleyball.

2.2.1 Block jump.

The block jump is a skill that requires defending athletes to get themselves in the correct position on the court close to the net relatively early, typically holding in a "half squat" or "loaded" position prior to the attacking opponent making contact with the ball. The defending athlete then needs to time their jump so they obtain their maximum jump height and reach as contact is made by the attacker. Ultimately, the higher an athlete can jump when performing a block jump, there is increased potential for a reduced effectiveness of an attacking opponent. There appears to be a lack of research detailing the block jump technique which is supported by Amasay (2008) who identifies two different versions of the block jump. One version starts from a more upright position while the other a lower squat position. Amasay goes on to say both types include a countermovement prior to jumping of some proportion and therefore a block jump is more like a countermovement vertical jump. Giatsis et al. (2004) suggests that the block jump more closely resembles a static squat jump which does not involve a countermovement and is more reliant on contractile strength and power. If this is the case, it would suggest that plyometric training may be less important due to the SSC having a smaller role. The difference in opinions on this between the two researchers may be due to the fact that Amasay (2008) was focussed on indoor volleyball and investigates indoor volleyball athletes whereas Giatsis et al. (2004) researches beach volleyball athletes. The experience of the current researcher, via his work with the Australian national beach volleyball team and close link with the Australian national indoor volleyball team, suggests that both Amasay (2008) and Giatsis et al. 2004 are correct and the different sports do promote slightly different techniques. Another key technical point of the block jump is that it is performed with no arm-swing. It has been shown that arm-swing has a significant contribution to vertical jump height (Lees, Vanrenterghem, & Clercq 2004), so due to this it could be presumed that block jump performance is very heavily reliant on the ability of an athlete to generate maximal power via the leg extensor muscles (contractile strength).

2.2.2 Spike jump.

There appears to be limited research specifically analysing the SPJ for both volleyball and beach volleyball, an observation also made by Tilp et al. (2009). As previously mentioned, it is an attacking jump that involves an athlete performing a horizontal 3-4 step approach prior to performing a fast CMJ. The horizontal approach is used in an attempt to increase the maximal force and power developed, particularly in regard to the SSC. Wagner et al. (2009) found that the horizontal approach velocity of the COM had a significant correlation ($r=0.71$, $p<0.05$) with the jump height of the SPJ. This in association with asymmetry of the SPJ suggested that an ideal approach technique needs to be developed to be able to obtain maximal spike jump reach height. By obtaining maximal spike jump reach height it can facilitate contact with the ball higher above the net, resulting in improved hitting angles or attacking options (Ciapponi, McLaughlin & Hudson 1996). It is worth mentioning that due to the timing and spatial awareness required to hit a moving target (the ball), obtaining maximal jump height may not always result in the ball being contacted at the highest point or correct execution of the spike. This type of jump has also been shown to be strongly linked to reactive strength and fast plyometric exercises so the efficiency and effectiveness of the stretch shortening cycle is an important component to target when developing training programs for volleyball (Sheppard, Cronin, et al. 2008). Batista, De Araujo and Guerra (2008) compared the vertical jumps of 38 high performance athletes from the 2006 Brazilian Beach Volleyball Circuit. The athletes were split into two groups, the first (G_1) composed of 10 players from the top seven teams, while the second (G_2) consisted of 28 players from teams ranked between eighth and seventeenth. The research identified that SPJ height on sand (G_1, 80.7 ±8.0cm and G_2, 76.3 ±5.3cm) was greater than BJ height on sand (G_1, 69.3 ±7.8cm and G_2, 63.6 ±4.8cm) for both groups. It is possible that the attributed difference between the two jump types is due to the combination of the approach steps used, a greater reliance on the SSC and the involvement of an arm-swing during the SPJ.

2.2.3 Effect of surface variation on block and spike jump.

There are few studies that have directly compared the two specific volleyball jumps (block and spike), particularly the changes and effects on performance between surfaces. Giatsis et al. (2004) compared the ability of volleyball athletes to perform a squat jump (a very similar movement to the block jump) on both hard and sand surfaces and found differences in the angle of the ankle and the hip joints during start posture and at point of take-off respectively as well as different ranges of motion and angular velocity of the ankle joint. To assess the validity and reliability of testing the block and spike jump on sand and hard surfaces, Bishop (2003) demonstrated significant correlations between the two jumps and strong correlations between surfaces for the same jump. The jump height performance on sand was also significantly lower ($p<0.05$) for both types which were linked to the low stiffness of the sand causing a substantial amount of energy being absorbed and not returned to the musculature. However, Bishop (2003) did not directly measure GRF at any stage. Like Bishop (2003), Tilp et al. (2008) found spike jump height performance on hard (indoor) surface was significantly higher than sand performance and the max velocity at point of take-off of the centre of mass (a variable closely related to jump height) was higher also. The upward phase was longer on the sand than the indoor surface which was explained as being due to the instability and compression of the sand at the start of the extension phase. This resulted in a loss of energy return to accelerate the centre of mass. Unlike the BJ, the SPJ technique comprises a horizontal approach that allows the athlete to develop an increased amount of downward force by arresting their horizontal velocity and transitioning it into increased countermovement acceleration. Tilp et al. (2008) assessed the mechanics of the horizontal approach and found biomechanical differences between the sand and indoor surfaces that they suggest are again due to the instability and the need for greater control of forces when performing a SPJ on sand.

2.2.4 Effect of jump training interventions on spike jump performance.

The SPJ has been identified as a key performance jump in volleyball. However, there appears to be no study that has examined the influence of a jump training program on SPJ performance. Both Newton, Kraemer and Hakkinen (1999) and Newton, Rogers, Volek, Hakkinen and Kraemer (2006) used volleyball players as the main subject group for their studies and utilised loaded squat jump exercises in an attempt to improve SPJ performance. Newton, Rogers, Volek, Hakkinen and Kraemer (2006) were able to demonstrate significant ($p<0.05$) improvement in SPJ performance (5.3%) after a 4-week intervention while Newton, Kraemer and Hakkinen (1999) also demonstrated a significant ($p<0.05$) improvement (6.3%) after an 8-week training intervention. Sheppard, Newton and McGuigan (2008) assessed changes in SPJ performance after a 12-week DJ training intervention, the study included a control group that performed the same jumping load as the DJ group but by performing CMJ instead of DJ. Both the control group and DJ group demonstrated significant ($p<0.05$) improvement in SPJ performance (ES 0.17 and 0.73 respectively) suggesting both jump types are effective at enhancing SPJ performance (Sheppard, Newton, et al. 2008). Further in-depth analysis of the results revealed that the difference in spike jump improvement was greater for the DJ group (control group 1.38 ±1.85cm and DJ group 4.63 ±2.72cm) and resulted in a large effect size (ES=1.40) in favour of the DJ group. Due to these key findings Sheppard, Newton, et al. (2008), suggest the DJ training improved the subject's ability to tolerate high stretch loads and this assisted in the ability to transfer horizontal movement into vertical propulsion as required in the

SPJ. A unique study completed by Sheppard, Dingley, Janssen et al. (2011) used elite volleyball players to evaluate the effect of assisted jump training on SPJ over a 5-week training period. The assisted jumping consisted of the subject being “unloaded” by approximately 10kg using a bungee jumping apparatus before they completed the required sets and repetitions (in the unloaded state) of the training program. Sheppard et al. (2011) used a within-subjects, counter-balanced, cross-over study design with subjects experiencing a three week wash out period between the assisted jump training and a normal jump training intervention (equal jump volume as assisted but done using a CMJ). In contrast to the findings of Sheppard, Newton, et al. (2008), Sheppard et al. (2011) found that the normal training (CMJ) did not result in any significant change in SPJ performance. The assisted jump training however, resulted in a 4.6 ±2.6cm ($p=<0.01$, ES=0.32) improvement in SPJ performance. Sheppard et al. (2011) discuss the idea that due to the elite level of the subjects used in the study, it was not surprising that the normal (CMJ) training did not elicit any jumping gains. Due to the elite training level the subject’s capacity to make gains in trainable aspects is already highly developed, therefore the normal (CMJ) training was unable to create a large enough stimulus for change. The assisted jump training did elicit change and this was suggested to be due to the novel stimulus being created and its difference from the subjects “normal” stimulus and loading.

2.3 Countermovement, Squat Jump, Drop Jump.

In sporting or athletic situations vertical displacement of the centre of mass (COM) can occur from various positions and with differing desired outcomes. It may occur from a low static start position (beach volleyball blocking), a tall standing start with a small or large countermovement (tennis serve, basketball rebounding) or even combined with horizontal projection (athletics long jump, high jump, volleyball spike). Within the field of athletic physical preparation, there are common exercises used to target and train improvements in vertical displacement of the COM as well as assess lower limb maximal power (Mackala et al. 2013).

2.3.1 Countermovement Jump

One of the most common jumps referred to and used in scientific research as an analysis of lower-body power is the CMJ (McGuigan, Sheppard, Cormack & Taylor 2013). The CMJ involves an immediate countermovement of the body prior to the upward projection of the centre of mass (Baker 1996; McGuigan, Sheppard, Cormack & Taylor 2013). The countermovement can be a long "deep" movement or a shorter movement depending on what is required. The role of the countermovement is to increase the muscle tension via the eccentric loading of the muscles and producing a level of stored elastic energy and pre-loading that will contribute to an increase in the force produced during the concentric phase (Baker 1996; Mackala et al. 2013). Walsh et al. (2007) identified a significant difference between the mean total body centre of mass rise when jumping with or without a countermovement for both males and females. In the same study they were able to demonstrate the positive effect of arm-swing on total body centre of mass rise for both a CMJ and SJ. The findings from Walsh et al. (2007) reinforce the important role of the countermovement and in turn the SSC in helping to obtain maximal vertical displacement of the COM, but also highlights another key affecting variable on CMJ performance, arm-swing. By swinging the arms during a CMJ it has been shown to increase the force of the jump but also affect the skill and coordination requirements of the jump (McLellan et al. 2011; Walsh et al. 2007). Research by Hubley and Wells (1983) estimated the arm-swing of a CMJ increases jump height by 10-15%. The increase in force and altering of the skill may also negatively impact on the ability to use CMJ as a measure of pure lower-body/leg extensor muscle power (McLellan et al. 2011). Due to the effect of arm-swing, to use a CMJ as an assessment tool of solely lower-body power subjects will often be instructed to jump with hands on hip, or holding a light stick across the back of the shoulders.

2.3.2 Squat Jump

The squat jump (SJ) is very similar to the CMJ, the key difference being the jump is not preceded by a countermovement, rather an entirely concentric action from a predetermined height (Baker 1996; Mackala et al. 2013). By placing approximately a three second pause prior to the concentric action, the SJ jump removes the pre-stretch/tension gained from performing a countermovement. This places a greater demand on the contractile properties of the leg extensor muscles to generate more force concentrically to overcome the resistance of gravity and body mass (Baker 1996; McGuigan, Sheppard, Cormack & Taylor 2013). Due to this removal of SSC influence the squat jump is seen as an important measure of leg extensor muscle power (Baker 1996; Impellizzeri et al. 2008; McGuigan, et al. 2013). Common descriptors of the SJ start position for assessment are; performed from a semi squat position (Markovic et al. 2007; McLellan et al. 2011), subjects started in a squat position (Walsh et al. 2007), subjects adopted a flexed knee position (approximate 90 degrees) (Campillo et al. 2013; Mackala et al. 2013). Like the CMJ, due to the effect of arm-swing, to use a SJ as an assessment tool of solely lower-body power subjects will often be instructed to jump with hands on hips, or holding a light stick across the back of the shoulders.

2.3.3 Drop Jump

The drop jump is, as its name suggests, a jump that occurs via dropping from a height on to a surface and then projecting the body's COM upwards off the surface. This type of jump is a plyometric jump (as described in the previous section) and common in plyometric training programs (Baca 1999; Campillo et al. 2013; Holcomb et al. 1998; Thomas et al. 2009). Drop jumps are plyometric exercises that focus on improving the power output of the leg extensors and not necessarily the co-ordination and timing of vertical jump performance (Holcomb et al. 1998; Thomas et al. 2009), so often they may be used as a measure of stretch-shortening cycle muscle function or reactive strength. The height at which an athlete should train (drop) from can vary and the literature researching the effect of drop jumps appears to be mixed in what is the ideal height. A review of plyometric training by Lundin (1985) describes various studies, a number of which were translated from the soviet era and the drop heights ranged from

0.4 metres up to 3.2 metres. There was also mixed results in regards to the reported optimal elevation to achieve maximal training stimulus. In reference to the drop depth (distance), Bobbert (1990) reviewed a range of studies and suggests that the drop height is not a crucial variable, however it does impact on performance and adaptations made from training. A review of literature by de Villarreal, Kellis, Kraemer and Izquierdo (2009) showed a non-significant effect size of drop height on gains made in vertical jump height and suggests that dropping from lower heights allows for increased training volume, improved trainability of performance at a reduced risk of injury. The technique of performing a drop jump is another variable that must be considered when using this as a training stimulus. When tasked with performing a DJ with no clear instruction on how it is to be done, athletes may self-select to perform a countermovement drop jump (CDJ), a bounce drop jump (BDJ) or a combination of the two. The CDJ is done with a relatively large (long) countermovement upon landing from the drop before pushing off, whereas the BDJ has a very small (short) countermovement before pushing off (Young, Prior & Wilson 1995). These variations in countermovement have been shown to effect the time spent in contact with the landing surface, body postures at the start of the concentric push off phase and the amount of pre-stretch experienced by the lower limb musculature (Bobbert 1990; Bobbert, Huijing, & Van Ingen Schenau 1987; Young et al. 1995). Bobbert (1990) goes as far as to state, "The most important variable to be controlled is the drop jump technique (p 21)". Cues given to athletes performing drop jumps need to be clear and consistent to ensure they are performing a technique that will elicit the desired stimulus from the drop jump. Examples of the types of cues that may be given are; minimise ground contact time while maximising height (Thomas et al. 2009), jump as high as you can, jump high a little faster (Arampatzis, Stafilidis, Morley-Klapsing, & Bruggemann 2004). Young et al. (1995) clearly demonstrated the effect that different instructions can have on DJ performance and the DJ's characteristics. When instructed to jump for maximum height subjects jumped significantly higher but had significantly longer ground contact time than when told to either perform a DJ jump for maximum height with minimum contact time, or a DJ with minimum contact time. Young's (1995) results also reinforced that there is a difference in the strength qualities being trained/challenged if an athlete is instructed to perform CDJ or a BDJ. Sheppard, Cronin, et al. (2008) identified that within a group of elite volleyball players absolute SPJ height significantly correlated ($r=0.80$, $p<0.01$) with absolute DJ height from 35cm. In association with this, during pilot testing they identified the specific population ground contact time ranged from 145 to 220ms, which suggests the DJ used assessed “fast SSC”. Considering the two findings and due to the minimal literature detailing the volleyball SPJ, the research by Sheppard, Cronin, et al. (2008) strongly lends itself to the theory that the SPJ is an example of a “fast SSC” type jump.

2.4 Muscle and Limb Coordination

Studies that have attempted to describe and/or assess the most efficient strategy to perform different variations of a vertical jump tend to break the body into key segmental components such as trunk or torso, upper leg, lower leg and foot. Linked to these common segments are key joints that the segments move about which are often labelled hip, knee and ankle respectively. EMG testing in vertical jump studies tend to focus on the muscles of the lower extremities such as; the gluteus maximus associated with hip extension, rectus femoris and or the Vasti muscle group associated with knee extension, the hamstrings muscle group associated with knee flexion, the calf (gastrocnemius, soleus) associated with ankle extension and tibialis anterior an ankle flexor (Arabatzi et al. 2010; Constable, Thornhill, & Carpenter 1994; Eloranta 1996; Lees, Vanrenterghem & Clercq 2004; Rodacki, Fowler & Bennett 2002; Pandy and Zajac 1991).

A key theory relating to vertical jump performance is the ability of one to transfer power proximally to distally (Eloranta 1996; Leirdal, Roeleveld, & Ettema 2008; Mackala, Stodoła, Siemienski, & Coh 2013; Robertson & Fleming 1987). This concept proposes that force production and generating power should be initiated through the large prime mover muscles responsible for hip extension followed by the knee extensors and finally ankle flexors. This combination along with the “segmental timing” of muscle recruitment will result in a subject generating maximal GRF and thus accelerate their centre of mass vertically at the maximal rate. Using a combination of both video analysis and EMG, Pandy and Zajac (1991) were able to assess the performance of subjects performing a squat jump. In association with this they also developed a mathematical model that would replicate squat jump performance based upon muscle/segmental force contributions. What they showed was the mathematical model was relatively accurate in predicting vertical jump performance and variables such as average jump height, peak vertical force and lift-off time.

Eloranta (1996) showed that there is a change in muscle activation through-out the course of a vertical jump, with analysis indicating increases in gluteus maximus activity at the point of take-off to highlight the proximodistal order. He also demonstrated that skilled jumpers appear to have a constant lower limb coordination model and this does not change if load or postural positioning is altered. Robertson and Fleming (1987) identified that the hip and ankle muscle groups were the major muscles responsible for energy production during a vertical jump and the knee extensors only responsible for one quarter of the work done. The results also suggest that there is a level of “timing” and summation of forces within the muscles acting upon the hip, knee and ankle joints. Hubley and Wells (1983) found a slightly different result when calculating energy contributions of the hip knee and ankle muscle groups with the muscles acting about the knee joint accounting for almost half of the total energy produced, while the hip and ankle musculature contributed 23% and 29% respectively.

2.5 Ground Reaction Force

The concept of the human body becoming a projectile when aiming to obtain maximal vertical jump height (Reiser et al. 2007), allows us to also consider the laws of physics, Newtons Laws of Motion specifically. This concept also allows a vertical jump to be assessed based on kinematic variables (variables produced by forces such as displacement, velocity and acceleration) and kinetic variables (variables relating to force such as rate of force development, peak force and power). In a vertical jump, the vertical ground reaction force (VGRF) accelerates the centre of mass (COM) to a peak velocity at the instant of take-off. It is this velocity that determines the eventual height reached. When performing a vertical jump, the initial velocity at the start of the propulsion phase will be equal to zero, which highlights the need to maximise final take-off velocity and potentially try to minimise the change in time. This is supported by Aragon-Vargas and Gross (1997) who identified through their research that vertical take-off velocity of the COM was a good predictor of vertical jump performance. The measurement of VGRF using specifically designed hardware and associated software provides scientists with the opportunity to assess and analyse vertical jump performance based on the laws of physics.

Other common kinetic values assessed and considered when evaluating vertical jump performance include, force (N), power (W) both peak and mean, rate of force development (kN/s), impulse as well as these measures relative to body mass. Two separate studies assessing squat jump performance of male beach volleyball athletes on a rigid surface used values such as peak force, peak power, rate of force development and COM displacement to assess jump performance (Giatsis et al. 2004; Riggs and Sheppard 2009). The results obtained showed similar peak power values (2678.8 ・340W and 2639.2 ・248W) for both groups and only slight differences in other variables, which suggests using this method of analysing vertical jump performance is relevant and valuable. Aragon-Vargas and Gross (1997), Dowling and Vamos (1993), Ferreira, Weiss, Hammond and Schilling (2010) and Harman, Rosenstein, Frykman and Rosenstein (1990) all identify peak (mechanical) power as a strong indicator of vertical jump performance also.

2.6 Resistance Training

A common training modality associated with trying to obtain improved vertical jump performance is resistance training (also referred to at times as strength training) (Markovic et al. 2007; McLellan et al. 2011).

> By definition, the term strength training (also known as resistance training) refers to a specialized method of physical conditioning that is used to increase one's ability to exert or resist force (Faigenbaum 2000, p 593).

Faigenbaum (2000) goes on to state, “The term strength training should be distinguished from the competitive sports of weightlifting, powerlifting, and bodybuilding (p 593)”. However, it is important that readers recognise a number of the training stimuli and programs set when developing a resistance training program originate from and or include elements of the three sports identified. The previous sections have identified the need for maximal force and power production to maximise vertical jump performance so as a result the supporting musculoskeletal system needs to be trained in a way that will facilitate these outcomes. By implementing strength training programs, adaptations and ultimately enhancements to the contractile properties of the muscle and improved neural activation to the targeted muscle groups are principally the goal of any program (Baker 1996; Gollhofer 2007).

Hakkinen and Komi (1983) used force-time curves produced during vertical jumps to assess the efficacy of a 16-week strength training program and found significant increases in drop jump height and other mechanical parameters after the training period. The training program used was focussed on relatively large volumes of heavy resistances (80-120% 1RM) through-out the 16-week training period. This form of resistance training stimulus is often associated with targeting gains in the concentric force and rate of force production capabilities (Baker, Nance & Moore 2001). In an attempt to train the peak power capacity of the lower body musculature, research has been conducted that suggests the loads lifted should be in the load range of 45-60% 1RM with low repetitions (1-3reps) while more ballistic type training should target 30-45% 1RM with repetitions ranging between 3-5 (Baker et al. 2001; Baker and Newton 2007; Hakkinen & Komi 1985; McBride, Triplett-McBride, Davie, & Newton 2002).

Specificity of strength training has also been shown to have an effect on improving vertical jump performance. Baker (1996) highlights research that has shown more specific strength training exercises that closely mimic the vertical jump movement pattern, like squats, have greater effect on improving vertical jump height than less specific exercise like seated leg extension. Due to this link to specificity, the use of Olympic weight-lifting exercises/movements like cleans and pull variations have also been studied and shown to have strong positive transfer to vertical jump ability (Arabatzi et al. 2012; Baker 1996).

2.7 Plyometric Training

Continued attempts to find better and new ways to elicit maximum physical and athletic performance from the human body has led to the development of various training methodologies/regimes. One particular methodology focuses on developing and improving elastic energy storage and utilisation qualities of muscle, which is called plyometric training (Radcliffe & Farentinos 1999). This method of training has been scientifically shown to develop and improve maximal power and in particular vertical jump performance (Campillo et al. 2013; Chu 1983; Crowther et al. 2007; Markovic 2007; Markovic et al. 2007; Potach & Chu 2000; Potteiger et al. 1999; Thomas et al. 2009).

It has been identified that volleyball athletes require high force, power and velocity production capabilities to be able to perform the tasks their sport demands (Sheppard, Cronin, et al. 2008). Plyometric training for volleyball athletes has been used and studied in various formats. Sheppard, Hobson, Chapman, et al. (2008) were able to improve CMJ (with no arm-swing) vertical jump height and related kinetic variables using an accentuated eccentric CMJ (a CMJ which overloads the subject with increased load during the eccentric phase only), while Sheppard, McGuigan, and Newton (2007) also demonstrated significant ($p<0.05$) performance enhancement in a BJ when using accentuated eccentric loading. These studies highlight the relevance and importance of the stretch shortening cycle for volleyball athletes. A study by Sheppard, Cronin, et al. (2008) assessed the relative importance of strength, power and anthropometric measures to jump performance of elite volleyball players and found that a plyometric depth jump from a 35cm drop was the best predictor of relative countermovement vertical jump and spike jump performance, explaining 84% and 72% of the performance respectively.

2.7.1 Analysis of the stretch shortening cycle.

A muscle can contract eccentrically while lengthening and performing negative work, or concentrically while shortening and performing positive work (Potach & Chu 2000). Eccentric actions tend to be associated with deceleration of the body and occur when the external force acting upon the body/muscle is greater than the internal tension force. Therefore, during eccentric movements at moderate to high speeds the muscle tendon insertion receives larger loads than during concentric actions and as a result produces the best force and power potential of the muscle being acted upon (Baker 1996; Potach & Chu 2000; Radcliffe & Farentinos 1999). Coupled with this is a muscle's elasticity. The better a muscle's elasticity (ability to lengthen and increase in tension), the better it is able to absorb and then use the strain/tension created during an eccentric movement, to react in the original direction with increased force, more efficiency or both. This may also be referred to as stored elastic energy (Potteiger et al. 1999; Radcliffe & Farentinos 1999). Muscles also experience what is known as the stretch reflex which is an involuntary response to a stimulus that stretches the proprioceptive organs, the muscle spindles, within the muscle. The stimulation of the muscle spindles causes a reflexive response that leads to increased activity of the agonist muscle that then results in increased force production (Potach & Chu 2000). The combination of increased muscle tendon loading, muscle elasticity and the stretch reflex allow for peak muscle recruitment in a limited time frame and this is referred to as the stretch shortening cycle (SSC). Plyometric exercises aim to train, improve the efficiency of and maximise the potential output and contribution of the stretch shortening cycle (SSC). Considering this, the SPJ in volleyball which is a key performance jump is performed using a three to four step approach with the aim of increasing eccentric loading, by enhancing the SSC it would seem beneficial to improving performance. The BJ however, another key performance, would rely less on SSC contribution due to the technique requiring an athlete to hold in a "half squat" or "loaded" position.

2.7.2 The importance of a sound strength base.

Due to the potential high impact and subsequent force loads that plyometric training can create, it is important that athletes have a sound strength training base (Allerheiligen & Rogers 1995; Baker 1996; Potach & Chu 2000). This base will help ensure the athlete is able to cope with the loading stimulus of the plyometric training and also develop the targeted capacities. Poor exercise technique, excessive time spent in the eccentric phase and/or excessive range of movement can all have a negative impact on the performance benefits of plyometric training drills (Radcliffe and Farentinos 1999).

2.7.3 Specificity.

It has been established that good vertical jump performance is heavily reliant on the effectiveness of the muscles that act upon the hip, knee and ankle joints. Based on this fact, it is critical that when designing a plyometric training program to improve vertical jump performance, the activities chosen target these key areas and have a high degree of specificity (Baker 1996). Furthermore, consideration of the principles of overload and recovery must also occur. For example if incorporating a drop jump in to a program it could be overloaded using resistance (increase force via increased external load), range (prescribe range of movement to travel through) or time (stipulate longer or shorter contact time) (Potach & Chu 2000).

2.7.4 Recovery to maximise benefit.

Recovery between repetitions and sets of plyometric exercise is also an important consideration when developing a plyometric training program. Recovery is important as it allows enough time for the body to recover between efforts and ensure the athlete can perform each repetition with maximal effort and speed. As an example, Allerheiligen and Rogers (1995) suggest for drop jumps, 10-15 seconds between repetitions and a three to four minute rest between sets. If an athlete is unable to train maximally they will most likely not be able to get the maximum benefit from the training (stimulus). Another effect of not ensuring adequate recovery can be attempting exercises whilst fatigued which may lead to degradation of technique and thus affect the quality of work being done, the desired stimulus being obtained and increase the potential for injury (Allerheiligen & Rogers 1995; Radcliffe & Farentinos 1999).

2.8 The Effect of Surface Type on Vertical Jump Performance.

As mentioned earlier, different sports compete on different surfaces. Surfaces like natural grass (football, AFL, Rugby League, Rugby Union, Cricket), artificial turf (hockey, American football), wooden floors (basketball, netball), sprung floors (gymnastics), and sand (beach volleyball) to outline a few. It is also well established that different types of surface can directly impact the ability of an athlete to impart force into/onto it (Arampatzis et al. 2004). A surface that has high shock-absorbing properties and is more compliant, like thick spongy mats, long soft grass and deep soft sand will absorb and dissipate more impact force than harder non-compliant surfaces like suspended wooden floors and specifically designed athletics tracks.

2.8.1 Surface effect on training adaptation

Campillo et al. (2013) conducted a study that assessed the effects of a 7-week plyometric training program on a hard wooden (non-compliant) surface and a softer thick athletic mat (compliant). Their results were that performance enhancements in fast SSC movements such as the drop jump were dependent on the training surface. The group that trained on a non- compliant surface showed significant improvement in the DJ from 20 and 40cm while the group that trained on the compliant surface did not. The compliant surface trained group did however exhibit a significant improvement in SJ performance and the non-compliant group did not. These results suggest that performing plyometric training on different surfaces may be associated with differing adaptations. LaChance (1995) not only links differing surfaces to differing adaptations but goes further to suggest that some types of surfaces may actually facilitate the absorption and then transfer of energy in to the performance.

2.8.2 Surface effect on technique.

Mini-trampolines are an example of a compliant surface that has been used in plyometric training and research. Crowther et al. (2007) studied the differences of performing both a CMJ and a DJ on a compliant surface (mini trampoline) and non-compliant surface (ground concrete). Their results showed that during the downward phase of the DJ onto a compliant surface ankle, knee, hip and trunk range of movement was less than compared to the same phase on a hard surface. The same was shown in the downward phase of the CMJ. Crowther et al. (2007) suggested this reduced amount of “crouch” allows the SSC to generate greater maximum leg power by using the compliant surface. Arampatzis et al. (2004) also found that by performing drop jumps onto a softer more compliant surface (gymnastic tumbling floor) resulted in greater benefit than onto a hard surface due to what appeared to be more energy storage in the surface and more returned from it. The results from the two studies goes against the recommendations put-forward by Potach and Chu (2000), who suggest that a compliant surface, specifically a mini-trampoline surface, is not effective for plyometric training. Holcomb et al. 1998 supports the notion of soft surfaces being ineffective for plyometric training stating, "soft surfaces that absorb a great amount of shock will diminish the effectiveness of the (plyometric) training (p 38)". While both a mini trampoline and a gymnastic tumbling floor are both discussed and referred to as compliant surfaces they are compliant in different ways. The mini trampoline's compliance is due to its elasticity and stores energy while the tumbling floor is a soft surface that contains little elasticity and is compliant due to its ability to deform and dissipate impact force. In consideration of the above mentioned studies, it appears that if a compliant surface has an affinity to storing energy (strain) it will be possible to increase DJ vertical jump height, not through increased contribution of the SSC but through the return of energy from the surface. Due to this, compliant surfaces that return energy will not be effective in overloading the SSC as the muscles acted upon will not experience a reactive strength overload, thus making them ineffective surface to train upon.

2.8.3 Surface effects on physical demand.

Sand surfaces are also seen as a compliant surface with little or no elastic recoil that has a direct impact and effect on the physical demands required to perform athletic movements (Bishop 2003; Miyama & Nosaka 2004). Various studies have identified differences between sand and hard surface movements. Lejeune, Willems, and Heglund (1998) demonstrated increased energy cost/expenditure when walking and running on the sand compared to hard stable surfaces. Pinnington and Dawson (2001) found degradation in elastic energy potentiation and increased foot contact times during sand running. There are alterations in joint kinematics and kinetics when performing squat jumps (Giatsis et al. 2004). Sand surfaces decreased levels of muscle damage (creatine kinase) and a reduction in reported muscle soreness (Impellizzeri et al. 2008; Miyama & Nosaka 2004). Bishop (2003) demonstrated that there was a 15% decrease in spike jump and a 6-7% decrease in static jump conditions on sand when compared to hard surface. It was proposed that this reduction in performance was attributed to the low “stiffness” of the sand and also due to the possibility of a single leg take off during the spike jump. The reported differences and effects on performance that sand may account for suggestions that the type of training, exercises used and technical execution of movement must be considered when training athletes for optimal performance on sand.

2.9 Summary

Sporting success, particularly in both forms of volleyball can largely be contributed to an athlete's ability to obtain a maximal vertical jump height above the playing surface. An athlete must be able to displace their COM as high as possible for this to happen. It was therefore necessary to investigate and review the literature that supports these key points for this research project to progress. It was shown that an understanding of the complexities of performing a vertical jump for maximal reach height, ways and means of improving vertical jump performance, various vertical jump types (with specific reference to the sport of volleyball) and the effect that surface may have on vertical jump performance was needed.

Due to complexity of and the interaction between the musculoskeletal system and neuromuscular system, there a various key components identified that can be trained and developed to improve vertical jump performance. The timing and recruitment of the correct muscle groups of the lower limbs as well as interaction of the torso and arms to ensure optimal biomechanical coordination is a factor that has been shown to contribute directly to performance. This highlights the need for correct jumping technique. Directly aligned with this coordination/technique factor is the strength and force production capacity of the muscle(s) involved in VJ performance. The greater the capacity to generate force the greater the ability to alter the COM acceleration, velocity and in turn displacement.

There are a number of research studies aiming to identify ideal training stimuli to elicit improvement in vertical jump height. It appears that the most consistent and heavily used methodologies are resistance training and plyometric training or a combination of both. Resistance training targeting adaptation of the musculoskeletal system with particular focus on improving the force production and or speed of muscle contraction (Baker 1996; Ham et al. 2007), while plyometric training aims to improve performance by enhancing the force and power contribution of the SSC to vertical jump height.

The sport of volleyball has two unique jump types, the block jump and spike jump, which are associated with competition success. These two jumps are technically different and appear to be reliant on different strength components, BJ more reliant on contractile strength and SPJ reactive strength. Due to the specificity of these jumps, there appears minimal research that reports directly on them and so the need to investigate more typical vertical jump types (SJ, CMJ & DJ) is required. These three jumps are not only considered key components of a vertical jump and plyometric training program but also good practical measures of leg neuromuscular function. Another uniqueness of volleyball is that it is played at an international level on two different surfaces in the form of a hard (non-compliant) indoor volleyball surface and a soft (compliant) sand beach volleyball surface. These two surfaces have been shown to directly affect the ability to perform the BJ and SPJ but little has been reported on the effect of training on either surface, the transfer to performance and between surfaces.

Subsequently, the theory and information gained through this literature review will directly guide and impact the research protocol, result analysis and interpretation.

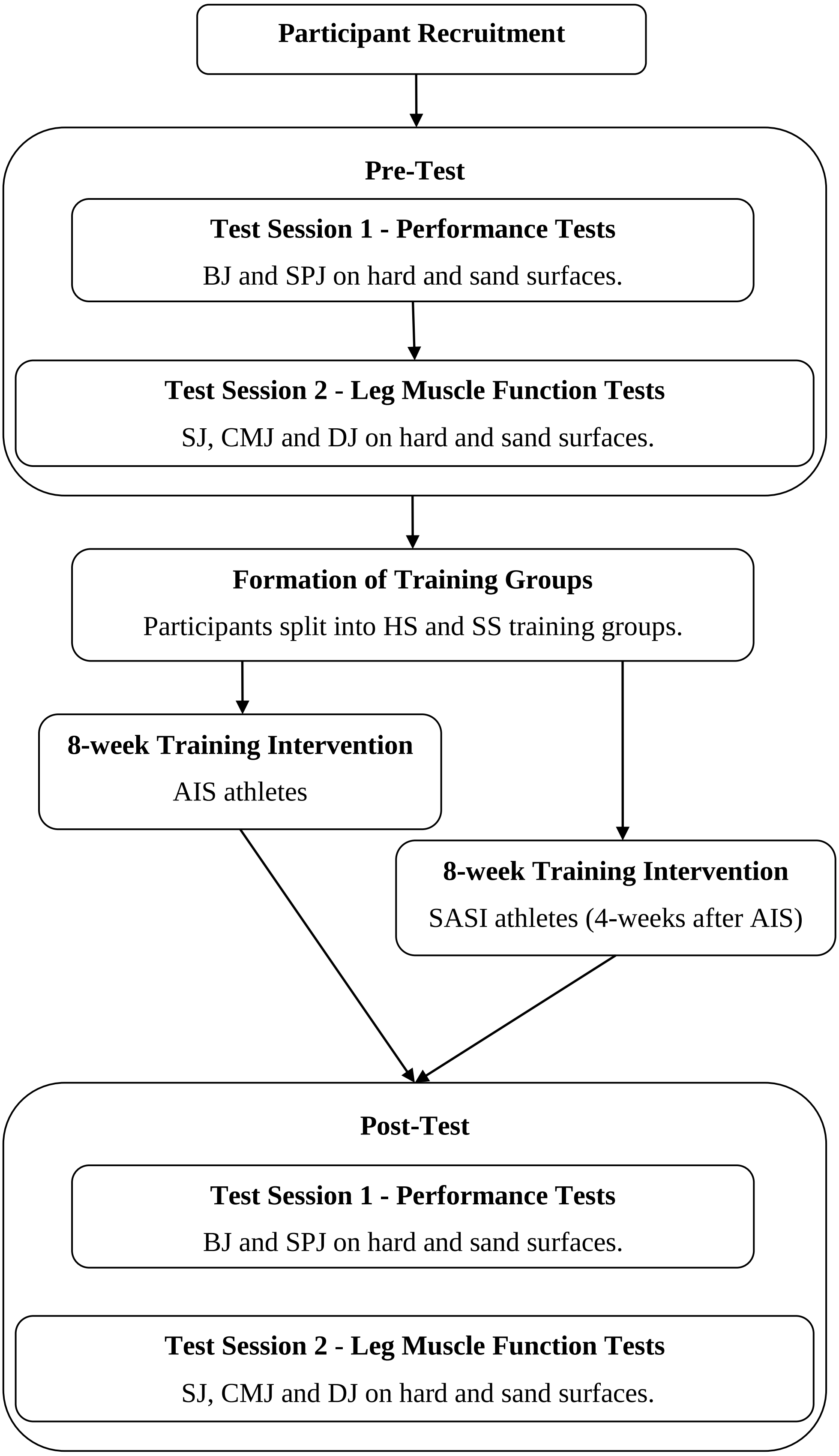
Chapter 3

3.0 Methodology

3.1 Experimental Approach

This research project was a within subject design using both male and female volleyball players, recruited from the AIS Beach Volleyball program and the SASI Volleyball program. Following participant recruitment, a pre-test consisting of two separate testing sessions (due to participant availability) was conducted. The pre-test was used to establish baseline data and divide the participants into two separate training groups, a hard surface trained (HS) intervention group and a sand surface trained (SS) intervention group. The participants then undertook an 8-week training program that was comprised of 24 individual training sessions (3 per week). The 8-week training program was supplementary to the normal training load of both the AIS and SASI programs. Due to differing training and competition schedules between the AIS and SASI programs, the SASI volleyball athletes began the 8-week training intervention four weeks after the AIS athletes. The week after the final training session, the participants underwent post-intervention testing that consisted of the same jump testing in the same order as done in the pre-testing. The SASI athletes completed their post testing four weeks after the AIS athletes (see **Figure 3.1**).

FIGURE 3.1 - Flow chart of experimental approach.



3.2 Subjects

A group of 25 volleyball athletes were recruited from the AIS, National Beach Volleyball program (*n*=12) and the SASI volleyball program (*n*=13). All participants were provided with an information sheet informing them of the study's purpose, known risks and the right to terminate their involvement at will **(Appendix A).** All participants through their respective scholarship agreements, gave consent to be a willing participant in the study. The Research Ethics Committee of the University of Ballart approved the study research design and testing procedures **(Appendix B).**

The 12 AIS athletes had very similar training workloads throughout the project duration. AIS participants experienced on average two 90-minute gymnasium-based strength training sessions, two 60-minute functional strength sessions and six 60-120-minute sand-based skill training sessions. The group consisted of athletes that were multiple Olympians (beach and indoor), had represented Australia at both junior and senior world championships, played on the FIVB international beach volleyball world tour and represented their states at national championships (beach and indoor). All AIS athletes had a minimum of four years resistance training experience. The 13 SASI athletes had very similar training workloads throughout the project duration but overall less total sessions than the AIS athletes. SASI participants experienced on average, two 90-minute gymnasium-based strength training sessions and three, 90-120-minute sand-based skill training sessions. The SASI group consisted of athletes that had represented Australia at junior world championships (beach and indoor) and represented their states at national championships (beach and indoor). All SASI athletes had a minimum of two years resistance training experience. Due to positional differences and varying coaching strategies, the training demands across the 8-weeks were not constant throughout. It is also worth noting that the AIS athletes had a twelve month beach volleyball focus however the SASI athletes had a beach volleyball focus for 5-months of the year (November-March) and an indoor focus for 6-months (April-September). The jump training intervention was conducted during the period when beach volleyball was the focus for the SASI athletes.

To try and establish an even spread of vertical jump ability in the training groups, the baseline data collected from the SPJ test on a hard surface was used to divide the participants into the HS group (*n*=12, 6 female, 6 male) and the SS group (*n*=13, 7 female, 6 male). The split of male and female participants in each group was not deliberately chosen. Each athlete's spike jump score was paired to the closest next score and then randomly each athlete placed in either the HS or SS groups until all athletes were allocated a training group. The mean age, body mass, standing height and standing vertical reach height for the HS and SS groups and are shown below. Also shown is the male and female mean anthropometric data (**Table 3.1**). To ensure the groups were not significantly different, a 2-tailed independent t-test was conducted on age, height, mass and reach height. The differences between means ranged from 0.5 - 3.0%, with all results showing non-significant differences (p>0.05) for all variables. These results suggest that the random allocation of participants created two similar groups.

Due to various significant injuries during the training intervention period, seven of the original 25 recruited and pre-tested participants were unable to complete the full training program and therefore discarded from all jump testing data. This resulted in a total of 18 participants that completed the intervention and all testing. The injuries were varied, one was a previous and repetitive toe injury, two were due to sand-based competition training (rolled ankles from landing on an opponent's foot), a fourth was a lower-limb muscle strain (gastrocnemius) that occurred during competition, fifth and sixth injuries were knee-related and the seventh a recurring lower-back injury. The training compliance of the 18 participants that completed the intervention was extremely high. One participant missed a single training session during week four of the intervention, the remaining 17 completed all sessions.

TABLE 3.1 – Anthropometric Data.

	Age (yrs)	**Mass (kg)**	**Height (cm)**	**Standing Vertical Reach (cm)**
Hard Surface Trained *(n=12)*	22.3 ±3.7	78.8 ±12.6	186.3 ±9.4	242.8 ±14.5
Sand Surface Trained *(n=13)*	21.5 ±6.3	77.3 ±8.9	187.2 ±8.3	243.9 ±11.9
Male *(n=12)*	20.9 ±4.9	87.3 ±7.3	194.9 ±3.6	255.3 ±6.2
Female *(n=13)*	22.7 ±5.3	69.5 ±3.9	179.3 ±3.5	232.4 ±5.5

3.3 Performance Test

The performance test consisted of 12 maximal jumps, spread across two jump types, a BJ and a SPJ. Jump height was assessed using a Yardstick (Swift Performance Equipment, Lismore, Australia). Tests were done in accordance with the Australian Institute of Sport's National Sport Science Quality Assurance protocols. Participants were required to perform three maximal jumps separated by 30seconds of passive rest between efforts, followed by a 3min passive rest between jump types to allow adequate recovery. Both jump types (BJ and SPJ) were completed on the hard surface first and then the participants performed both on the sand surface. The best jump height obtained on each test was recorded. Although the sand surface testing always followed the hard surface, the recovery between jumps was considered adequate to prevent any order effect. Prior to the beginning of each test session the atmospheric conditions of temperature [C^0], relative humidity [%] and Pressure [mmHg] were collected using an Oregon Scientific environmental sensor (Model N^o: BA888) that was regularly calibrated to National Association of Testing Authorities (Australia) standards. All participants performed a standardised 10min dynamic warm-up involving a light jog, a variety of functional range of movement exercises (e.g. sumo squat, forward walking lunge and reach, snatch squat) as well as some ballistic co-ordination exercises (e.g. forward jump to single-leg landing, clap push up, "spiderman" crawl) prior to the start of testing.

3.4 Leg Muscle Function Test

The leg muscle function test consisted of three different jump types; A drop jump from 40cm (DJ) (Typical Error: HS= 2.0cm, SS=3.0cm), a countermovement jump (CMJ) (Typical Error: HS= 2.0cm, SS=1.0cm) and a squat jump (SJ) (Typical Error: HS= 1.0cm, SS=2.0cm). The DJ height was set at 40cm based on the study by Sheppard, Cronin, et al., (2008) which showed a similar drop height elicited performances strongly correlated to CMJ and spike jump in volleyball athletes. All participants were instructed to minimise ground-contact time and jump as high as possible when performing the DJ. The participants self-selected the depth of the countermovement for the CMJ and were instructed to jump as high as they possibly could. The SJ required the subjects to lower themselves into a flexed knee start position that created approximately a 90 degree angle at the knee. The researcher visually assessed each of the start positions to ensure consistency. Once in the correct position the participants were instructed to hold the start position for three seconds (as counted by the researcher) before they attempted to jump maximally, vertically, without a countermovement. If the subject performed a countermovement from the start position, the jump was not included and had to be repeated. Participants were required to perform two of each jump type with 30 seconds of passive rest between jumps and a 3 minute passive rest between jump types. The jump trial that recorded the highest vertical jump height was identified and the corresponding force-time data was retained and used for analysis.

GRF data for each jump type was collected using the AccuPower power assessment system operating at 200Hz (AMTI, Frappier Acceleration, USA), which uses a triaxial force plate and specifically designed data acquisition software. Using the force-time data, muscle function variables were obtained using Microsoft Excel (Microsoft Corporations, Redmond, Washington, USA). Sand-based GRF data was collected in the same manner as the hard surface however the force plate was covered by a purpose built fitted wooden box measuring 102.5cm x 77.5cm x 45cm (height, width, depth). The box was then filled with an even 30cm layer of sand. The type and quality of the sand used conformed to the FIVB beach volleyball sand regulations (FIVB Beach Volleyball Handbook, 2012). Vertical jump height for all GRF testing was calculated for each jump using a linear cable transducer and Gymaware software (Kinetic Performance Technology, Canberra, Australia), placed on the ground next to the force plate, and connected to a two metre length of light wooden dowel which was held by the athlete across the back of the shoulders. Prior to the beginning of each test session the atmospheric conditions of temperature [C^0], relative humidity [%] and Pressure [mmHg] were collected using an Oregon Scientific environmental sensor (Model N^o: BA888) that was regularly calibrated to National Association of Testing Authorities (Australia) standards. All participants performed a standardised 10min dynamic warm-up involving a light jog, a variety of functional range of movement exercises (e.g. sumo squat, forward walking lunge and reach, snatch squat) as well as some ballistic co-ordination exercises (e.g. forward jump to single-leg landing, clap push up, “spiderman” crawl) prior to the start of testing. The muscle function variables assessed for each jump type using the force-time data acquired are listed below in **Table 3.2**.

TABLE 3.2 - Key muscle function variables measured for each jump type.

Muscle Function Variable	Description	DJ	CMJ	SJ
Peak Force (N)	Maximum vertical force generated during jumping motion.	Yes	Yes	Yes
Rate of Force Development (kN/s)	Maximum rate of force generation during jumping motion - slope of the force curve.	Yes	Yes	Yes
Impulse (N.s)	The area under the force vs time graph when body weight is taken to account.	Yes	Yes	Yes
Peak Power (W)	The maximum power applied to ground during the jumping motion.	No	Yes	Yes
Time (ms)	Time from first detected movement until take-off.	Yes	Yes	Yes
Relative Peak Force (N/kg)	Peak force scaled by body-weight.	Yes	Yes	Yes
Relative Peak Power (W/kg)	Peak power scaled by body-weight.	No	Yes	Yes
RSI (cm/s)	The ability to change from an eccentric to concentric action (jump height/contact time)	Yes	No	No

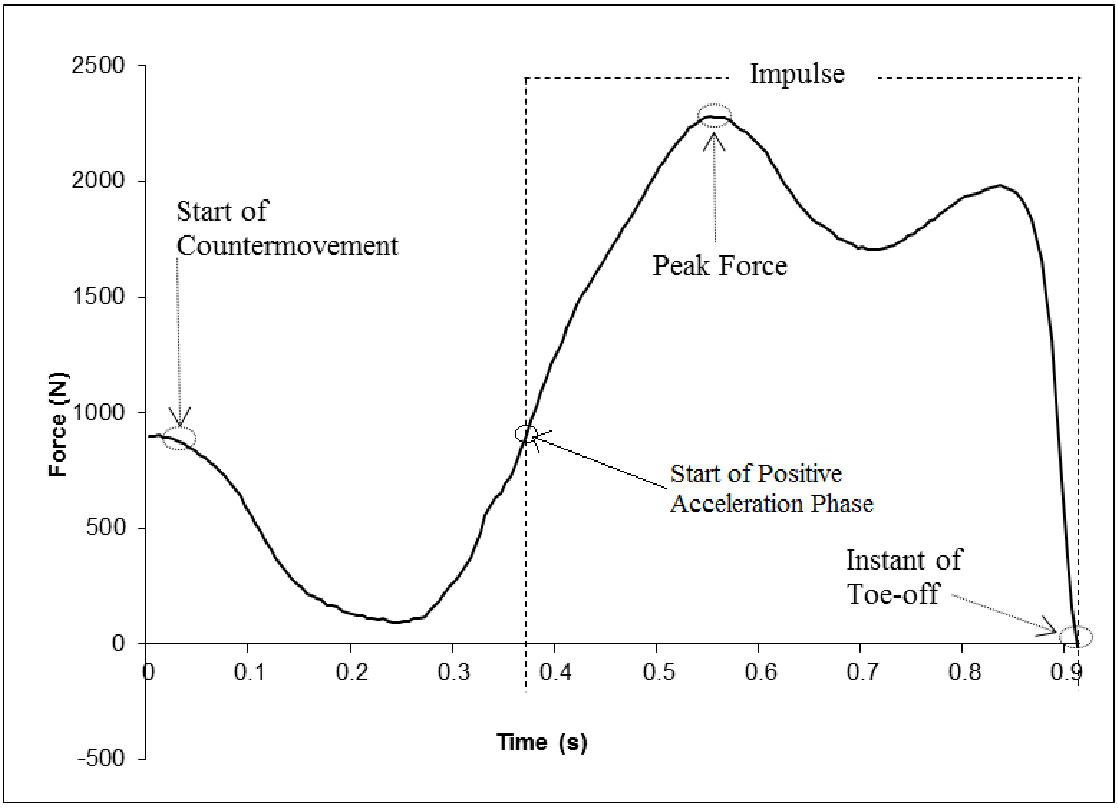
Using the same technique as Riggs and Sheppard (2009), impulse was calculated from the force-time curve, using the below equation:

$I = m.a.\Delta t$

I= Impulse, m = mass (kg), a = acceleration (ms^{-2}), Δt = change in time

The change in time (Δt) was deemed as the point at which the force in the propulsive phase of the CMJ was equal to or as close to equal to the athlete’s body weight in Newtons to the point at which the force trace dropped to zero (**Figure 3.2**). This point was labelled toe-off. The SJ change in time (Δt) was deemed as the point at which the force trace began to increase from a steady state to the point at which the force trace dropped to zero and the DJ change in time (Δt) was deemed as the point at which the athlete contacted the force plate to the point at which the force trace dropped to zero.

FIGURE 3.2 - Illustration of the procedure for determining the start and end point for impulse calculations in a CMJ



3.5 Jump Training Program

The vertical jump training program (VJTP) consisted of three identical training sessions per week over an 8 week period (see **Table 3.3**). While this is two weeks less than the ideal program duration recommended by de Villarreal et al. (2009), due to the training and competition schedules of the participants, this was the maximum length of time possible. Each week the total (jump) volume was gradually increased. The participants progressed from a total of 120-jumps per week (40/session) during week one to a total of 240-jumps per week (80/session) during week seven. During the fourth and eighth week the training volume returned to baseline level (120-jumps/week) and week three volume (165-jumps/week) respectively as these were designated “recovery” weeks to allow for a super-compensatory response. Total jumps for the program equated to 1,380. To maximise the impact of the VJTP and minimise technical complexity, only four traditional jump training exercises were used and progressive overload was achieved simply through modification of training volume.

The first training exercise was a DJ performed by dropping from a 40cm step, with the instruction to jump as high as possible while minimising ground contact time. The DJ included an arm-swing. The second exercise was a CMJ for maximal jump and reach height, performed with an arm-swing and the instruction to jump as high as possible. The third exercise was a SJ performed by squatting and lowering buttocks to the edge of 40cm step, pausing for three seconds and given the instruction to jump as high as possible. The participants performed this jump with their hands at eye level and without arm-swing to partially replicate the technique required for blocking. The fourth exercise was a repeated tuck jump (RTJ) a combination of a CMJ and DJ where the subject jumps maximally, brings their knees up to chest height (tuck), lands and attempts to minimise ground contact time and then repeats the jump. Three of the four jumps used (SJ, CMJ & DJ) were identified by de Villarreal et al. (2009) as eliciting maximal gains when used and combined during plyometric training. The DJ and the RTJ were incorporated to target fast reactive strength, CMJ to target slower reactive strength and SJ to target concentric power (McGuigan, Sheppard, Cormack & Taylor 2013).

All participants performed a standardised 10min dynamic warm-up involving a light jog, a variety of functional range of movement exercises (e.g. sumo squat, forward walking lunge and reach, snatch squat) as well as some ballistic co-ordination exercises (e.g. forward jump to single-leg landing, clap push up, "spiderman" crawl) prior to all VJTP sessions. Each set of exercises contained five repetitions in an attempt to facilitate a sport specific training stimulus based on the findings from Turpin et al. (2008) who showed that beach volleyball athletes performed on average 5.8 jumps per point during competition. In conjunction with this, maintaining consistency in reps ensured superior athlete compliance. Participants were given a 90 second passive recovery between sets and a 120 second passive recovery between exercises based on the recommendations of Potach & Chu (2000) and Radcliffe and Farentinos (1999). The participants performing the jump program on sand were required to lightly rake the sand between sets to ensure a level starting point and minimise the impact of sand being compacted. The participants performing the VJTP on hard surface used a solid cement floor covered with wooden parquetry (un-sprung).

TABLE 3.3 - Vertical jump training program.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Exercise								
DJ 40cm	2 x 5	2 x 5	3 x 5	2 x 5	3 x 5	4 x 5	4 x 5	3 x 5
RTJ	2 x 5	2 x 5	2 x 5	2 x 5	3 x 5	4 x 5	4 x 5	2 x 5
CMJ	2 x 5	3 x 5	3 x 5	2 x 5	4 x 5	4 x 5	4 x 5	3 x 5
SJ	2 x 5	3 x 5	3 x 5	2 x 5	3 x 5	3 x 5	4 x 5	3 x 5
Total Jumps/Session	40	50	55	40	65	75	80	55
Total Jumps/Week	120	150	165	120	195	225	240	165

3.6 Statistical Analysis

Standard descriptive statistics (means, standard deviation) were obtained for both hard surface and sand-trained group variables. To determine if there were any statistically significant differences between the groups over time, Analysis of Variance (ANOVA) with repeated measures were conducted for the jump performance and muscle function variables. Statistical significance was set at $p<0.05$ and no multiple statistical comparison was done due to the increased chance of a type II error. Pearson correlations and a stepwise multiple regression were performed to assess relationships between baseline BJ and SPJ variables and leg extensor muscle function variables. Correlation descriptors were based on the following criteria: 0.9-1.0 nearly perfect; 0.7-0.89 very large; 0.5-0.69, large; 0.3-0.49, moderate; 0.1-0.29, small; 0-0.09 trivial (Hopkins 2013). Two-tailed paired T-tests were applied to examine differences in pre and post intervention results, Cohen's effect size (Cohen's d) were calculated to assess the magnitude of any differences observed with the following criteria: >1.2, large; 0.6-1.19, moderate; 0.3-0.59, small; 0.0-0.19, trivial (Hopkins 2013). All statistics were performed with the Statistical Package for the Social Sciences (SPSS, version 19).

Chapter 4

4.0 Results

4.1 Effect of vertical jump training on volleyball jump performance.

A key focal point of the research was the effect of the vertical jump training program on BJ and SPJ vertical jump height. Analysis of the paired t-tests indicated that the HS group demonstrated trivial and small training gains in block jump on hard surface and block jump on sand surface respectively (**Table 4.1**). The SS group only achieved statistically significant ($p<0.05$) gains for the block jump on the sand. This suggests that there is some transfer in gains from training on a hard surface to performance on a sand surface. It also highlights the opposite is not true, that is, training on a sand surface does not transfer into hard surface performance. The change in spike jump performance was not significant ($p>0.05$) for either training group on either surface although a small gain was seen in the SS group on the sand surface. Although not statistically significant, the 5.6% improvement in SPJ on sand demonstrated by the SS group would be seen as a positive and favourable result from a coaching, strength and conditioning practitioner and athlete perspective. Further to this when the individual change in performance was examined for this group, two of the eight participants improved their performance by 9cm and 11cm, a very favourable gain in the practical setting. However, as the large standard deviation suggests there were two participants whose performances decreased by 1cm and 5cm and the remaining four participants only increased performance by 1-5cm. ANOVA with repeated measures showed no group by time interactions ($p>0.05$) for any performance tests (**Figure 4.1 - 4.4**), indicating that changes in performance test jump height were not different for the two training groups.

TABLE 4.1 - Performance test jump heights (mean) on different surfaces.

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
Block Jump (Hard) *(cm)*	49.8 ± 10.7	51.1 ± 10.8	2.6	**0.033**	0.12	trivial
Block Jump (Sand) *(cm)*	47.9 ± 10.1	51.1 ± 10.2	6.7	**0.019**	0.32	small
Spike Jump (Hard) *(cm)*	68.1 ± 12.9	69.3 ± 14.4	1.8	0.317	0.09	trivial
Spike Jump (Sand) *(cm)*	62.2 ± 13.4	62.8 ± 15.5	1.0	0.656	0.04	trivial
Sand Surface Trained (*n=8*)						
Block Jump (Hard) *(cm)*	46.8 ± 10.6	47.3 ± 12.8	1.1	0.627	0.04	trivial
Block Jump (Sand) *(cm)*	43.0 ± 11	47.2 ± 12.9	9.8	**0.009**	0.35	small
Spike Jump (Hard) *(cm)*	66.5 ± 15.8	67.7 ± 14.6	1.8	0.290	0.07	trivial
Spike Jump (Sand) *(cm)*	57.5 ± 14.6	60.7 ± 17.7	5.6	0.141	0.20	small

Bold p values represent signficant scores

FIGURE 4.1 - Block jump mean jump height on hard surface pre versus post (error bars represent standard deviations).

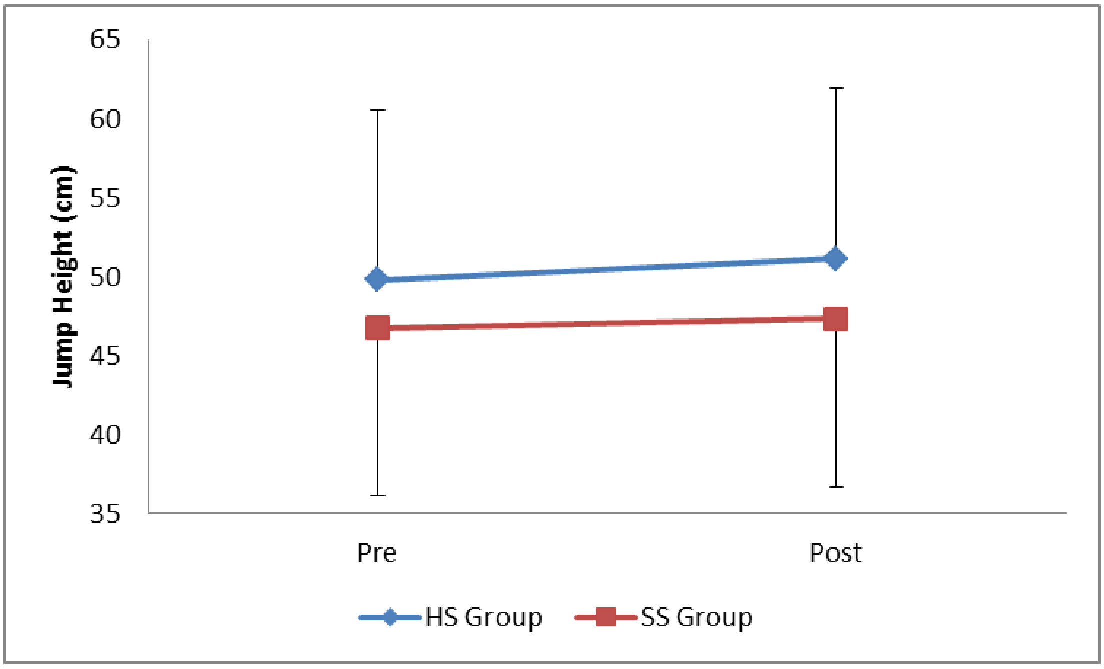


FIGURE 4.2 - Block jump mean jump height on sand surface pre versus post (error bars represent standard deviations).

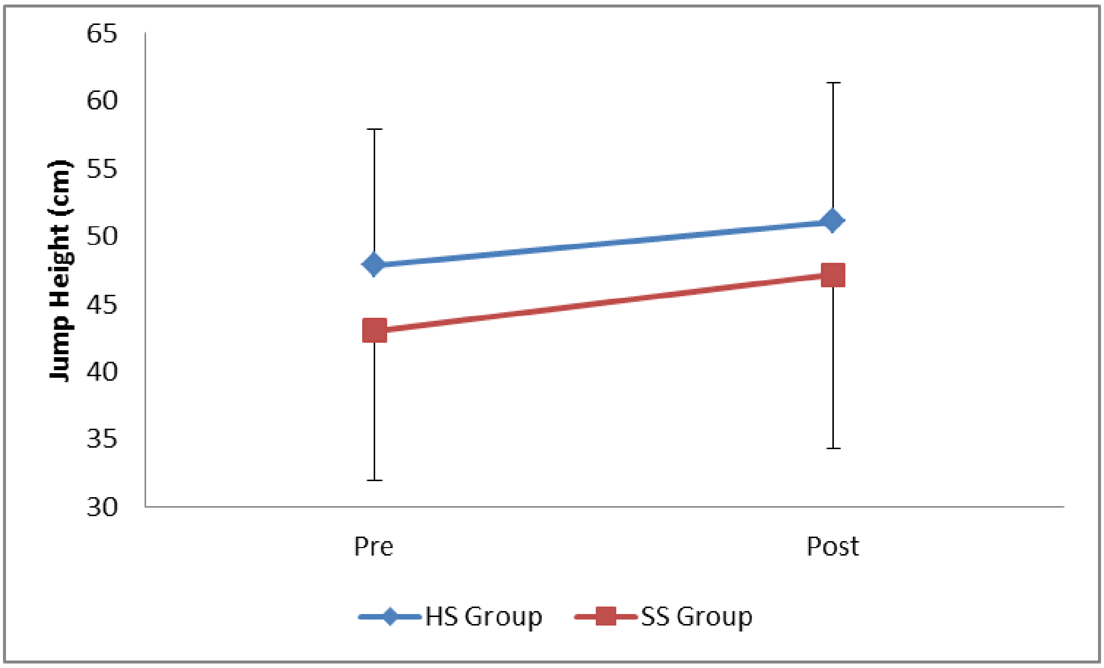


FIGURE 4.3 - Spike jump mean jump height on hard surface pre versus post (error bars represent standard deviations).

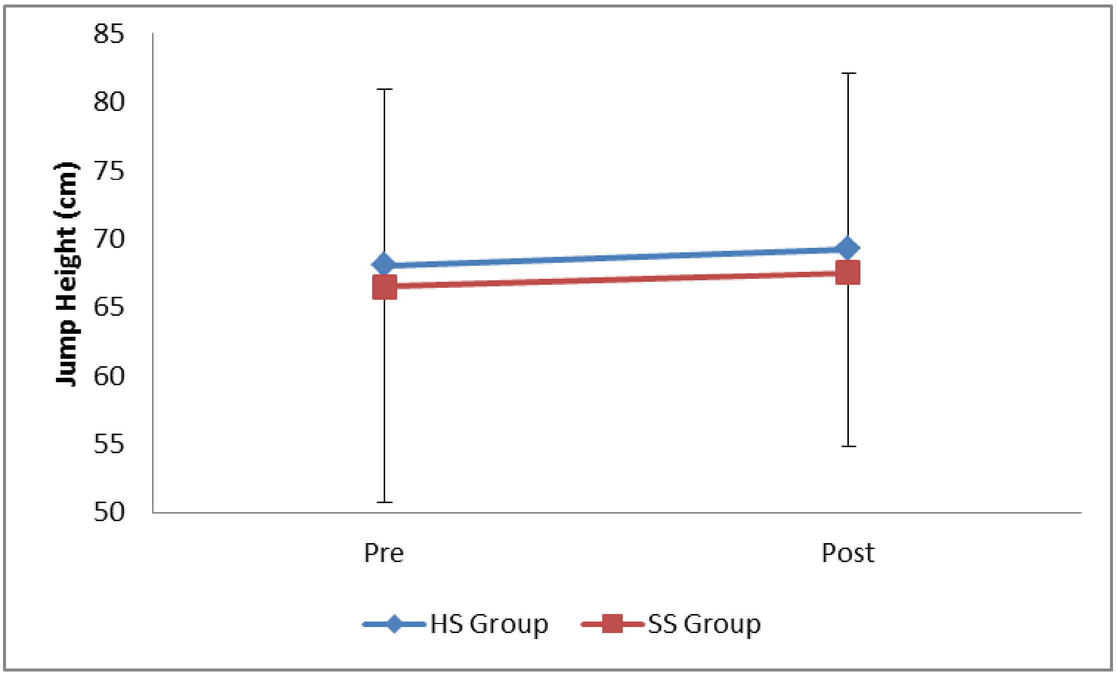
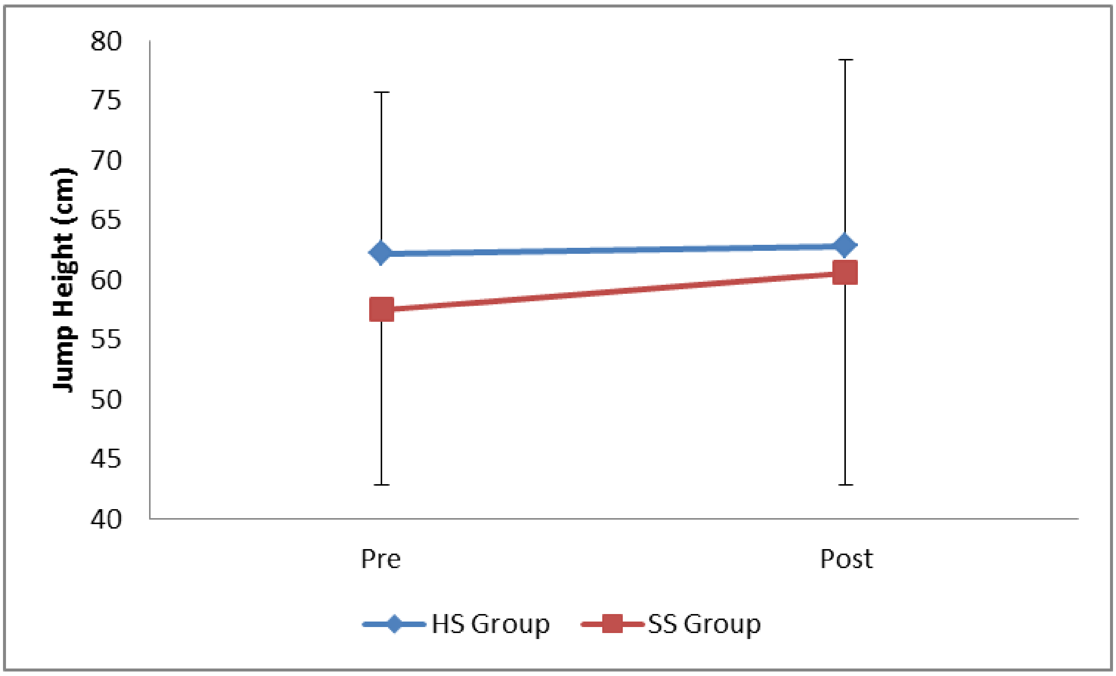


FIGURE 4.4 - Spike jump mean jump height on sand surface pre versus post (error bars represent standard deviations).



4.2 Inter-relationships among volleyball jumps and surfaces.

Correlations of pre-intervention performance tests were conducted (**Table 4.2**) to assess relationships between tests. By doing this, it was possible to identify the relationship between the skills like-for–like (e.g. block jump v block jump) on differing surfaces, the relationship between differing skills (block jump v spike jump) on the same surface and finally any relationship between differing skills on differing surfaces. They were assessed as a combined squad and also by gender to help identify any possible influence that this may have had on results. Nearly all results correlated strongly suggesting a level of consistency in the participants jumping ability regardless of the type of surface or skill (jump) that was being performed. It appears that the effect of combining both genders is minimal however may be slightly skewed towards the female data based on the very high correlations across all measures (**Figure 4.5 - 4.6**).

TABLE 4.2 - Correlations pre performance test jumps within groups (combined, male and female).

	Combined (n=18)			**Males (n=9)**			**Female (n=9)**		
	r	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**
Effect of Surface									
Block Hard v Block Sand	0.96(NP)	93	**<0.001**	0.94(NP)	88	**<0.001**	0.94(NP)	88	**<0.001**
Spike Hard v Spike Sand	0.96(NP)	92	**<0.001**	0.88(VL)	77	**0.002**	0.951(NP)	90	**<0.001**
Effect of Skill									
Block Hard v Spike Hard	0.91(NP)	83	**<0.001**	0.79(VL)	62	**0.012**	0.95(NP)	90	**<0.001**
Block Sand v Spike Sand	0.96(NP)	92	**<0.001**	0.9(NP)	81	**0.001**	0.964(NP)	93	**<0.001**
Effect of Surface and Skill									
Block Hard v Spike Sand	0.95(NP)	90	**<0.001**	0.90(VL)	80	**0.001**	0.95(NP)	90	**<0.001**
Block Sand v Spike Hard	0.89(VL)	79	**<0.001**	0.67(L)	45	0.470	0.97(NP)	94	**<0.001**

Bold p values represent signficant scores

† *(%) refers to the Common Variance* (r^2 *x 100)*

r value descriptors: (NP) nearly perfect; (VL) very large; (L), large; (M), moderate; (S), small; (T) trivial

FIGURE 4.5 - Scatterplot of male and female spike jump and block jump on hard surface.

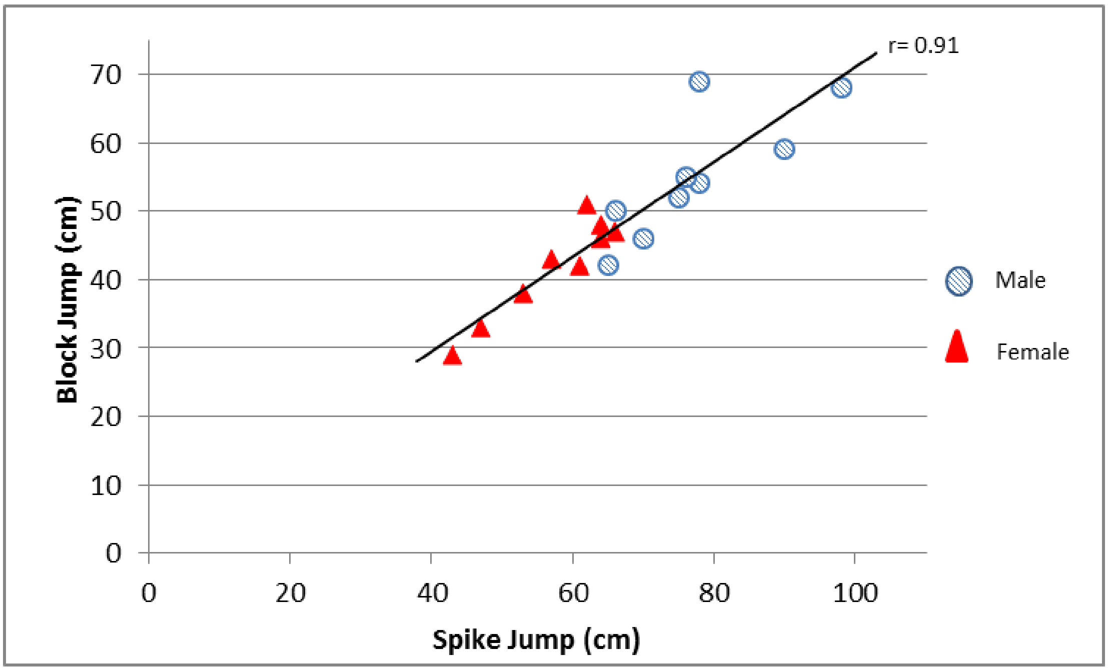
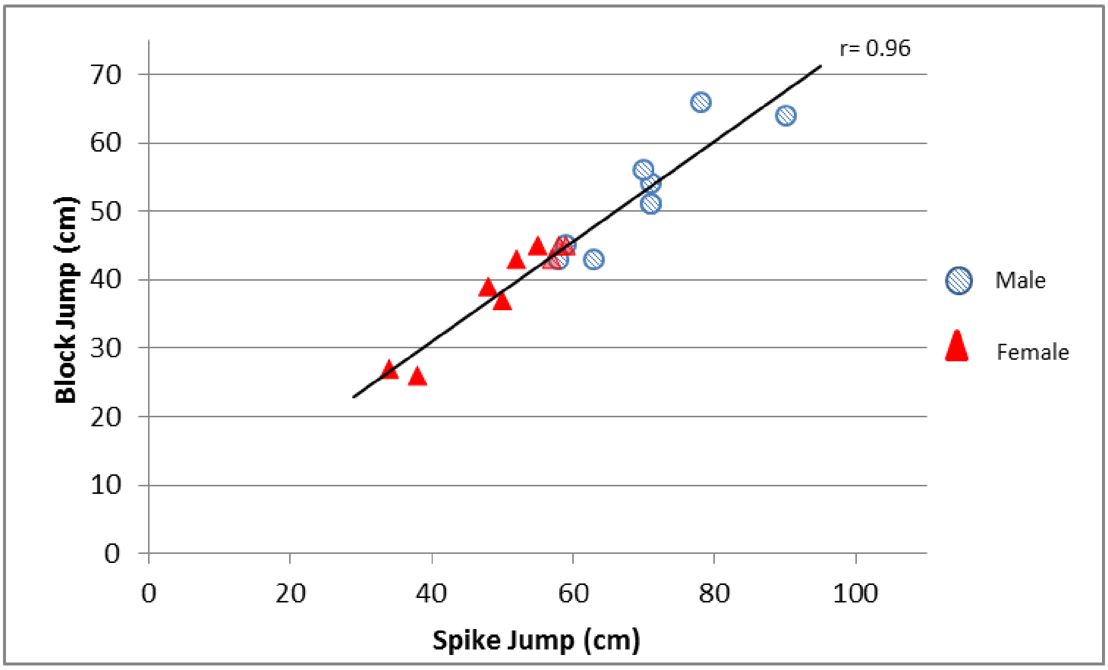


FIGURE 4.6 - Scatterplot of male and female spike jump and block jump on sand surface.



4.3 Relationships between volleyball jumps and leg muscle function.

Relationships between pre-training intervention performance tests (BJ, SPJ) and pre intervention muscle function tests (CMJ, SJ and DJ), for the two differing surfaces, was assessed using correlation coefficients (**Table 4.3 and Table 4.4**). When visually inspecting the data, four key variables were identified for both hard and sand surface results, jump height, impulse, peak power and relative peak power. These four variables for both SJ and CMJ appeared to be consistently strongly correlated to all performance jump types. Measures taken from the DJ on a hard surface did show some large correlations with the performance tests but this was not consistent with the sand surface results.

TABLE 4.3 – Correlations pre-test performance jumps on hard surface and hard surface muscle function tests (*n*=18).

		Block Hard			**Spike Hard**			**Block Sand**			**Spike Sand**		
		r	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**
Squat Jump	Jump height	0.88(VL)	77	**<0.001**	0.86(VL)	75	**<0.001**	0.86(VL)	75	**<0.001**	0.85(VL)	72	**<0.001**
	Peak Force	0.68(L)	46	**0.002**	0.75(VL)	56	**<0.001**	0.72(VL)	52	**0.001**	0.78(VL)	61	**<0.001**
	RFD	0.60(L)	36	**0.008**	0.64(L)	41	**0.004**	0.54(L)	29	**0.022**	0.64(L)	40	**0.005**
	Impulse	0.83(VL)	69	**<0.001**	0.82(VL)	67	**<0.001**	0.88(VL)	78	**<0.001**	0.86(VL)	74	**<0.001**
	Peak Power	0.79(VL)	62	**<0.001**	0.80(VL)	64	**<0.001**	0.80(VL)	64	**<0.001**	0.83(VL)	69	**<0.001**
	Time	-0.34(M)	12	0.164	-0.34(M)	12	0.162	-0.19(S)	4	0.451	-0.25(S)	6	0.318
	Relative Peak Force	0.59(L)	34	**0.010**	0.69(L)	47	**0.002**	0.58(L)	34	**0.011**	0.68(L)	46	**0.002**
	Relative Peak Power	0.83(VL)	69	**<0.001**	0.84(VL)	70	**<0.001**	0.80(VL)	64	**<0.001**	0.85(VL)	71	**<0.001**
Countermovement Jump	Jump height	0.93(NP)	86	**<0.001**	0.87(VL)	76	**<0.001**	0.91(NP)	84	**<0.001**	0.91(NP)	83	**<0.001**
	Peak Force	0.71(VL)	50	**0.001**	0.76(VL)	58	**<0.001**	0.73(VL)	53	**0.001**	0.78(VL)	60	**<0.001**
	RFD	0.36(M)	13	0.144	0.43(M)	19	0.073	0.42(M)	18	0.080	0.46(M)	21	0.057
	Impulse	0.79(VL)	62	**<0.001**	0.87(VL)	76	**<0.001**	0.84(VL)	70	**<0.001**	0.88(VL)	78	**<0.001**
	Peak Power	0.71(VL)	50	**0.001**	0.75(VL)	57	**<0.001**	0.74(VL)	55	**<0.001**	0.78(VL)	61	**<0.001**
	Time	0.25(S)	6	0.316	0.17(S)	3	0.478	0.27(S)	7	0.275	0.25(S)	6	0.325
	Relative Peak Force	0.56(L)	31	0.150	0.61(L)	37	**0.008**	0.46(M)	21	0.560	0.54(L)	29	0.200
	Relative Peak Power	0.72(VL)	52	**0.001**	0.77(VL)	60	**<0.001**	0.74(VL)	54	**<0.001**	0.78(VL)	61	**<0.001**
Drop Jump	Jump height	0.65(L)	42	**0.004**	0.76(VL)	58	**<0.001**	0.70(VL)	49	**0.001**	0.72(VL)	52	**0.001**
	Peak Force	0.58(L)	33	**0.012**	0.53(L)	28	**0.024**	0.49(M)	24	**0.041**	0.54(L)	29	**0.022**
	RFD	0.60(L)	36	**0.008**	0.5(L)	25	**0.035**	0.61(L)	37	**0.008**	0.57(L)	33	**0.013**
	Impulse	0.45(M)	20	0.063	0.56(L)	31	**0.016**	0.56(L)	31	**0.017**	0.60(L)	36	**0.009**
	Time	-0.25(S)	6	0.318	-0.10(S)	1	0.685	-0.11(S)	1	0.680	-0.09(T)	1	0.732
	Relative Peak Force	0.24(S)	6	0.345	0.17(S)	3	0.499	0.09(T)	1	0.716	0.15(S)	2	0.555
	RSI	0.64(L)	40	**0.005**	0.66(L)	44	**0.003**	0.59(L)	34	**0.011**	0.61(L)	37	**0.008**

Bold p values represent signficant scores

† *(%) refers to the Common Variance* $(r^2 \times 100)$

r value descriptors: (NP) nearly perfect; (VL) very large; (L), large; (M), moderate; (S), small; (T) trivial

TABLE 4.4 – Correlations pre-test performance jumps on sand surface and sand surface muscle function tests (*n*=18).

		Block Hard			Spike Hard			Block Sand			Spike Sand		
		r	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**	**r**	**Common Variance (%)†**	**p**
Squat Jump	Jump height	0.90(NP)	81	**<0.001**	0.87(VL)	75	**<0.001**	0.90(NP)	81	**<0.001**	0.88(VL)	77	**<0.001**
	Peak Force	0.77(VL)	59	**<0.001**	0.83(VL)	69	**<0.001**	0.79(VL)	62	**<0.001**	0.83(VL)	69	**<0.001**
	RFD	0.73(VL)	53	**0.001**	0.63(L)	40	**0.005**	0.67(L)	44	**0.003**	0.69(L)	48	**0.001**
	Impulse	0.81(VL)	65	**<0.001**	0.82(VL)	68	**<0.001**	0.85(VL)	73	**<0.001**	0.87(VL)	75	**<0.001**
	Peak Power	0.84(VL)	71	**<0.001**	0.90(NP)	80	**<0.001**	0.88(VL)	77	**<0.001**	0.90(NP)	83	**<0.001**
	Time	-0.20(S)	4	0.439	-0.17(S)	3	0.512	-0.04(S)	0	0.867	-0.18(S)	3	0.465
	Relative Peak Force	0.69(L)	48	**0.001**	0.82(VL)	68	**<0.001**	0.67(L)	45	**0.002**	0.74(VL)	55	**<0.001**
	Relative Peak Power	0.88(VL)	77	**<0.001**	0.95(NP)	89	**<0.001**	0.88(VL)	78	**<0.001**	0.92(NP)	85	**<0.001**
Countermovement Jump	Jump height	0.86(VL)	74	**<0.001**	0.91(NP)	83	**<0.001**	0.90(NP)	80	**<0.001**	0.92(NP)	85	**<0.001**
	Peak Force	0.57(L)	32	**0.014**	0.61(L)	38	**0.007**	0.59(L)	35	**0.009**	0.65(L)	42	**0.004**
	RFD	0.03(T)	0	0.917	0.74(VL)	55	0.771	0.05(S)	0	0.854	0.09(T)	1	0.734
	Impulse	0.80(VL)	64	**<0.001**	0.87(VL)	75	**<0.001**	0.85(VL)	72	**<0.001**	0.89(VL)	79	**<0.001**
	Peak Power	0.75(VL)	56	**<0.001**	0.82(VL)	66	**<0.001**	0.81(VL)	66	**<0.001**	0.84(VL)	70	**<0.001**
	Time	0.44(M)	19	0.071	0.25(S)	6	0.316	0.44(M)	20	0.067	0.33(M)	11	0.184
	Relative Peak Force	0.21(S)	4	0.407	0.28(S)	8	0.255	0.17(S)	3	0.500	0.27(S)	7	0.276
	Relative Peak Power	0.72(VL)	51	**0.001**	0.80(VL)	64	**0.000**	0.76(VL)	58	**<0.001**	0.80(VL)	63	**<0.001**
Drop Jump	Jump height	0.12(S)	1	0.631	0.31(M)	9	0.218	0.04(T)	0	0.891	0.16(S)	3	0.521
	Peak Force	0.67(L)	45	**0.002**	0.64(L)	41	**0.004**	0.57(L)	33	**0.013**	0.15(S)	2	0.555
	RFD	0.66(L)	44	**0.003**	0.55(L)	30	**0.019**	0.60(L)	37	**0.008**	0.63(L)	40	**0.005**
	Impulse	0.40(M)	16	0.100	0.49(M)	24	**0.041**	0.52(L)	27	**0.026**	0.59(L)	35	**0.010**
	Time	-0.18(S)	3	0.485	-0.07(T)	0	0.788	0.01(T)	0	0.966	0.54(L)	29	0.210
	Relative Peak Force	0.33(M)	11	0.182	0.29(S)	8	0.249	0.15(S)	2	0.554	-0.03(T)	0	0.908
	RSI	0.25(S)	6	0.323	0.33(M)	11	0.180	0.04(T)	0	0.889	0.17(S)	3	0.501

Bold p values represent signficant scores

† (%) refers to the Common Variance (r^2 x 100)

r value descriptors: (NP) nearly perfect; (VL) very large; (L), large; (M), moderate; (S), small; (T) trivial

4.4 Prediction of volleyball jump performance from leg muscle function tests.

The top four muscle function test variables identified from the performance versus muscle function test correlations were then analysed via a multiple regression (**Table 4.5**). By performing this analysis, it was possible to narrow the most strongly related muscle function tests/measures down from the initial 23 to two for each performance test. By assessing the common variance it was established that the leg muscle function predictors shown in **Table 4.5** accounted for 86-89% of the variance associated with the volleyball performance jump tests. SJ height was associated with three of the four performance tests but did not feature in the largest correlation group, spike jump on sand.

TABLE 4.5 – Multiple regression analysis of performance tests and top 4 muscle function test variables.

	Kinematic Predictors	**Adjusted R Square**	**p**
Block Hard	CMJ Height Hard, SJ Height Hard	0.88	**<0.001**
Spike Hard	CMJ Impulse Hard, SJ Height Hard	0.86	**<0.001**
Block Sand	SJ Height Sand, SJ Peak Power Sand	0.86	**<0.001**
Spike Sand	CMJ Height Sand, CMJ Impulse Sand	0.89	**<0.001**

Bold p values represent signficant scores

4.5 Effects of training on leg muscle function.

Analysis of the top four identified muscle function test variables pre and post (**Table 4.6 – 4.9**) show trivial to moderate effect sizes across all measures but little statistical significance ($p<0.05$). Deeper investigation of the SS individual CMJ heights on sand identified all but one participant increased performance, with percent improvements ranging from 2-36%. The single participant whose CMJ height decreased did so by 18%. The results from the ANOVA with repeated measures showed group x time interactions ($p<0.05$) for CMJ peak power on a hard surface ($p=0.04$) and sand surface ($p=0.005$), while CMJ relative peak power on a hard surface was very close to significant ($p=0.059$). Pre and post intervention data for DJ RSI (**Table 4.10**) is also presented due to the large positive absolute percent change in performance for the hard trained group on sand surface despite only a moderate effect size and non-statistical significance (p>0. 05).

TABLE 4.6- Leg muscle function test CMJ and SJ jump heights (mean) on different surfaces.

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
SJ (Hard) *(cm)*	46.5 ± 8.6	47.2 ± 7.5	1.5	0.603	0.09	trivial
SJ (Sand) *(cm)*	43.1 ± 11.2	45.3 ± 7.4	5.1	0.285	0.23	small
CMJ (Hard) *(cm)*	48.1 ± 8.9	48.5 ± 7.1	0.8	0.827	0.05	trivial
CMJ (Sand) *(cm)*	45.6 ± 10.4	48.2 ± 8	5.7	0.171	0.28	small
Sand Surface Trained (*n=8*)						
SJ (Hard) *(cm)*	42.0 ± 8.8	43.9 ± 9.4	4.5	0.321	0.21	small
SJ (Sand) *(cm)*	41.2 ± 10.4	42.5 ± 10.9	3.2	0.380	0.12	trivial
CMJ (Hard) *(cm)*	46.3 ± 12	46.5 ± 11.2	0.4	0.900	0.02	trivial
CMJ (Sand) *(cm)*	41.4 ± 11.8	45.6 ± 9.8	10.1	0.072	0.39	small

Note: scores are significant $p < 0.05$

TABLE 4.7 - Leg muscle function test CMJ and SJ impulse (mean) on different surfaces

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
SJ (Hard)	195.3 ± 47.6	194.0 ± 46.5	-0.7	0.728	0.03	trivial
SJ (Sand)	192.5 ± 48.9	191.8 ± 47.1	-0.4	0.855	0.01	trivial
CMJ (Hard)	188.3 ± 43.9	190.1 ± 49.9	1.0	0.679	0.04	trivial
CMJ (Sand)	187.7 ± 45.8	186.6 ± 45.7	-0.6	0.758	0.02	trivial
Sand Surface Trained (*n=8*)						
SJ (Hard)	173.7 ± 39.9	182.8 ± 43.4	5.2	0.147	0.22	small
SJ (Sand)	186.8 ± 38.2	178.5 ± 46.5	-4.4	0.456	0.20	small
CMJ (Hard)	182.9 ± 48.7	191.6 ± 44.8	4.8	0.058	0.19	trivial
CMJ (Sand)	181.9 ± 39.6	183.1 ± 42.8	0.7	0.672	0.03	trivial

Bold p values represent signficant scores

TABLE 4.8 - Leg muscle function test CMJ and SJ peak power (mean) on different surfaces.

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
SJ (Hard)	3897.3 ± 1214.2	3810.9 ± 1115.6	-2.2	0.385	0.07	trivial
SJ (Sand)	3676.8 ± 1077.8	3733.9 ± 991.77	1.6	0.456	0.06	trivial
CMJ (Hard)	4274.4 ± 1352.5	4085.9 ± 1151.4	-4.4	0.187	0.15	trivial
CMJ (Sand)	3972.7 ± 1017.7	4131.9 ± 1197.3	4.0	0.626	0.14	trivial
Sand Surface Trained (*n=8*)						
SJ (Hard)	3683.3 ± 1617.7	3910.2 ± 1139.8	6.2	**0.021**	0.16	trivial
SJ (Sand)	3512.6 ± 1077.0	3600.5 ± 1137.2	2.5	0.233	0.08	trivial
CMJ (Hard)	3958.1 ± 994.7	4206.3 ± 1692.7	6.3	**0.005**	0.18	trivial
CMJ (Sand)	3813.4 ± 1234.7	4225.4 ± 1462.5	10.8	**0.013**	0.30	small

Bold p values represent signficant scores

TABLE 4.9 - Leg muscle function test CMJ and SJ, relative peak power on different surfaces.

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
SJ (Hard) *(W/kg)*	48.9 ± 8.6	48.0 ± 7.6	-1.8	0.335	0.11	trivial
SJ (Sand) *(W/kg)*	46.6 ± 7.6	47.3 ± 6.2	1.5	0.489	0.10	trivial
CMJ (Hard) *(W/kg)*	53.6 ± 9.7	51.5 ± 7.4	-3.9	0.202	0.25	small
CMJ (Sand) *(W/kg)*	50.4 ± 6.5	52.2 ± 8.0	3.6	0.917	0.25	small
Sand Surface Trained (*n=8*)						
SJ (Hard) *(W/kg)*	46.3 ± 9.3	48.7 ± 10.1	5.2	**0.045**	0.25	small
SJ (Sand) *(W/kg)*	44.6 ± 9.5	44.9 ± 10.0	0.7	0.337	0.03	trivial
CMJ (Hard) *(W/kg)*	49.9 ± 8.8	52.5 ± 10.4	5.2	**0.032**	0.27	small
CMJ (Sand) *(W/kg)*	48.4 ± 11.3	52.5 ± 12.6	8.5	**0.019**	0.34	small

Bold p values represent signficant scores

TABLE 4.10 – Leg muscle function test DJ RSI on different surfaces.

	Pre	Post	%	p	ES	
Hard Surface Trained (*n=10*)						
DJ RSI (Hard)	117.8 ± 25.5	130.9 ± 22.0	11.1	0.069	0.55	small
DJ RSI (Sand)	99.2 ± 20.97	130.2 ± 43.2	31.3	0.109	0.91	moderate
Sand Surface Trained (*n=8*)						
DJ RSI (Hard)	115.8 ± 58.6	139.9 ± 43.2	20.8	0.083	0.47	small
DJ RSI (Sand)	122.1 ± 29.8	137.7 ± 23.97	12.8	0.113	0.58	small

Note: scores are significant $p < 0.05$

Chapter 5

5.0 Discussion

5.1 Effect of vertical jump training on volleyball jump performance.

One of the key outcomes of this research was to identify the effect of the same vertical jump training program performed on either a hard or sand surface on spike and block jump performance. The results showed that after the 8-week intervention, the group that trained on the hard surface significantly improved their block jump performance on both surfaces (hard surface 2.6%, ES= 0.12, p= 0.033, sand surface 6.7%, ES= 0.32, p= 0.019) and the sand trained group only showed significant gains on the sand surface (9.8%, ES= 0.35, p= 0.009). Neither group showed significant ($p<0.05$) gains in spike jump height. These results are contradictory to the study by Crewe (2004) who showed that after training and competing on sand (for a full beach volleyball season) a group of volleyball athletes showed significant ($p<0.05$) improvement in spike and CMJ performance on both surfaces. However, Crewe (2004) identified that the group that was used had no previous experience in playing and jumping on sand surfaces prior to their baseline testing so the gains made may have been strongly due to learning the skill and technique of jumping on a compliant surface. Further to this point, the length of the season was longer than the 8-weeks in the present study. The participants in this current study were well acquainted with performing both block and spike jump on sand so any gains seen in performance would not be likely due to skill learning. Furthermore, due to the participants being at an elite level, having an already high level of jump training experience and being habituated to training on hard and sand surfaces, there is a possibility that a number of them were close to their genetic and physical potential and their capacity or "window for improvement" was small. If the groups consisted of participants from the general population with minimal jump training experience, greater change may have been seen.

The hard surface trained group were able to significantly ($p<0.05$) improve their BJ performance on both surfaces but the sand trained group were only able to significantly ($p<0.05$) improve BJ performance on a sand surface. This suggests that the ability to transfer gains between surfaces may not be bi-directional. Adaptations made on hard surfaces may be transferable to sand performance but adaptation made from training on a sand surface may not transfer to a hard surface performance.

However, considering the group by time interactions were taken into account, it can be seen that whilst the BJ gain on the hard surface for the hard trained group (2.6%) was significant ($p<0.033$) pre to post it was not significantly greater ($p>0.05$) than the 1.1% gain shown by the sand trained group. Impellizzeri et al. (2008) demonstrated what appeared to be a different training response in jumping ability between groups after an identical 4-week plyometric training program was performed on either a grass or a sand surface. The group that trained on a sand surface produced a significant ($p<0.05$) effect for time over the grass group in SJ performance (testing was performed on a hard non-compliant surface) but no significant ($p>0.05$) improvement in CMJ performance. Conversely, the grass trained group showed a significant ($p<0.05$) gain pre to post test for CMJ and eccentric utilisation ratio (CMJ/SJ). Campillo et al. (2013) demonstrated similar finding to this when two groups performing the same 7-week plyometric program, one on a hard (non-compliant) surface the other a soft (compliant) surface. Again the compliant trained group exhibited a gain in SJ performance, whereas the non-compliant group showed no significant gains in SJ but did in DJ's performed from 20cm and 40cm. Both Impellizzeri et al. (2008) and Campillo et al. (2013) suggested that these results illustrate that the surface trained on can influence the type of adaptation to plyometric training. Compliant surfaces demanding greater adaptation of the concentric strength and power characteristics, while the non-compliant surfaces lead to greater gains and development of the characteristics associated with the SSC. When considering the effect of surface type on training adaptation and in particular sand surfaces, it should be noted that there are various types of sands with varying levels of compliance so this should be taken into account. In view of the findings of Campillo et al. (2013), Impellizzeri et al. (2008), and the results from this research project, it seems that whilst training surface can influence the type of adaptations made there is not enough evidence to suggest that gains made on either a compliant or a non-compliant surface are not transferable to one another. This is also supported by the correlations seen in **Table 4.2**.

Newton et al. (2006) was able to reduce the decline in approach jump and reach performance (spike jump) of collegiate level women volleyball players at the end of the season by introducing a 4-week ballistic resistance training regime. During the initial 7-weeks of the season, the volleyball players continued with traditional strength training exercises and a reduction in jump height was seen. The reduced decline and improvements back to pre-season scores was achieved by replacing traditional strength training exercises with loaded jump squats set at individual optimal loads that elicited peak power production. The training intervention by Newton et al. (2006) was shorter than the present training intervention by 4-weeks, had less training drills targeting improved vertical jump height, and used additional load when performing the ballistic training. By adding additional weight the forces experienced in the eccentric and concentric phases would be greater than if performed with just body-weight. It would also increase the demand placed on the SSC and also greater demand of the contractile strength and power of the leg extensors. Sheppard, Hobson, et al. (2008) found that by performing countermovement jumps with an accentuated eccentric load (individualised for gender) for 5-weeks improved power, velocity and jump height of high-performance volleyball players compared to no improvement in those who performed traditional body-weight countermovement jump training. Newton et al. (1999) used male collegiate volleyball players to assess the impact of an 8-week ballistic resistance training program (loaded jump squats) on standing vertical jump and reach (SJR) as well as a three-step approach jump and reach (AJR). The group that trained using the loaded jump squats showed significant ($p<0.05$) increase in jump performances (SJR 5.9 ±3.1% and AJ 6.3 ±5.1%) pre and post intervention as well as significantly greater gains ($p<0.05$) than the control groups pre to post change. All these studies have shown that potentially highly trained volleyball athletes require an increased load stimulus (be it eccentric and concentric or eccentric only), additionally, all three studies introduced a novel training stimulus into the training program. The current study did not use any externally loaded training drills in the jump training program and the drills used did not introduce a novel stimulus so this may be a contributing factor as to why no significant gains where shown in the SPJ performance.

5.2 Inter-relationships among volleyball jumps and surfaces.

Within this study, for all vertical jump types and all vertical jump heights measured, the average jump height of sand performances were all less than the average results obtained from the hard surfaces. It is proposed that this commonality between results is most likely due to a loss of power (reduced GRF) due to the instability and the compliance of the sand. Results from a study by Tilp et al. (2008) demonstrated a significant ($p<0.05$) difference between SPJ height on a hard surface and sand surface (67.7 ±5.7 and 60.0 ±2.7cm respectively) and identified significant alterations in the jump biomechanics when performing the SPJ on the two surfaces. Alterations in COM variables (e.g. jump height, max velocity of COM), approach technique variables (e.g. stride length, max left and right foot internal rotation) and lower limb joint angle ranges were all present. Results from Bishop (2003) displayed spike jump scores slightly less than those of Tilp's (64.9 ±11.1cm [hard surface] and 55.3 ±11.4cm [sand surface]) and block jump scores of 49.8 ±8.2cm (hard surface) and 46.9 ±8.8cm (sand surface). Giatsis et al. (2004) compared SJ performance of beach volleyball athletes on a hard and a sand surface, calculating jump height (COM) from take-off velocities but again like the previously mentioned studies, found sand surface jump height significantly less ($p<0.05$) than hard surface (24.8 ±4.1cm and 28.8 ±4.5cm respectively). All three separate studies displayed the same trend of lower jump heights on sand and support the contention that the decrease is a result of reduced/lost power and altered GRF due to the instability and the compliance of the sand. Smith (2006) also agrees with this concept of lost power due to instability and identifies this as a major implication for strength and conditioning coaches working with beach volleyball athletes.

Through the analysis of the correlation coefficients for the volleyball performance test jumps it was shown that there was a strong relationship between the same skill on differing surfaces, the different skills on the same surface and also strength in the relationship between differing skills on different surfaces. Batista, De Araujo, and Guerra (2008) compared the SPJ and BJ performance of top male Brazilian beach volleyball athletes on the Brazilian beach volleyball circuit, on sand, by splitting them into two groups. Group one (G1) consisted of players from the top seven teams, the other group (G2), consisted of players ranking from 8^{th} - 17^{th}. Both groups demonstrated strong significant correlations between spike jump height and block jump height, G1 $r=0.95$ ($p<0.01$) and G2 $r=0.94$ ($p<0.01$). These results are slightly higher than the scores for the males in this study ($r=0.90$, $p<0.001$) but it appears that elite male beach volleyball athletes exhibit a strong relationship between the performance of both jump types on sand. Results collected by Sattler et al. (2012) supports this notion also but jump performance in their study was only assessed on a hard surface. Bishop (2003) compared the effect of testing spike jump and block jump on both a hard and sand surface using state-level volleyball athlete. Bishop's study had the same size group-total as this current study (n=18, 10 males, 8 females) and obtained R-values of 0.93 for block jump and 0.92 for spike jump, only slightly less than those obtained in this study (0.96 for both jump types). The scores when compared based on gender were not as close but very similar in range. The similarity between studies suggests the skill of performing a block or spike jump is relatively consistent within well-trained elite-level volleyball athletes, male and female. The slight differences between the male and female correlations (**Table 4.2**) could possibly be due differences in anthropometrics and strength (Newton et al. 1999), muscle architecture (Smith et al. 1992), and capability of storing elastic energy (Komi & Bosco 1978). It has also been recognised that there are differences in upper body and lower body anthropometric proportions as well as the GRF characteristics of SJ and CMJ between males and females (Dugan et al. 2004; Laffaye et al. 2013; Riggs & Sheppard 2009). Further to this, it appears that the high correlations between SPJ and BJ indicate that the jumps are influenced by similar characteristics or factors such as physical qualities and skill factors. This would suggest if you improve in one of the jumps there should be a strong tendency to improve in the other.

Studies that have researched differences between vertical jumps with and without a horizontal approach have shown that the jumps where an approach is incorporated have a higher jump height than those without (Bishop 2003; Ham et al. 2007; Young 1994; Young et al. 1997), as was seen in this study. The ability to maximise the use of the approach in achieving maximal vertical jump height appears to be a trainable characteristic (Ham et al. 2007). Therefore, the lack of significant change and improvement, by either the hard surface or sand surface group, in spike jump height may be as a result of the jump training program not including any exercises that specifically targeted the capacity of being able to effectively transfer momentum from an approach into maximal vertical displacement. Conversely, the correlations from the studies by Young (1994) and Young et al. (1997) between the jump types (approach v no approach) were not as strong as those seen in this study (spike v block). It is theorised that the strong relationships seen between the block and spike jump, on both surface types within this study may be due to additional demand placed on volleyball athletes not to project themselves too far forward when spiking (due to the net). Volleyball athletes may be coached technically to jump more vertically than horizontally thereby reducing the effect/contribution of the approach. Analysis of this theory however, was well beyond the scope of this study.

5.3 Relationships between volleyball jumps and leg muscle function testing.

The leg muscle function tests (SJ, CMJ and DJ) were conducted to determine if the training intervention was successful in improving the explosive leg muscle function and if so, what were the particular qualities (concentric only, SSC and reactive strength). Due to the large number of variables, the initial step was to identify the leg muscle function measures that best predicted volleyball specific (BJ and SPJ) jump height for elite volleyball athletes. There appears limited numbers of studies that have investigated this relationship directly and most that have used volleyball athletes have simply focussed on SJ and CMJ jump height and how that compares to BJ and/or SPJ jump height. Very few have compared the interaction of compliant and non-compliant surfaces with GRF characteristics and performance.

From the ground reaction force data collected, it appears that the BJ and SPJ performance can be partially linked to the performance of the SJ and CMJ. In addition to this, it appears BJ and SPJ are both heavily reliant upon the contractile strength of the leg extensors muscles and less on the fast (reactive strength) SSC contribution. Both SJ and CMJ jump height have been shown to be dependent on jump impulse, peak power and relative power (Anderson & Pandy 1993; Aragon-Vargas & Goss 1997; Giatsis et al. 2004; Shan 2009; Young et al. 2011), so considering this it is not surprising to find that these four variables consistently demonstrate high correlations with BJ and SPJ performance within this study also. Sheppard, Cronin, et al. (2008) analysed the CMJ and SPJ performances of elite male indoor volleyball athletes and identified (as in this study) significant positive correlation between CMJ and SPJ performance ($R=0.84$, $p < 0.01$). However, participants in this study did not show any significant change in DJ performance. It is recognised that the SPJ does involve a horizontal approach and a countermovement but it appears the elite volleyball athletes within this study were not able to utilise or maximise the effect of the force produced by the eccentric loading of the countermovement, potentially due to relatively long amortisation phase. The results from this study are contradictory to those of (Sheppard, Cronin, et al. 2008) who showed a strong relationship between drop jumps and CMJ and SPJ performance. A possible reason for this difference may be due to the fact that a majority of the participants in this study were predominantly beach volleyball-based athletes. As a result their capacity to perform a DJ with the same skill and speed as specialist indoor athletes was diminished. Due to the weak relationship between DJ and other jump performances within this study it is recommended that when developing physical training programs for elite volleyball athletes a large emphasis should be placed upon trying to improve the contractile force and power profile by using a loaded or unloaded CMJ, which is a concept supported by Sheppard, Cronin, et al. (2008).

5.4 Prediction of volleyball jump performance from leg muscle function tests.

The multiple regression analysis identified squat jump height as a common predictor of performance for block hard, spike hard and block sand (*Note*: while SJ height was not identified as a common predictor for spike sand performance the r values for hard and sand surface were still quite strong at 0.85 and 0.88 respectively). Due to this finding, it reinforces the fact that contractile strength and power of the leg extensor muscles is an important property to develop and train when developing volleyball-specific vertical jump training programs. Riggs and Sheppard (2009) identified that among elite male and female beach volleyball athletes SJ relative peak power had a strong positive correlation to squat jump COM displacement (jump height), again reinforcing the importance of contractile strength and power for volleyball athletes. The fact that 86-89% of the variance associated with the volleyball jump performance was due to SJ and CMJ variables reinforces that explosive leg muscle function is a dominant quality related to performance. It also seems that this is the same for the two jump types and across both the sand and hard surface. An interesting difference found in this study compared to Sheppard, Cronin, et al. (2008) is that neither CMJ nor DJ was more strongly related to spike jump performance than SJ. The fact that a large percentage of the participants were predominately beach volleyball based athletes, where as those in Sheppard's study were primarily indoor-based athletes, may be a contributing factor to this.

The skill of performing a BJ or SPJ on either a hard or sand surface may also impact the ability to predict performance based on leg muscle function testing. As was shown by Tilp et al. (2008) and Giatsis et al. (2004), there are variations in limb and joint function between performing like skills on differing surfaces. Alterations occurred in the biomechanical loading and as such slightly altering the way a jump is performed. Giatsis et al. (2004) does highlight the fact that for elite beach volleyball athletes the skill and body positioning for performing a BJ is very similar and common to that of a SJ so it is not surprising to find a close affinity between these two jump types in this study. If an athlete is unfamiliar with the BJ or SPJ or the surface they are tested on, their ability to execute the skill will be effected and as a result, jump height will most likely not be a true reflection of their force and power production capacity. If however the athlete were tested using both the performance tests as well as the leg muscle function tests (SJ, CMJ) it would provide an assessment of both their capacity to perform the skill and also a more true measure of leg extensor power.

5.5 Effects of training on leg muscle function.

It appears that the jump training program used in this study had minimal impact on improving the leg muscle function of the participants. There was no significant change ($p>0.05$) in SJ and CMJ jump height or DJ RSI for either surface, despite the sand trained group displaying significant trivial to small gains in mean peak power and relative peak power for SJ and CMJ on a hard surface and CMJ on sand (**Table 4.6 - 4.10**). This change in the peak and relative peak powers of the SS group and not the HS group raises the question, "Do performances on sand demand a greater concentric strength and power contribution than the same performance on a hard surface?" This may be why Campillo et al. (2013) and Impellizzeri et al. (2008) both found groups that trained on compliant surfaces demonstrated greater improvement in SJ than non-compliant surface trained subjects. Due to the applied nature of this research it was interesting to see the percent change measured for the SS group CMJ height on sand, 10.1% (**Table 4.6)**. While not statistically significant ($p>0.05$) this type of change would be seen by both athlete and S&C practitioner as a very favourable result. Results from the plyometric training meta-analysis conducted by de Villarreal et al. (2009) showed that individual sports characteristics resulted in sports specific plyometric training exercises and as a result identified similar effect sizes for sport activities. Due to this, plyometric training should be performed in conditions very similar to competition to achieve sport-specific gains. Therefore it is possible that surface would play a role in the type of adaptations that occurs from specific plyometric training drills.

As previously discussed, there is a large skill component associated with the volleyball performance tests and in particular the skill of performing a BJ is closely aligned to SJ. Therefore, it could be that the positive changes seen in BJ performance were not due to improved leg extensor force and power capacity rather an improvement or alteration in the execution of the skill of performing the jump. Whilst not statistically significant, the effect sizes seen in DJ RSI pre and post intervention for both training groups ranged from small to moderate (absolute change ranged from 11.1 – 31.3% improvement) which suggest there is some type of learning affect that is not being accounted for by the assessment of leg muscle function only. Furthermore, the HS group was able to significantly ($p<0.05$) improve the BJ on both surfaces but no significant change ($p>0.05$) in leg muscle function was identified. An outcome such as this suggests that the HS group improved volleyball performance through a mechanism other than physical adaptation, like skill improvement. It was beyond the scope of the study to assess joint and segmental changes and this may be something that needs to be assessed in future research. Additionally, all participants continued with their normal training regimes which consisted of volleyball-specific training that included vertical jumping through-out. This means the changes seen in performance may not be uniquely due to the training intervention implemented and the positive or negative impact of other training stimuli is difficult to account for. This was identified as a limitation of the project and is a draw-back of working with elite athletes and coaches focussed on competition success (not research).

The concept that elite volleyball athletes require external loading when using ballistic-type exercises to make significant gains in volleyball specific jump types may be partially explained by assessing their “normal” training stimuli. Volleyball athletes will traditionally perform a high number of unloaded vertical jump repetitions during their skill-based training sessions and within competition. They are conditioned to endure high volumes of body-weight vertical jump repetitions. Due to this conditioning it may be that simply increasing the number of total jumps performed within a training week, and using bodyweight only loading does not create an overload stimulus (particularly neurological) great enough to elicit improved force and power production capacity, a notion supported by Sheppard et al. (2011). By adding additional external load to the eccentric-only or both eccentric and concentric components of vertical jump training drills it may overload and overcome the “sports specific conditioning". As a result, the overload places a demand on physical adaptation that results in improved body-weight vertical jump height performance. In reference to the current study it may be possible that by including the squat jump and all training drills not requiring any external loading, the jump training program may have lacked adequate SSC stimulus and overload for elite volleyball athletes. This may then be why more favourable gains were seen in the skill that was more dependent on contractile strength and power, the BJ and not the SPJ.

The fact that there was minimal change seen in leg muscle function is somewhat disappointing and surprising as the training program was based on logical scientific training and overload principles. It is possible that due to the 'normal' jumping volume of the volleyball athletes the volume overload of the VJTP was not as large as required and it may have not been a large enough stimulus. The length of the intervention may not have been long enough due to the level of athlete involved in the project also. A majority of the participants having a high training history and physical development level may have meant either the stimulus was not large enough or more time was needed to illicit change. de Villarreal et al. (2009), recommended 10-weeks as the ideal length of time to illicit change but as previously mentioned, due to the training and competition schedules of the participants 8-weeks was the maximum length of time possible. Also the concurrent training and competition during the intervention period may have impacted on the athlete's recovery and their ability to perform every jump training session in peak physical condition and with maximal effort. As an example, if an athlete was successful during competition and reached the final gold medal match they would have played potentially two extra matches compared to athletes who did not make it past the quarter finals. This would result in the more successful team only having 24 hours recovery, as opposed to 48 hours for the less successful team, before the next training session. The lack of recovery in combination with the increased jump training may have resulted in a level of overtraining or neural suppression.

Chapter 6

6.0 Conclusion

The objective of this study was to investigate the effect of an eight week jump training program performed on two differing surfaces (sand and hard), on the vertical jump performance of elite volleyball players. This was carried out using 18 national and state level athletes (9 male, 9 female) split into two randomised groups one training on a hard (cement floor covered with wooden parquetry) surface (HS, *n*=10) and the other sand (SS, *n*=8). Both groups were assessed pre and post intervention, on both surface types, in volleyball specific vertical jumps (BJ, SPJ) as well as three other vertical jump types (SJ, CMJ, DJ) to assess leg muscle function. The results were significant ($p<0.05$) gains in BJ performance on sand for both groups but only the HS group showed gains on the hard surface. No significant gains ($p>0.05$) were seen in SPJ performance. There were strong correlations between SPJ and BJ performance for both surfaces, with 86-89% of the variation being accounted for by SJ and CMJ variables. It appears that the jump training program did not greatly improve the overall vertical jump performance of elite volleyball athletes. It seems surface does impact performance directly but any gains made from training on either surface are not necessarily isolated to performance on the same surface being trained on. Contrary to other studies, SPJ performance did not demonstrate a strong link to DJ variables, in fact, within this study it appears that the skill of performing a BJ and SPJ are closely related, both rely heavily upon concentric power and this is part of why such strong correlations were seen between the two jump types. Due to the subject pool consisting of elite volleyball players, a potential lack of external loading in the program and/or the training volume not overcoming the sport specific vertical jump conditioning/tolerance may have influenced the limited changes observed.

6.1 Practical applications

To be able to truly identify the sole impact of a vertical jump training program on elite volleyball players, vertical jump performance requires all facets of their training (technical, skill-based, game-play and strength training) to be controlled and measured. Due to this it is necessary both coach and strength and conditioning coach develop a harmonious integrated training plan. Without this there are a number of factors that are difficult to account for. Along with this, better efficacy may be gained through conducting the study during a period where physical preparation takes precedence in a periodised program, even if this is not ideal from a competition perspective. Also, due to the requirements of the game of volleyball, athletes will naturally perform a large number of bodyweight vertical jumps as a part of the regular training and competition workload. Due to this, any strength and conditioning coach working with this sport and considering implementing a vertical jump training program must assess if it is it truly going to provide an overload stimulus. It appears that the overload may not be found by simply increasing volume of jumps completed, rather altering loads that create greater demand of the contractile properties of muscle (both eccentric and concentric) would be more effective.

There is minimal scientific research into the sports specific movements of the BJ and SPJ. The majority of work that has been done has had a typically hard surface, indoor volleyball focus. Due to this, scientific studies outlining the physical preparation of beach volleyball athletes appears lacking. So from a beach volleyball aspect, results from this study suggests that there is no significant negative effects on performance based on training surface and there is some level of transfer between compliant and non-compliant surfaces. Therefore if beach volleyball players are unable to train on a sand surface they can still make positive gains in vertical jump performance. In addition it appears at an elite level BJ and SPJ performance are strongly linked so developing training programs that aim to improve both concurrently would be advantageous. It is also suggested that if plyometric drop jumps are used to target SSC adaptations, it is critical that clear instruction is given on the type of jump required. If training for sand performance, a countermovement drop jump could potentially yield greater gains than a bounce drop jump. Alternately, indoor performance may be better suited to the bounce drop jump.

When assessing vertical jump height performance, consideration of the skill of performing a BJ or SPJ correctly must occur. To negate the potential misleading information that may come from poor technique, a recommendation would be for developing athletes to be assessed on their power production capabilities based on the SJ and CMJ due to both tests showing strong correlation to the BJ and SPJ performance. As athletes progress and develop their skills, BJ and SPJ assessment could be introduced and used as assessments of sports specific power. Testing SJ and CMJ in elite athletes could help identify where training improvements are coming from (improved strength, improved power production and/or skill development) and the effectiveness of physical preparation training blocks.

6.2 Recommendations for further research

It was apparent that by using elite level volleyball players who are acclimatised to large vertical jump loads that there is a potential benefit to assess the effect of a loaded ballistic training program on sand and hard surface vertical jump performance. Second to this, biomechanical assessment of both the BJ and SPJ on sand needs further investigation to increase the body of knowledge surrounding variations in technique, particularly compared to hard surface performance.

Due to the horizontal approach associated with the SPJ, the effect an approach can have on vertical jump height, as well as the compliance of sand, another aspect of research that this current study was unable to take into account was changes or alterations on approach performance. Therefore, it would be valuable to study the impact of training SPJ height with drills that incorporate a horizontal component and those without. It would be advantageous if SPJ performance pre and post could be assessed as a complete movement (approach and vertical jump together) and not individual components or just absolute jump height.

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Appendices

Appendix A - Subject Consent Form

Subject Consent Form

THE EFFECT OF AN EIGHT WEEK JUMP TRAINING PROGRAM PERFORMED ON A HARD AND SAND SURFACE ON VERTICAL JUMP PERFORMANCE IN ELITE VOLLEYBALLERS

Researcher's name: **Michael Riggs**

Full name of participant: ______________________

I consent to being a participant in this study to determine the affects an eight week jump training program on either a hard or sand surface has on vertical jump performance.

Your written consent is required to ensure that you are clear that this research project will be conducted in an ethical manner:

- I have received information about this research project.
- I understand the purpose of the research project and my involvement in it.
- I understand that I am free to withdraw consent and discontinue participation in this study at any time without prejudice.
- I understand my respective coach will have identifiable access to my results but will only be done so in strict confidence.
- I understand that all information provided and data collected will be treated as strictly confidential. I agree that research data gathered for the study may be published provided no name or other identifying information is used.

If you have any questions concerning this study, please feel free to call Michael Riggs, School of Human Movement & Sport Sciences, University of Ballarat, on 0400 211 325, Mr Warren Young (Supervisor) on (03) 5327 9685 or Mr Jeremy Sheppard (Supervisor) on (07) 3872 0109.

Signed by Participant: ______________________

Signed by Parent/Guardian:
(If under 18 years of age) ______________________

Date:

I have provided information about the research to the research participant and believe that they understand what is involved.

<u>Researcher's name and affiliation:</u>

Michael Riggs

School of Human Movement & Sport Sciences

University of Ballarat

Researcher's Signature: **Date:**

Appendix B – Ethics Approval

Approval

Human Research Ethics Committee

University of Ballarat
Learn to succeed

Principal Researcher:	Warren Young
Other/Student Researcher/s:	Jeremy Sheppard Michael Riggs
School/Section:	HMSS
Project Number:	A10-135
Project Title:	The effect of an eight week jump training program performed on indoor and sand surfaces on vertical jump performance in elite volleyball players
For the period:	13/12/2010 **to** 20/2/2013

Please quote the Project No. in all correspondence regarding this application.

REPORTS TO HREC:

An annual report for this project must be submitted to the Ethics Officer on:
13 December 2011
13 December 2012
www.ballarat.edu.au/ard/ubresearch/hdrs/ethics/humanethics/docs/annual_report.doc

A final report for this project must be submitted to the Ethics Officer on:
20 March 2013
www.ballarat.edu.au/ard/ubresearch/hdrs/ethics/humanethics/docs/final_report.doc

Ethics Officer
13 December 2010

If any changes are to be made to this project, a 'Request for Amendments' form must be completed and forwarded to the Ethics Officer for approval.

CRICOS Provider No. 00103D

Page 1 of 1