# Proprioception, jumping capacity and agility in beach versus indoor volleyball players

*A dissertation presented by Christine Glossop-von Hirschfeld (VHRCHR002) in partial fulfilment of the requirements for the MSc Sports & Exercise Physiotherapy from the University of Cape Town.*

Supervisors:

Dr Bouwien Smits-Engelsman, PhD: bouwienengelsman@icloud.com

Dr Gillian Ferguson, PhD: gillian.ferguson@uct.ac.za

Faculty of Health Sciences

The University of Cape Town

South Africa

*WORDS: 20173*

# DECLARATION

I, Christine Glossop-von Hirschfeld, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work or any part thereof has been, is being or is to be submitted for another degree at this or any other university.



Signed by candidate

1 December 2020

# ACKNOWLEDGEMENTS

Completing this thesis would not have been possible without the incredible support and guidance from the following people:

- Prof Bouwien Smits-Engelsman and Dr Gillian Ferguson – an incredible supervisor team who helped me mould this study into what it became and gave ongoing feedback to ensure that I could finish on time.

- All the participants who gave up their time and energy to take part in the study.

- My husband, Alistair Glossop, who not only inspired my research but also supported me through hours of data collection and write-up time.

- Sue and Peter von Hirschfeld – I could not ask for better parents, who supported me and helped me proof-read a hundred drafts of my thesis.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| BVB | Beach Volleyball |
| IVB | Indoor Volleyball |
| VSA | Volleyball South Africa |
| SA | South Africa |
| OSTRC | Oslo Sports Trauma Research Centre |
| mBESS | modified Balance Error Scoring System |
| SLHBT | Single Leg Hamstring Bridge Test |
| SLTHD | Single Leg Triple Hop for Distance |
| CMJA | Countermovement Jump test with Arm Swing |
| MAT | Modified Agility T-test |
| WPVU | Western Province Volleyball Union |
| UCT | University of Cape Town |
| TPD | Two-Point Discrimination |
| ROM | Range of Motion |
| ICC | Intraclass Correlation Coefficient |
| AMEDA | Active Movement Extent Discrimination Assessment |
| EMG | Electromyography |
| LSI | Limb Symmetry Index |
| HREC | Human Research Ethics Committee |
| BVC | Beach Volleyball Cape Town |
| $VO_2$ | Volume of Oxygen consumption |

# GLOSSARY OF TERMS

**Acute injury:** A physical complaint causing the body's tissues to lose structural or functional integrity. This is caused by an instantaneous transfer of energy to the body (Finch & Cook, 2014).

**Overuse injury:** A physical complaint caused by an accumulated energy transfer or repetitive microtrauma, rather than a clearly identifiable single event (Finch & Cook, 2014).

**Proprioception:** The identification of the body's position and movement in three-dimensional space (Han, Waddington, Adams, Anson, & Liu, 2016).

**Active Movement Extent Discrimination Apparatus (AMEDA):** A method to test proprioception under normal weight-bearing conditions, without physical constraints, while obscuring vision of the target position (Han, Waddington, Adams, & Anson, 2013).

**Injury recall:** The ability to remember information related to a past injury (Gabbe, Finch, Bennell, & Wajswelner, 2003).

**Undisturbed sand:** Sand that has not been walked on, moved or compressed other than by natural forces.

**Countermovement jump:** A jump in which the stretch-shortening cycle is utilised: A squat is followed by a jump.

**Stretch-shortening cycle (SSC):** An eccentric (lengthening) muscle contraction followed directly by a concentric (shortening) muscle contraction.

**Stretch (myotatic) reflex:** The automatic regulation of muscle length following the stretching or lengthening of a muscle due to increased signals sent from the nerve endings in the muscle to the spinal cord.

**$VO_{2max}$:** The maximum amount of oxygen that a person can utilise during exercise. It is commonly used to determine aerobic fitness levels.

# ABSTRACT

**Background:** Beach volleyball (BVB) is rapidly developing into a popular activity both for recreational and competitive athletes. The majority of injuries sustained playing volleyball (beach and indoor) are considered non-contact. While commonly injured areas (ankle, knee, lower back and shoulder) are similar in beach volleyball (BVB) and indoor volleyball (IVB), injury incidence in BVB players is reported as 3.9-4.9 per 1000 hours, which is significantly lower than in IVB (1.7-10.7 per 1000 hours). Several factors contribute to the level of performance as well as to injury risk in volleyball players: body composition, changes in training load, previous injury, balance, proprioception, joint kinematics and muscle strength.

There has been recent growth in the literature investigating the role of proprioception in the assessment, management and prevention of musculoskeletal injuries. Proprioceptive retraining strategies are diverse and yet no conclusive evidence demonstrating the superiority of one exercise over another is available. However, consensus exists that proprioceptive training requires movement on an unstable or uneven surface. Although proprioceptive exercises are commonly integrated into sports rehabilitation, there is a lack of high-quality evidence proving that proprioception can be trained.

Maximal vertical jumping, lateral cutting sprints and diving to play the ball are repetitively demanded of volleyball players. BVB players complete these actions on sand (an uneven and unstable surface), making this sport, by definition, a continuous proprioceptive training exercise. By comparing two groups (IVB and BVB players) who perform a very similar sport on different surfaces (indoor and sand), we wish to investigate whether this may have led to differences in proprioception. Furthermore, we would like to measure the possible influence of this training aspect on functional capacity (lower limb range and strength, agility and vertical jump height).

**Aim**: To compare proprioception, functional lower limb capacity, agility and jumping capacity on two different surfaces, between non-professional BVB and IVB players.

**Methods**: A descriptive, cross-sectional, analytical study was conducted. The study adhered to the research ethics guidelines of the Declaration of Helsinki. The study protocol was submitted and approved by the Faculty of Health Sciences Human Research Ethics Committee, University of Cape Town. Convenience sampling was used to recruit 30 non-professional volleyball players (15 BVB and 15 IVB players) in the Western Cape, who met the inclusion criteria. Each player attended a testing session where they were given an informed consent sheet. If they decided to consent to participate and sign the form, a screening questionnaire was administered to determine eligibility to participate. Due to the COVID pandemic, participants also completed a COVID-19 screening tool.

If eligible to continue to take part in the study, participants completed two questionnaires (Training and Injury History questionnaire and OSTRC (Oslo Sports Trauma Research Centre) questionnaire), after which they completed seven physical tests (the wedge test, two-point discrimination test, modified balance error scoring system (mBESS) test, modified star excursion balance test (mSEBT), knee-to-wall test, single leg hamstring bridge test (SLHBT) and eccentric-concentric calf raise test). They then proceeded to perform two jumping tests (countermovement jump with arm swing (CMJA) test and single leg triple hop for distance (SLTHD) test) and an agility test agility (modified agility T-test (MAT)) both on sand and hard surfaces.

Descriptive statistics were used to present the demographical data, training and injury history. A t-test was used to determine whether the two groups were comparable on anthropometric data. Differences between the two groups (BVB and IVB players) in proprioception, agility and jumping capacity were analysed using Mann-Whitney U and unpaired t-tests. Repeated measures ANOVA were used to determine any differences in agility, jumping height or hopping distance between IVB and BVB players when tested on different surface conditions (the surface being the within-group factor and player type being the between-group factor). Effect size analysis was also reported for the physical outcome measures data, to determine the strength of any trends in differences existing between the two player groups

Results: IVB and BVB groups were similar regarding demographics, training history and injury prevalence. Age was the only variable found to be significantly higher in BVB players than IVB players ($p = <.001$). There were no significant differences in most measures of balance, strength, agility or jumping capacity between the groups. While the results of the proprioception measure (wedge test) were also not significant ($p= 0.08$), a medium effect size (Cohen's $d = 0.66$) was found, with the BVB group identifying more differences in wedge heights correctly. There was a significant difference in the anterior reach of the Y-balance test (right and left legs) between the groups ($p < 0.05$), with the BVB group out-performing the IVB group. The study showed no significant correlations between proprioceptive measures and functional outcomes.

A repeated-measures ANOVA determined that there was a significant main effect of surface type on mean CMJA heights (Wilks' Lambda = 0.799, $F(1,28) = 7.040$, $p = .013$), mean left leg SLTHD distances (Wilks' Lambda = 0.522, $F(1,28) = 25.654$, $p = <.001$) and mean right leg SLTHD distances (Wilks' Lambda = 0.473, $F(1,28) = 31.169$, $p = <.001$). However, no surface by player group interactions emerged, indicating that the impact of the surface was not different between groups of players: All volleyball players ran faster, jumped higher and hopped further on the indoor floor than on the sand.

Discussion and conclusion: The findings of this study suggest that there are no consistent differences in functional capacity between IVB and BVB players. Despite limited findings, the current study contributes to the literature, as it is one of a few studies to assess the effect of habitual sand training on functional performance measures between IVB and BVB players. It is hoped that this study could provide a basis for further investigation into training on different surfaces to improve functional outcome measures, for overall performance improvement.

**Keywords**: *beach volleyball, indoor volleyball, proprioception, joint position sense, neuromuscular control, sensorimotor training, agility, countermovement jump, vertical jump height, agility, sand training, unstable surface training*.

# CHAPTER ONE: INTRODUCTION AND SCOPE OF THESIS

## 1.1 Introduction

Beach volleyball (BVB) and indoor volleyball (IVB) are variations of a sporting code that have many similarities in terms of game format and rules, but with two main obvious differences: The number of players on the court (two for BVB, six for IVB) and the surface played on (sand and hard surface, respectively) (Balasas, Christoulas, Stefanidis, Vamvakoudis, & Bampouras, 2018). Jumping capacity and agility are two of the most important functional performance indicators for both disciplines, and methods of improving these skills are constantly being challenged and updated (Giatsis, Panoutsakopoulos, & Kollias, 2018). Training on sand has been studied using randomised control trials and shown to improve cardiovascular fitness (Balasas, Van Makoudis, Christoula, Stefanidis, & Evangelia, 2013), lower limb strength (Balasas et al., 2018), jumping height (Impellizzeri et al., 2008) and agility (Gortsila, 2013) when compared to hard-surface training.

There has been a recent surge in the literature investigating the assessment and training of proprioception (Clark, Roijezon, & Treleaven, 2015; Han et al., 2016; Han, Waddington, Anson, & Adams, 2015; Roijezon, Clark, & Treleaven, 2015). Proprioception has been proposed to contribute to optimal performance and injury prevention, particularly non-contact injuries, due to feed-forward and feedback mechanisms (Nagai, Schilaty, Strauss, Crowley, & Hewett, 2018; Ribeiro, Santos, Gonçalves, & Oliveira, 2008; Roijezon et al., 2015). Proprioceptive retraining strategies are diverse and yet there is no conclusive evidence demonstrating the superiority of one exercise over another. However, consensus exists that proprioceptive training is often performed on an unstable or uneven surface (Clark et al., 2015). There is currently no known research demonstrating the use of sand training to improve proprioception. Furthermore, whether proprioception is linked to performance such as jumping capacity and agility has yet to be investigated.

As BVB players perform their sport on the sand, which demands greater muscle recruitment (Brown et al., 2017), it is expected that they would have superior performance in lower limb power, speed and jumping capacity compared to IVB players, who train on a hard surface.

**Hypothesis**:

Habitual training on the sand causes BVB players to have better proprioception than IVB players and this may contribute to their jumping and agility performance.

## 1.2 Aim and objectives

### 1.2.1 General aim

To compare proprioception, functional lower limb capacity, agility and jumping capacity on two different surfaces, between non-professional BVB and IVB players.

### 1.2.2 Specific objectives

- To assess differences in proprioception between BVB and IVB players.
- To compare lower limb functional capabilities (balance, range of movement (ROM) and strength) of BVB and IVB players.
- To assess differences in jumping capacity on two surfaces, indoor and sand, between BVB and IVB players.
- To assess differences in agility on two surfaces, indoor and sand, between BVB and IVB players
- To assess the relationship between measures of lower limb functional capacity, proprioception, jumping capacity and agility and in both groups
- To outline the prevalence of injuries in the two groups (BVB and IVB).

## 1.3 Significance of this study

There is currently no research comparing proprioception between these two groups (BVB and IVB players), who perform a very similar sport on different surfaces (sand and hard surface). Most studies evaluating the effect of so-called "proprioceptive training" (training on uneven and unsteady surface), use joint position sense (JPS) and balance as outcome measures (Aman, Elangovan, Yeh, & Konczak, 2014). Therefore, these measures along with cutaneous sensation (known to influence proprioception) were assessed in both groups. Furthermore, lower limb functional strength and range tests, agility and jumping performance tests, all highly relevant to the biomechanics of volleyball and contributing to performance, were conducted in both groups (Sheppard, Gabbett, & Riggs, 2013). Players from the two groups were tested on both surfaces comparing agility and jumping capacity under these familiar and less familiar task conditions. Thus, the potential influence of proprioception on these functional capacities was explored.

## 1.4 Outline of thesis

Chapter two of this dissertation reviews the current literature pertaining to: 1) the differences between beach and indoor volleyball, 2) the effects of habitual sand training versus firm surface training on tasks measured 3) the association between proprioception and performance, particularly jumping capacity and agility. Chapter three details the original research conducted in the study: *Proprioception, agility and jumping capacity in beach versus indoor volleyball players*. Chapter four presents the main findings of this study, a discussion interpreting these results and suggestions for future studies. Finally, chapter five provides a summary and conclusion.

# CHAPTER TWO: LITERATURE REVIEW – PROPRIOCEPTION, JUMPING CAPACITY AND AGILITY IN BEACH VERSUS INDOOR VOLLEYBALL PLAYERS

## 2.1 Introduction

A literature search was conducted using a computer-based search of the following scientific and medical databases: EBSCOhost, Scopus, ClinicalKey, PubMed, JOSPT, Google Scholar and Wiley online library. Search terms included "*beach volleyball*", "*proprioception*", *"joint position sense", "neuromuscular control", "sensorimotor training",* "*countermovement jump*", "*jump height*", "*agility*", "*sand training*" and "*unstable surface*". References of selected articles were also further explored.

This review focuses on exploring and critically appraising literature available on the effects of proprioceptive training on functional performance and relating this specifically to beach volleyball players. Section 2.2 describes volleyball as a sport and the physical capabilities required for the sport, specifically jumping capacity and agility. The main differences between indoor volleyball (IVB) and beach volleyball (BVB) and the physiological effects of training on different surfaces will be highlighted. Section 2.3 explores the published research around the benefits of proprioceptive training and methods used to do this. Section 2.4 investigates and describe instrumentation used to measure proprioception, jumping capacity and agility in an athletic population and finally, Section 2.5 summarises the literature, highlighting the gaps in the field.

Volleyball is one of the most commonly played sports in the world (Migliorini et al., 2019), is widely popular amongst amateurs and professionals and is subjected to extensive research. Several studies have been conducted on biomechanical factors affecting performance and injury statistics among volleyball players (prevalence, risk factors and prevention protocols) (Roald Bahr & Reeser, 2003; James, Kelly, & Beckman, 2014; Migliorini et al., 2019; Reeser et al., 2010; Reeser, Verhagen, Briner, Askeland, & Bahr, 2006).

In both beach and indoor volleyball, jumping capacity and agility are considered two key performance measures needed to determine a player's ability to excel on the court (Barnes et al., 2007; Iglesias-Caamaño, Carballo-López, Álvarez-Yates, Cuba-Dorado, & García-García, 2018; Tramel, Lockie, Lindsay, & Dawes, 2019). There is a vast amount of literature investigating methods of improving these two aspects of functional performance, and good evidence suggesting that training under more difficult conditions (e.g. on sand) would lead to favourable physical adaptations in lower limb strength (Giatsis et al., 2018).

Decreased proprioception has been documented as a significant risk factor to lower limb injury in jumping athletes, such as volleyballers, with authors suggesting various strategies for retraining proprioception after injury (Reeser et al., 2006; Verhagen et al., 2004). Performing proprioceptive exercises as a form of injury prevention has also repeatedly been recommended (Nagai et al., 2018), though there is a paucity of high-quality randomised control trials confirming a reduction in injuries following these exercises (Aman et al., 2014; James et al., 2014). There is however good evidence demonstrating improved postural control and balance following an intervention using proprioception exercises (Clark et al., 2015). Zech et al. (2010) reviewed several studies which tested athletes from a variety of sports (e.g. soccer, ski jumping, figure skating) and found that implementing balance training may benefit performance (in particular jumping capacity and agility). They further concluded that plyometric or strength training showed greater improvements in these measures. The balance training implemented in these studies was however limited to performing exercises on an unstable platform over 4-12 weeks. The authors alluded to the fact that the longer the training programme is, the more effective it may be.

The concept of training specificity suggests that task-specific adaptations occur in athletes who consistently train the same movement patterns under specific circumstances (Behm & Colado, 2012). Thus, it could be expected that indoor volleyball (IVB) players would perform better on a hard indoor surface than a soft beach surface. Beach volleyball (BVB) may be viewed as a form of training that includes plyometrics and agility, while continuously challenging the proprioceptive and balance systems, as it occurs on a soft, uneven surface. Based on the positive physical adaptations seen in individuals subjected to training on the sand, BVB players are expected to be stronger than IVB players. The author is unaware of any published literature that investigates the effects that BVB may have on proprioception and functional performance, specifically jumping capacity and agility.

The questions are: 1) Is there a surface-specific effect for jumping capacity and agility (due to a biomechanical effect)? 2) Would IVB players perform better on a hard surface than BVB players and vice versa (due to training specificity)? 3) Would BVB players relatively outperform IVB players on sand and on a hard surface (due to a training effect)? 4) Do BVB players have better proprioception as they are constantly challenging their stability system and thus technically performing proprioceptive training?

## 2.2 Volleyball: beach versus indoor

Beach and indoor volleyball are disciplines of the same sport (Jimenez-Olmedo & Penichet-Tomás, 2015). Although no official statistics exist, Volleyball South Africa (VSA) estimates there to be a combined total of 5000 volleyball players in South Africa, with the Western Cape reportedly having the largest percentage of BVB players in the country. Searches for previous research on volleyball in South Africa yielded only one small study investigating strength and power characteristics in thirteen elite beach volleyball players (Davies, 2002). The author concluded that these BVB players had superior leg strength compared to other volleyball players training on hard surfaces and suggested these physical adaptations may have occurred due to their sand training.

Volleyball is considered a non-contact sport, challenging athletes in bursts of multi-directional high-intensity exercise interspersed with periods of low to moderate levels of activity (Oliveira et al., 2018). Players are required to repeatedly jump (during the jump serve, jump set, block and spike) and perform short-distance sprints on the court requiring high levels of lower limb strength and agility (Sheppard et al., 2008). BVB teams consist of two players, typically one blocker and one defence player although players often categorise themselves as universal (or having no specialisation) (Palao, Valadés, Manzanares, & Ortega, 2014). Games are played in sets (best-of-three sets to 21 points) and last 35-60 minutes. IVB teams have six players on the court and typically play games in sets, best-of-five to 25 points, which last slightly longer (approximately 67 minutes) (Balasas et al., 2018). In both disciplines, events often span multiple days with several games played per day (Magalhães, Inácio, Oliveira, Ribeiro, & Ascensão, 2011). The ball used in BVB is softer and slightly bigger but weighs the same as an IVB ball (Reeser et al., 2006). No studies could be found relating the different balls to injury incidence.

Volleyball players across various skill levels are at risk of developing injuries; in higher-level athletes due to the increased number of playing hours, and in recreational athletes due to poor technique or deconditioning (Seminati & Minetti, 2013). Injury incidence in BVB is reported as 3.9-4.9 per 1000 hours (Jimenez-Olmedo & Penichet-Tomás, 2015). This is significantly lower than for IVB (1.7-10.7 per 1000 hours), which could be attributed to the lower number of players on the court or the inherent differences in the game, such as playing surface and game format (Kilic, Maas, Verhagen, Zwerver, & Gouttebarge, 2017; Reeser et al., 2006). The most common conditions seen in BVB players are injuries of the knee (30%), ankle (17%), finger (15%), shoulder (13.1%) and back (5.7%) (Jimenez-Olmedo & Penichet-Tomás, 2015). Injuries in IVB players follow a similar pattern, showing a prevalence of 28.9% ankle injuries, 14.5% knee injuries, 10% shoulder injuries, 8% back injuries and 7% finger injuries

(Migliorini et al., 2019). IVB injuries were predominantly classified as minor (38.4%) to moderate (40.8%) in intensity with only 20.8% being major injuries (Migliorini et al., 2019). Similarly, injuries reported in BVB players were 78% minor, 17% moderate and only 4% major (Bahr & Reeser, 2003).

H Meeuwisse, Tyreman, Hagel, and Emery (2007) first described a recursive model of injury, emphasising that intrinsic and extrinsic factors form a "chain of shifting circumstances". There are several factors thought to contribute both to the level of performance as well as to injury risk in volleyball players: body composition, changes in training load, a history of a previous injury, joint kinematics, muscle strength and proprioception (Alvim, Lucareli, & Menegaldo, 2018; James et al., 2014; Oliveira et al., 2018; Reeser et al., 2006; Seminati & Minetti, 2013).

The main obvious difference between BVB and IVB is of course the surface played on. Sand, being a softer and more unstable surface, brings with it challenges for the musculoskeletal system. The energy cost to perform movements such as running and jumping is higher as more energy is absorbed by the ground during jumping preparation (Pinnington, Lloyd, Besier, & Dawson, 2005). The risk of injury may be increased due to the unpredictable shifting of the soft sand underfoot (Bishop, 2003; Pinnington & Dawson, 2001). However, other studies have suggested that playing on sand reduces the risk of injury as there is a lower impact on the musculoskeletal system and a higher rate of muscle activation (Binnie, Dawson, Pinnington, Landers, & Peeling, 2014). Impellizzeri et al. (2008) proposed that sand training could be used during rehabilitation as it caused a reduction in stress on the musculoskeletal system and in turn less post-training muscle soreness. This finding was replicated by Brown et al. (2017), who found that training on sand incurred less musculoskeletal strain than a training session of matched intensity on a firm surface. Thus, a sand training surface may also be useful for athletes returning from injury, allowing for the improvement of aerobic fitness with a concurrent lower risk of muscle damage and injury.

Landing on a soft surface such as sand leads to different expectations than when landing on a hard surface. Authors van der Krogt et al. (2009) described the role of neural anticipation (feed-forward control), which increased the electromyography (EMG) activity in muscles prior to landing on an expected hard or soft surface. The authors also discussed the contribution of passive mechanical adaptations in the joints of the lower limb during landing (decreased leg stiffness and increased knee flexion angle). They concluded that on landing, passive mechanisms were responsible for altering leg stiffness before any changes in muscle activity occurred. That being said, feed-forward control increased muscle activity prior to landing, providing more lower limb stability (Moritz & Farley, 2004; van der Krogt et al., 2009).

BVB players average 219 jumps per match (100 per set) (Medeiros, Palao, Marcelino, & Mesquita, 2014). When landing these jumps, the body is required to dissipate a large amount of force in a short period of time, requiring sufficient strength and control of the lower limbs to do so without placing undue stress on the joints and muscles (Prilutsyky & Zatsiosky, 1994). To do this effectively there needs to be a balance between stability, mobility and proprioception of the lower back, hip, knee and ankle as well as sufficient strength of the muscles surrounding these joints (Roijezon et al., 2015). Feed-forward proprioceptive mechanisms, using neural anticipation to pre-activate muscles around the hip, knee and ankle prior to landing a jump, increase stability around these joints by adjusting musculotendinous and joint stiffness, thus allowing optimal force transmission through the leg, reducing the risk of injury (Mornieux, Gehring, Tokuno, Gollhofer, & Taube, 2014).

There is a debate amongst researchers regarding the importance of task-specific training in developing and perfecting functional skills and reducing the risks of injury. Taube, Gollhofer, and Lauber (2020) conducted a study investigating the effects of task-specific training and showed that, in line with previous research, ballistic strength training resulted in an improvement in explosive performance, while balance training improved balance performance. Thus, repetitively training a skill improves the capacity to excel in this skill. Based on the theory that task-specificity is the most important component of an athlete's capability, each volleyball player group is expected to excel under their normal task conditions, as they have developed the optimal stategies to deal with this environment through training and developing correct muscle activation patterns and to utilise their biomechanics most effectively (Taube et al., 2020). If, however, force production is more significant for performance, BVB players may be stronger and have better-developed musculature for jumping because they trained under more difficult jump conditions, and would therefore be expected to outperform IVB in jumping capacity and agility on both hard and soft surfaces. Marquez, Aguado, Alegre, and Fernandez-Del-Olmo (2013) measured the activation of lower limb musculature during repetitive jumping on an elastic surface (trampoline) compared to a rigid surface. Participants who jumped repetitively on an elastic surface and subsequently performed a countermovement jump on a hard surface, had changes in neuromuscular activation patterns in the knee extensor muscles and increased co-activation of the ankle musculature.

Techniques to improve jumping capacity and agility – the two performance measures used most commonly to assess a volleyball player's level of play and skill – have been investigated thoroughly, with plyometric strength training being most commonly used to achieve these positive adaptations (Markovic & Mikulic, 2010). Interventions using uneven or soft surfaces on which to perform this plyometric training have long been a field of interest for many sports physicians, trainers and researchers who seek to improve training outcomes in a variety of athletes (soccer, basketball, volleyball). Sand, grass and other unstable surfaces (e.g. balance pad) have been used to investigate changes in physical measures such as cardiovascular fitness, strength, speed, jumping capacity and agility (Arazi, Mohammadi, & Asadi, 2014; Balasas et al., 2013; Binnie, Dawson, Arnot, et al., 2014; Cressey, West, Tibero, Kraemer, & Mares, 2007; Gortsila, 2013; Impellizzeri et al., 2008; Mirzaei, Norasteh, & Asadi, 2013; Negra et al., 2017; Pinnington et al., 2005). *Table 1* outlines how these studies exposed a group of participants to training programmes conducted on different surfaces and measured outcomes thereafter. Some authors noted that a greater exposure to sand training may result in greater improvements in performance, though this was not tested in their study (Binnie, Dawson, Pinnington, et al., 2014).

*Table 1. Physiological effects of training on different surfaces*

| **Study** | Surfaces tested | Study participants | Intervention | Outcome measures | Results | Conclusions drawn |
|---|---|---|---|---|---|---|
| Balasas et al. (2013) | Sand | 11 male amateur indoor volleyball players | 12 weeks of beach volleyball training | Running economy (RE) and cardiorespiratory endurance (heart rate (HR), relative and absolute $VO_2$, respiratory exchange ratio (RER), minute ventilation (VE), absolute/relative $VO_{2max}$) | Improvement of RE: significantly decreased HR, relative and absolute $VO_2$, RER and VE.<br><br>A significant increase in $VO_{2max}$ both in absolute and relative values. | Systematic beach volleyball training leads to an improvement of RE and $VO_{2max}$ of amateur indoor volleyball players. |
| Impellizzeri et al. (2008) | Sand and grass | 37 amateur soccer players | 4 weeks of high-intensity plyometric training | 10-m and 20-m sprint time<br><br>Squat jump (SJ), countermovement jump (CMJ), and eccentric utilisation ratio (CMJ/SJ)<br><br>Muscle soreness | No training surface/time interactions were found for sprint time.<br><br>The grass group improved their CMJ more than players in the sand group.<br><br>The sand group improved their SJ more than players in the grass group.<br><br>The sand group experienced less muscle soreness than those in the grass group. | A grass surface seems to be superior in enhancing CMJ performance while the sand surface showed a greater improvement in SJ. Therefore, plyometric training on different surfaces may be associated with different training-induced effects on some neuromuscular factors related to the efficiency of the stretch-shortening cycle. Training on the sand induced less muscle soreness than grass training. |
| **Binnie, Dawson, Arnot, et al. (2014)** | Sand and grass | 24 well-trained female team-sport athletes (netball and field hockey) | 8-week conditioning programme | Leg strength, balance, vertical jump, agility, 20-m speed, repeat speed (8 × 20-m every 20s), running economy and maximal oxygen consumption ($VO_{2max}$) | Significant improvements in jump, sprint and agility performance in both training groups: moderate effect sizes suggesting larger improvements in CMJ and sprint performance in the sand group. Significantly greater improvements in $VO_{2max}$ in the sand group compared to grass. | Substituting sand for grass training surfaces in an 8-week conditioning programme can significantly increase the relative exercise intensity and training load, leading to superior improvements in aerobic fitness. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mirzaei et al. (2013) | Sand | 27 healthy males | 6 weeks of plyometric training | EMG (quadriceps) and vertical jump (VJ) | Significant increases in quadriceps EMG and VJ performance following training on sand. | DJ and CMJ plyometric training on sand improved EMG activity and jump performance. |
| Cressey et al. (2007) | Inflatable rubber discs (unstable group) and stable surface (stable group) | 19 healthy, trained male soccer players | 10-week conditioning programme with lower-body exercises | Bounce drop jump (BDJ) and countermovement jump (CMJ) heights, 40- and 10-yard sprint times and T-test (agility) times | The stable group improved significantly on BDJ and CMJ; no significant changes were noted in the unstable group.<br><br>Both groups improved significantly on the sprint time, the stable group showed greater improvements.<br><br>Both groups improved significantly on T-test performance; no statistically significant changes between the groups. | These results indicate that training using inflatable rubber discs attenuates performance improvements in healthy, trained athletes. Such implements have proved valuable in rehabilitation, but caution should be exercised when applying unstable surface training to athletic performance and general exercise scenarios. |
| Arazi et al. (2014) | Sand and hard court | 14 healthy males | 6 weeks DJ plyometric training on sand | Vertical jump test (VJT), standing long jump test (SLJT), 20-m and 40-m sprint, agility (T-test), and one repetition maximum leg press (1RM) | Significant improvements in VJT, SLJT and 1RM were seen for both groups.<br><br>Significant decreases for both groups in 20-m and 40-m sprint and T-test times.<br><br>The hard-court group had larger effect sizes for VJT and SLJT, and the sand group had larger effect sizes for agility and 1RM. | Based on the effect sizes, it can be recommended that athletes use hard court training for enhancing sprint and jump capacity and sand training for improving agility and strength. |
| Negra et al. (2017) | Stable surface and unstable surface (Airex | 33 male adolescent soccer players | 8-week plyometric training programme: PTS (plyometric training on a | Countermovement jump (CMJ), standing long jump (SLJ), reactive strength index (RSI), 20-m sprint test, modified Illinois change of direction test (MICODT), stable stork balance | No significant between-group differences were observed for CMJ, SLJ, RSI, 20-m sprint test, MICODT and SSBT.<br><br>Statistically significant between-group differences were noted for | PTS or PTC training resulted in similar performance improvements in components of physical fitness, except for dynamic balance. From a performance-enhancing perspective, PTC is |

| | | | | | | |
|---|---|---|---|---|---|---|
| | balance pad and Thera-Band stability trainer) | | stable surface) or PTC (plyometric training on combined stable and unstable surfaces) | test (SSBT) and unstable stork balance test (USBT) | the USBT in favour of the PTC group. | recommended for paediatric strength and conditioning coaches because it produced comparable training effects to PTS on proxies of muscle power, muscle strength, speed, agility, static balance, and additional effects on dynamic balance. |
| Gortsila (2013) | Sand and hard surface | 45 pre-pubescent girls | 10-week training programme | Agility (T-test and 505-test) and passing skills | Improvement in agility significantly greater in the sand group, regardless of the surface (hard or sand) that the test was executed on.<br>Both groups had significantly improved passing accuracy, but the sand group achieved the greatest improvement. | Training on the sand surface could be a useful and effective tool for improving agility and passing skills in prepubescent female volleyball players. |

## 2.3 Proprioception

The neurophysiologist Charles Sherrington first described the concept of proprioception in 1906. He defined proprioceptors as receptors that received stimuli from the body's own movements and relayed this information to the brain, thus defining proprioception as the body's sense of joint position in space at rest and during movement (Evarts, 1981). This concept has also been described as neuromuscular control, dynamic balance or sensorimotor awareness (Taube, Gruber, & Gollhofer, 2008).

The proprioceptive system works together with the visual and vestibular systems to relay information about body position in space (also known as postural control) to the central nervous system (CNS) (Proske & Gandevia, 2012). Proprioception has three components that all contribute to creating a mechanical framework of the musculoskeletal system in the brain: joint position sense (JPS), the sense of movement (kinaesthesia) and the pressure exerted on a limb (Stillman, 2002).

The proprioceptive feedback mechanism utilises the myotatic reflex loop, commonly known as the stretch reflex (Gottlieb & Agarwal, 1973). Proprioceptors, also known as mechanoreceptors, are found in the structures of the somatosensory system (muscles, joints, tendons and skin). These specialised receptors are innervated by nerve endings, which are stimulated during movement and relay this information to the CNS (Hillier, Immink, & Thewlis, 2015). Here the ideal contraction or elongation of a muscle (muscle tone) is determined and the feedback is sent back to the appropriate muscle to adjust and thus optimise body posture and control (Stillman, 2002). Feed-forward strategies to control joint position have also been proposed and validated in sensorimotor research studies. In this case, the brain anticipates the muscle contraction required for optimal stability of a joint and increases muscle activation around the joint prior to impact (e.g. landing a jump) (Finley, Dhaher, & Perreault, 2012). Lastly, Gandevia, Smith, Crawford, Proske, and Taylor (2006) conducted a study in which the upper limb was paralyzed before completing a position matching task. This study concluded a definite "central control signal" in planning movement. When all proprioceptive pathways are functioning optimally, this results in well-controlled movements with decreased injury risk, and as such, the importance of proprioception during high-demand tasks like exercise becomes obvious.

A person's proprioception is influenced by several intrinsic factors: age (Yang, Waddington, Adams, & Han, 2019), cutaneous sensation (Hillier et al., 2015), ankle range of movement (ROM), fatigue (Göktepe, Çakır, Göktepe, & Şenel, 2019), performance level (Han et al., 2015), pain and effusion

(Roijezon et al., 2015). Should these factors be negatively affected, this can in turn reduce proprioception and have a harmful effect on the musculoskeletal system by decreasing appropriate muscle contractions and reactions, potentially increasing the risk of injury (Stillman, 2002).

Clark et al. (2015) described proprioceptive testing using either specific or non-specific tests. Specific tests would need to explicitly test one of the three components described above, contributing directly to proprioception: JPS, kinaesthesia or force sensing. JPS tests can further be divided into loaded or unloaded tests, which are performed respectively either in weight-bearing or non-weight-bearing positions. Loaded tests were found to have more clinical relevance when testing athletic populations, due to their functional simulation (Stillman & McMeeken, 2001). Non-specific proprioceptive tests would include balance tests, as these use a combination of JPS as well as visual and vestibular CNS processing. Balance testing has been used to assist in providing a measure of improvement in proprioception (Stillman, 2002). It has been suggested that by removing visual input (closing eyes) or using an unstable surface, this test may be more valuable in contributing to a proprioception assessment (Roijezon et al., 2015). The modified star excursion balance test (mSEBT) also measures proprioception, as it challenges an individual to maintain balance on one leg while moving the other into various directions (Plisky, Rauh, Kaminski, & Underwood, 2006).

Proprioceptive retraining techniques have long been investigated in the literature, and there is a large volume of research examining the feasibility of retraining proprioception and suggesting the best methods for doing this (Aman et al., 2014; Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001; Hrysomallis, 2011; Taube et al., 2008). Initial rehabilitation of proprioception post-injury addresses pain, swelling and fatigue by using passive modalities such as joint mobilisations, strapping or massage (Clark et al., 2015). When considering athletes, it has also been shown that exercise in general can cause an improved JPS (Salgado, Ribeiro, & Oliveira, 2015), however, it is unclear whether certain exercises may have superior effects over others. There is no doubt that proprioception underlies movement control, but there is a paucity of high-quality research linking proprioceptive training to functional capacity such as jumping height or agility (Hrysomallis, 2011).

Proprioception contributes to the body's postural control, which in turn is regulated partly by the spinal reflex system (Taube et al., 2008). This system is adaptable to changes in the environment such as surface stability or input from other sensory systems (e.g. vision). Moving on unstable surfaces has been said to increase corticospinal excitability when compared to hard surfaces (Mouthon & Taube, 2019). The authors suggest that long-term exposure to activities that challenge the postural control system would lead to modified spinal reflexes, which could account for improved performance in balance tasks (Taube et al., 2008). Furthermore, this increase in corticospinal excitability has been found to have a positive effect on force production, as there may be increased recruitment of muscles. As such, the value of balance training to improve explosive performance should be further explored. Another component to improved performance following training is the idea that accuracy in feed-forward control improves with training (Shadmehr, Smith, & Krakauer, 2010). Motor control is improved through trial and error, and over years of practice and repetition, the accuracy of the prediction of the environment and resulting muscle activation is perfected (Krakauer, Hadjiosif, Xu, Wong, & Haith, 2019; Shadmehr et al., 2010).

A study by Mornieux et al. (2014) investigated reactions in lower limb kinematics when exposed to an unexpected change in the surface during a lateral hop task. Since feed-forward motor control strategies cannot be implemented in an unpredictable situation, this may lead to unfavourable lower limb kinematics, which can potentially increase the risk of injury. This study found that, indeed, increased hip and knee abduction angles and ankle inversion were observed in unpredictable situations such as these. The authors suggested that training interventions should be included to improve motor control strategies to minimise the risk of injury in these unpredictable situations. This becomes relevant in athletes such as volleyball players, who are required to perform lateral cutting movements frequently and are a population group at high risk for severe injury if they perform this task unsuccessfully (Bahr & Krosshaug, 2005).

Training on unstable surfaces (e.g. Rocker board, foam, wobble plate) in isolation or combination with ballistic, plyometric exercise has been found to significantly improve JPS (Clark et al., 2015), postural control strategies (Göktepe et al., 2019; Williams III, Murray, & Powell, 2016) as well as increase force production (Gruber, Gruber, Beck, & Gollhofer, 2007). Researchers however clearly state that further research into the most effective combination of exercises to facilitate proprioceptive retraining needs to be conducted (James et al., 2014).

A small cohort study conducted on basketball players (sample size = 23) found that balance training is beneficial in improving vertical jump height (Boccolini, Brazzit, Bonfanti, & Alberti, 2013). One feasibility study found beneficial results of proprioceptive training on jumping height (Son, Stewart, Ward, & Farrar, 2018). The authors however noted the short duration of their study as a limitation. A systematic review by Zech et al. (2010) concluded that balance training caused significant improvements in proprioception, measured using the SEBT and single-leg balance time, but that further evidence with high methodological quality is needed to infer that balance training may benefit functional performance measures.

Plyometric training on an unstable surface such as sand is said to recruit more motor units during muscle activation, as the stretch part of the muscle activation cycle is longer (Kibele, Classen, Muehlbauer, Granacher, & Behm, 2014; Mirzaei et al., 2013). Due to the softness of the sand, the energy produced by the muscles is absorbed by the surface rather than returned (as it would on a hard surface), causing an increased contraction time of the muscles (longer stretch of the knee extensors and plantarflexors), allowing the leg muscles to build up a larger force before shortening (utilising the stretch-shortening cycle) (Mirzaei et al., 2013).

While playing BVB, the athlete is continuously performing plyometric exercises on an unstable surface (sand), which requires constant CNS processing and adaptations to adjust to changing demands. Impellizzeri et al. (2008) suggested that habitual sand training may act in a similar way to unstable surface training, which could thus result in improvements in balance, kinaesthetic sense and proprioception.

## 2.4 Instrumentation

Determining and measuring the factors contributing to performance in sport is a complex process. This should combine the assessment of specific physiological adaptations contributing to functional capacity (e.g. muscle strength, joint range of movement, proprioception), while also incorporating tests that mimic sport-specific demands (e.g. countermovement jump test) (Zemkova & Hamar, 2018).

This section introduces all the physical tests conducted in this study. Justification for using each test, both in terms of biomechanical relevance to volleyball and assessment of a component related to proprioception, jumping capacity or agility, is noted. The psychometric properties of the tests are also listed and described.

### 2.4.1 Testing factors contributing to lower limb functional capacity

#### **2.4.1.1** Two-point discrimination (TPD)

Cutaneous receptors in the body are activated during skin stretch created by moving a joint (Duysens, Clarac, & Cruse, 2000). Information from these skin receptors together with the input provided from the muscle spindles produces peripheral feedback sent to the brain, creating proprioceptive awareness of the body (Collins, Refshauge, Todd, & Gandevia, 2005). Changes in lower limb position are sensed primarily by changes in the muscle fibres. However, cutaneous receptors of the sole of the foot can contribute to sensing this change and provide input to the proprioceptive system (Duysens et al., 2000). Although assessing cutaneous sensation in isolation provides information on whether the sensation is present or not, more valuable information regarding tactile acuity and cortical organisation is gained by assessing two-point discrimination (TPD) (Viseux et al., 2019). TPD is described as the participant's ability to distinguish between two points being touched at the same time and to decide whether it feels like one or two points. This is typically measured using a calliper or a Touch Test® two-point discriminator tool, which when tested at the foot has an intraclass correlation coefficient (ICC) of 0.86 (intra-rater reliability) (Cashin & McAuley, 2017; Franco, Bohrer, & Rodacki, 2012). TPD should be equal in both lower limbs in healthy individuals (Valagussa et al., 2016) and can be negatively affected by pain, effusion or previous injury (e.g. ankle sprain). A decreased TPD can in turn contribute to altered proprioception (Franco et al., 2012; Rawlinson, 2016). Although not tested specifically in BVB and IVB players, a study conducted by Schlee, Sterzing, and Milani (2007) found that barefoot athletes had better sensitivity to vibration at the foot than shod athletes. TPD may thus also be affected by playing volleyball in shoes or barefoot.

#### 2.4.1.2 Modified Balance Error Scoring System (mBESS)

The original Balance Error Scoring System (BESS) was created to measure postural stability post-concussion and has since been modified to be an appropriate measure of static postural control in an athletic population (Hunt, Ferrara, Bornstein, & Baumgartner, 2009). The modified test eliminates ceiling and floor effects for three of the positions used in the original BESS. Participants are required to perform stride stance (once with each leg behind) on foam and single-leg stance (once on each leg) on two surfaces (firm ground and foam) with their hands on their hips and eyes closed for 20 seconds. During this time the researcher counts any errors made, including lifting their hands off their hips, opening their eyes or falling out of position (Ozinga et al., 2018). The mBESS has been validated in various populations since its creation and found to have good reliability (ICC = 0.88) and documented normative scores for healthy adults (Bell, Guskiewicz, Clark, & Padua, 2011). A higher error score on the mBESS has been positively correlated with an increased risk of ankle sprains (Murphy, Connolly, & Beynnon, 2003) – one of the most common volleyball-related injuries.

#### 2.4.1.3 Modified star excursion balance test (mSEBT)/Y-balance test

This test was adapted from the star excursion balance test (SEBT), a well-known lower extremity test designed to measure dynamic balance (Coughlan et al., 2014). The test has since been modified and is now also known as the Y-balance test, measuring dynamic postural control in three directions in the form of a "Y" (Plisky et al., 2006). Participants are required to balance on one leg on a plate in the centre of the "Y" while performing a maximum reach into each direction with the other leg, pushing a slider along a PVC pipe that has a measuring tape attached to it (van Lieshout et al., 2016). This requires adequate hip, knee and ankle strength, range of motion and proprioception, and is one of the most reliable clinical tests (ICC = 0.85-0.89) for assessing dynamic balance in different directions (Garbenytė-Apolinskienė, Šiupšinskas, Salatkaitė, Gudas, & Radvila, 2018). Reach scores have been positively correlated with better proprioception and when decreased, as a predictor of lower limb injuries (Gribble, Hertel, & Plisky, 2012). Furthermore, this test has been used to monitor changes in proprioception following a neuromuscular control exercise intervention (Coughlan et al., 2014).

#### 2.4.1.4 Knee-to-wall test

This test measures ankle dorsiflexion range of movement (ROM) in a closed-chain (weight-bearing lunge) position. The participants perform a lunge perpendicular to a wall; the maximum distance achieved between the big toe and the wall while keeping the knee against the wall and the heel down is measured, with each centimetre equating to approximately $3.6^{0}$ of dorsiflexion ROM (Konor, Morton, Eckerson, & Grindstaff, 2012). This method of measuring dorsiflexion ROM has been tested in various athletic populations and found to be more functional and psychometrically sound when compared to an open-chain test (intra-rater reliability = 0.95-0.99) (Powden, Hoch, & Hoch, 2015). It is common for dorsiflexion ROM to become limited following an ankle sprain (Malliaras, Cook, & Kent, 2006). This decreased ROM has in turn been linked to lower jumping capacity, a higher incidence of patellofemoral pain (Macrum, Bell, Boling, Lewek, & Padua, 2012), recurring ankle sprains (Loudon, Reiman, & Sylvain, 2014) and decreased dynamic balance ability (Hoch, Staton, & McKeon, 2011).

#### 2.4.1.5 Single leg bridge hold test (SLBHT)

This strength test, also known as a unilateral hip bridge endurance test, assesses posterior chain muscle endurance and core stability, challenging the neuromuscular control of the lumbopelvic muscles (Butowicz, Ebaugh, Noehren, & Silfi, 2016). Electromyography during this test shows significant recruitment of the longissimus thoracis, lumbar multifidus, gluteus medius and gluteus maximus muscles (Alvim et al., 2018; Donatelli, Dimond, & Holland, 2012). Participants are asked to lie on their back, assume a bridge position, extend one leg and maintain this position as long as possible without losing form (dropping their contralateral hemipelvis) (Dennis, Finch, Elliott, & Farhart, 2008). The SLBHT was found to have excellent within-session reliability (ICC = 0.94–0.95) (Butowicz, Pontillo, Ebaugh, & Silfies, 2019) and moderate inter-rater reliability (ICC = 0.56), and has been used as an injury prevention screening test in cricket players (Dennis et al., 2008). The muscles tested in the SLHBT test play a key role in producing the power a volleyball player needs to achieve maximum jumping capacity. When landing these jumps, the body is required to dissipate a large amount of force in a short period of time, requiring sufficient strength and control of the lower limbs to do so without placing undue stress on the joints and muscles (Prilutsyky & Zatsiosky, 1994).

#### 2.4.1.6 Eccentric-concentric calf raise test

This test incorporates the full range of ankle motion and quantifies plantarflexion endurance. Participants are asked to stand on a step with their heel off the edge of the step and repeat as many heel raises as possible before fatiguing, through full ankle ROM, set to a metronome to standardise the speed of movement (Dennis et al., 2008). This is extremely relevant as plyometric strength, used in repetitive jumping and especially landing, relies heavily on plantarflexion strength (Alvim et al., 2018; Malliaras et al., 2006). This test demonstrates excellent intra-tester reliability (ICC = 0.99-1.0), and normative values have been established (Dennis et al., 2008; Hebert-Losier, Wessman, Alricsson, & Svantesson, 2017).

### 2.4.2 Testing proprioception

#### 2.4.2.1 Wedge test

Joint position sense (JPS) is a component of proprioception (Roijezon et al., 2015) that can be tested using the wedge test. The wedge test is a loaded test, which measures limb position sense using a bilateral matching task; namely asking the participants to assess the joint position of both ankles and determine which gradient is steeper. This test uses the principles of the Active Movement Extent Discrimination Assessment (AMEDA) (Han et al., 2016) as it requires participants to stand with each foot on a plastic wedge of a different (or equal) angle of inclination and determine which feels higher (in essence which ankle is in more plantarflexion) without looking down. Although this test has no documented psychometric properties yet, it detected differences in proprioception in a study comparing hypermobile and non-hypermobile individuals (Ituen, Smits-Engelsman, Ferguson, & Duysens, 2020). As discussed above, proprioception underlies movement control and is critical in the development of specialised skills needed in volleyball players (Han et al., 2015).

### 2.4.3 Testing jumping capacity

#### 2.4.3.1 Countermovement jump with arm swing (CMJA)

Jumping forms an integral part of a volleyball player’s skill and is a big contributor to the success of a player’s performance (Magalhães et al., 2011). The CMJA requires participants to jump as high as possible from a standing position, through a squat and allowing arm swing, but keeping the legs straight during flight (Heishman et al., 2018). This jump test is commonly used to assess athletes' lower limb strength and is classically measured using a force platform or Vertec device (Rago et al., 2018; Yingling et al., 2018). More recently, the validity of the MyJump 2 application (using a smartphone) was tested in football players and found to have high validity and reliability for measuring vertical jump height when compared to data obtained from a contact mat (ICC = 0.92) (Coswig et al., 2019). This application is affordable and can easily be used in a practice setting (Brooks, Benson, & Bruce, 2018; Driller, Tavares, McMaster, & O'Donnell, 2017; Gallardo-Fuentes et al., 2015; Yingling et al., 2018).

#### **2.4.3.2** Single leg triple hop for distance (SLTHD) test

As its name implies, this jump test requires participants to hop forwards on one leg three times, aiming to achieve maximum distance. The SLTHD test is a strong predictor of lower limb muscle strength (quadriceps and hamstrings) in an athletic population, and an economical test to use in practice (Hamilton, Shultz, Schmitz, & Perrin, 2008). Volleyball players also often land a spike jump on one leg, which justifies the inclusion of a single leg hop test in addition to the above bilateral jumping test (Iglesias-Caamaño et al., 2018). It is one of the most common and reliable (ICC = 0.95) tests used to screen for lower limb weakness as well as to determine return-to-play readiness post-injury (Williams, Dott, & Dawes, 2017).

### 2.4.4 Testing agility

#### **2.4.4.1** Modified agility T-test (MAT)

This agility test requires participants to sprint forwards for 5 meters (m), shuffle to one side of a demarcated "T" for 2.5m, then shuffle in the opposite direction for 5m, shuffle back to the centre of the "T" and then backpedal back to the starting position. Successful volleyball players need an aptitude to sprint explosively, change direction, shuffle and backpedal into all directions to ensure optimal court positioning for receiving or attacking the ball (Tramel et al., 2019). The MAT protocol is modified from the original by decreasing the distances, making it appropriate for sports like volleyball where short-distance sprints are required, and has an excellent inter-tester reliability (ICC = 0.92-0.95) when tested in recreational athletes (Sassi et al., 2009).

## 2.5 Summary

Athletes of all calibres continually strive to improve their performance, while avoiding injury. In volleyball, the areas targeted for optimising performance include improving jumping capacity and agility (Sheppard et al., 2008). Historically, plyometric training has been prescribed to achieve these goals (Markovic & Mikulic, 2010; Mirzaei et al., 2013; Zech et al., 2010). More recently, the use of unstable surface training in improving functional outcome measures has been studied (Balasas et al., 2018; Impellizzeri et al., 2008). These studies have shown promising effects of sand-based training on cardiovascular fitness and strength. Little high-quality research has been done looking at the possible effect sand training may have on proprioception. Furthermore, an association between better proprioception and functional performance such as jumping capacity and agility has not yet been investigated.

There is currently no research comparing proprioception between these two groups (BVB and IVB players), who perform a very similar sport on different surfaces. As BVB players repeatedly stimulate their proprioceptive systems by training on the sand, this may lead to developing muscle activation strategies that enhance stability and kinaesthetic sense, thus improving proprioception.

We hypothesised that BVB players would implement the same jumping technique used to jump on the sand when asked to jump on a hard surface. This jump would have both the benefit of the increased proprioception from training on an unstable surface causing larger muscle activation (Finley et al., 2012; Lorentzen et al., 2018; Shadmehr et al., 2010; Taube et al., 2008), as well as the increased force production and neuromechanical adaptation from habitual sand training (Marquez et al., 2013). In addition, the increased ground reaction forces of the hard surface would cause increased passive kinematic changes in the lower limb (van der Krogt et al., 2009). This would then result in generating a higher vertical jump. Conversely, we expect IVB players, who are not used to jumping on a soft surface (sand), to produce lower jump heights as they expect high ground reaction forces (experienced on a hard surface) and thus have decreased leg stiffness and delayed onset of muscle activation causing a lower jump height (Moritz & Farley, 2004).

By testing both indoor and beach players, on indoor as well as sand surfaces, the author wishes to investigate whether differences in proprioception exist and whether there are possible associations between these differences and functional performance measures, such as jumping capacity and agility.

# CHAPTER THREE: PROPRIOCEPTION, JUMPING CAPACITY AND AGILITY IN BEACH VERSUS INDOOR VOLLEYBALL PLAYERS

## 3.1 Introduction and study setting

Decreased proprioception has been highlighted as one of the risk factors for injury both in beach and indoor volleyball players (James et al., 2014; Reeser et al., 2006; Ribeiro et al., 2008). Proprioceptive retraining strategies frequently implement the use of an unstable surface (e.g. foam, Swiss ball, grass or sand) to perform an exercise to attempt to improve proprioception (Aman et al., 2014; Hubscher et al., 2010). Thus, BVB players playing on the sand are by definition performing continuous proprioceptive training. By comparing two groups (IVB and BVB players) who perform a very similar sport on different surfaces (hard surface and sand), the researchers wish to investigate whether this may have led to differences in proprioception. Furthermore, we would like to discuss the possible influence of this on functional performance (jumping capacity and agility).

The aim is to compare proprioception, functional lower limb range and strength, jumping capacity and agility between non-professional BVB and IVB players. The specific objectives of the study are described in Section 1.1.2 above.

The study was conducted at the UCT lower campus Sports Centre in Cape Town, where access to a quiet testing room, an indoor court and a beach court was granted to the researcher.

### 3.1.1 Hypothesis

BVB players have better proprioception, agility and jumping capacity on the beach and hard surfaces compared to IVB players.

## 3.2 Methodology

### 3.2.1 Research design

A descriptive, cross-sectional, analytical study was conducted. This allowed for conducting multiple tests in a single contact session, making it cost-effective and eliminating the risk of loss of participants to follow up. A pilot study was conducted prior to data collection.

### 3.2.2 Participants

#### 3.2.2.1 Inclusion criteria

Healthy participants who were 18 years or older and participated in moderate-intensity exercise for at least 30 minutes three times a week were eligible for inclusion. For the BVB player group specifically, BVB players who met the general inclusion criteria and had played BVB for 12 months or longer were included. For the IVB player group, IVB players who met the general inclusion criteria and had played IVB for 12 months or longer were included.

#### 3.2.2.2 Exclusion criteria

Participants who could not safely take part in physical activity, as determined by a screening questionnaire (Appendix B), were excluded. Participants who had undergone surgery, after which they had not been cleared by their doctor to return to full sports participation, were excluded. Participants who had any injury or condition causing them to stop training in the past six weeks were excluded. For the IVB player group specifically, any history of playing BVB would exclude them from the study.

### 3.2.3 Sample size calculation

As this was an exploratory study using multiple physical tests, an absolute sample size could not be calculated. Gortsila (2013) used the agility T-test to compare volleyball players' speed after ten weeks of training either on sand or indoor surface. The study found that the mean time ± standard deviation (seconds) taken on an indoor surface by the indoor group was 14.4 ± 0.6, and 13.2 ± 0.2 by the sand group. Using these results as parameters, and at a statistical power of 95%, 6 participants were needed per group (https://clincalc.com/stats/samplesize.aspx). A total of 30 participants were recruited for this study; 15 participants per group to ensure sufficient statistical power because the agility T-test was only one of the outcome measures used in the study.

### 3.2.4 Recruitment

Convenience sampling was used to recruit non-professional volleyball players in the Western Cape between December 2019 and May 2020. Volleyball clubs in the Western Cape were asked to post a recruitment flyer (Appendix A) on their websites and social media pages (Facebook and Instagram) and e-mail it to their players each month during the data collection period. Flyers were also handed out to all players at the BVB training beaches. Eligible participants were selected according to the inclusion and exclusion criteria.

Participants for the pilot study were recruited from the UCT volleyball team by contacting their coach and asking for four volunteers (two BVB and two IVB players). The data from these participants were not used in the main study.

### 3.2.5 Data collection tools or instruments

This study used tests that are easy to reproduce either in a basic physiotherapy practice or on a volleyball court:

#### 3.2.5.1 Questionnaires

**Pre-participation Health Screening questionnaire for exercise professionals (Appendix B)**

An exercise pre-participation health screening questionnaire developed by the American College of Sports Medicine (ACSM) ensured that participants were medically safe to partake in physical testing (Magal & Riebe, 2016).

**Training and Injury History questionnaire (Appendix D.1/.2)**

This questionnaire was used in previous sports injury studies (Rawlinson, 2016) and was amended to be appropriate to either indoor or beach volleyball players. It provided demographic data, training and injury history. This questionnaire was trialled in the pilot study and found to be suitable. Injuries were described by area and pain score.

**OSTRC Overuse Injury questionnaire (Appendix E)**

Clarsen, Myklebust, and Bahr (2013) developed the OSTRC Overuse Injury questionnaire for effective recording and monitoring of overuse injuries, as athletes frequently do not register these and continue playing, which can have detrimental effects on their long-term performance, leading to longer forced periods of rest (Seminati & Minetti, 2013). This questionnaire has been tested in various sporting codes and has high internal consistency (Cronbach's $\alpha = 0.91$). It was used to collect injury history data pertaining specifically to common lower limb overuse injuries in volleyball (lower back, knee and ankle).

#### 3.2.5.2 Anthropometry

**Body mass, height, waist circumference, leg length**

Anthropometric testing was conducted to ensure that the IVB and BVB groups were comparable for matching. Body mass was measured using a digital scale (Omron HN288 Weight Scale) (kilogram (kg)), height using a tape measure fixed to a wall (centimetre (cm)) and waist circumference using a tape measure half-way between the lowest rib and the iliac crest (cm) (Nordhamn et al., 2000). Participants' leg lengths were measured using a tape measure. The measurement was taken from the anterior superior iliac spine (ASIS) to the medial malleolus on each side, and an average leg length was calculated.

#### 3.2.5.3 Lower limb physical tests

**Distal tactile acuity using a two-point discrimination test (Viseux et al., 2019)**

Part of one's proprioceptive capability is based on distal tactile acuity – namely the ability to discriminate between two points of a Touch Test® two-point discriminator (Franco et al., 2012). Participants were asked to lie on their stomach, and the tool was used at plantar hallux to measure the distance (millimetre (mm)) at which participants could feel two points versus one. This was done twice: The test began with 15mm between the two points on the tool. The tool was pressed to the skin until first blanching and the participants were asked whether they perceived one or two points. The distance between the two points was then decreased in 1mm increments until the participants reported feeling only one point. This distance was recorded. On the second iteration, the tool was set with a 0mm distance between the points and gradually increased until the participants reported feeling two points. This distance was also recorded. This testing procedure has good reliability (ICC = 0.86) (Cashin & McAuley, 2017).

The test was conducted once on each foot, with the best score used for data analysis. A practice test was performed on the palmar aspect of the index finger on the dominant hand to ensure a full understanding of the test.

**Static balance using the modified balance error scoring system (mBESS) (Ozinga et al., 2018)**

Static balance was tested in four positions: tandem stance on hard ground, single-leg stance on hard ground, tandem stance on foam, single-leg stance on foam. The foam was a 500mm x 410mm x 60mm block. Participants were asked to hold each of these positions with their hands placed on their hips. Once stabilised into a still position they were asked to close their eyes and maintain that position for 20 seconds. Participants were instructed to return to the test position as quickly as possible if they lost their balance. Errors made during the 20 seconds were recorded. Each of the four surfaces was tested three times per leg with the best score taken as the representative value for data analysis. Errors included:

- Opening of eyes
- Lifting hands off of hips
- Stepping, stumbling or falling out of position
- Swaying of hip into more than 30 degrees of flexion or abduction
- Lifting the forefoot or heel
- Remaining out of the testing position for more than 5 seconds

The mBESS has been validated in athletic populations and has good reliability (ICC = 0.88) (Bell et al., 2011).

**Dynamic balance using the modified star excursion balance test (mSEBT) (van Lieshout et al., 2016)**

Participants were asked to stand in the centre of a device used to measure reach distance (foot on the centre of the wooden plate). They were instructed to reach with one foot as far as possible and push a plastic slider along the tape measure arm of the device before returning to the starting upright position. The tester read off the spot to which the participants pushed the plate and the reach distance, recorded to the nearest 0.5cm. When using the right foot as the reaching foot, and the left leg to balance, the participants completed the circuit in a clockwise fashion (anterior, posterior-medial, posterior-lateral). When balancing on the right leg, the participants performed the circuit in an anti-clockwise fashion. The participants repeated this with the same foot for all three reach directions before changing feet. After completing a full circuit (every reach direction) with each foot, this process was repeated three times per leg. Failed attempts included the following:

- Letting a hand touch the standing leg to aid balance
- Loss of balance resulting in toe/foot contact with the floor

With the test completed and all performances measured and recorded, the best reach per leg into each direction was used and normalised for the participant's average leg length:

- Normalised distance in each direction = (Best distance in each direction/leg length)*100

These calculations were performed for both the right and left leg in each direction, providing a total of 6 scores per athlete used for analysis. Furthermore, a composite reach score was calculated for the left and right leg respectively for analysis:

- Composite reach score = (Average of three normalised distance scores per leg / (3*Average leg length))*100

The mSEBT is one of the most reliable clinical tests (ICC = 0.85-0.89) for assessing dynamic balance in different directions (Garbenytė-Apolinskienė et al., 2018).

**Static posterior chain strength using the single-leg bridge hold test (SLBHT) (Dennis et al., 2008)**

The participants were asked to lie on their back on a mat on the floor, knees bent to 90$^0$ with feet and arms on the mat. If an excessive chin poke was observed, a foam block was placed under the head to bring the cervical spine into neutral. Participants were instructed to roll up into a bridge position such that their hips, pelvis and knees were in line, and extend one leg keeping their knees parallel. This position was then maintained for as long as possible with the tester keeping time on a stopwatch. The test was stopped if one of the following occurred:

- Lower back pain was experienced
- The hamstring cramped
- One of the ASIS (anterior superior iliac spines) did not stay horizontal
- Inability to maintain the position any longer due to fatigue

The participants were allowed to assume the position once before official testing commenced, holding only for 2-3 seconds to prevent fatigue. The tester was allowed to give the participants one correction cue (e.g. correcting ASIS height) before terminating the test. The maximum time held per leg was taken as the representative value for data analysis. The SLBHT was found to have excellent within-session reliability (ICC = 0.94–0.95) (Butowicz et al., 2019) and moderate inter-rater reliability (ICC = 0.56), and has been used as an injury prevention screening test in cricket players (Dennis et al., 2008).

**Ankle dorsiflexion range using the knee-to-wall test (Konor et al., 2012)**

A weight-bearing lunge was used to assess closed-chain dorsiflexion ROM. Participants were asked to stand in a stride stance position facing a wall, using two fingertips against the wall for balance. Their front foot was positioned on a tape measure with the big toe touching the 10cm mark. They were asked to keep the heel of their front foot on the ground while bending the knee, keeping it in line with their second toe, and attempt to touch the wall. If they could touch the wall, their foot was progressed away from the wall 1cm at a time and the participants were asked to repeat the lunge until they were unable to touch the wall with their knee without lifting the heel off the ground. If the participants were not able to touch their knee to the wall without lifting the heel from the ground at the initial 10cm start position, they were asked to move their foot forwards toward the wall 1cm at a time until they could touch their knee to the wall while keeping the heel on the ground. The knee-to-wall test has excellent reliability (ICC= 0.96-0.97) (Konor et al., 2012).

Maximal dorsiflexion ROM was defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel. Heel contact was monitored by the tester by lightly placing their fingers on the heel to feel for heel movement, while also visually examining the heel for movement. When the participants reached the final lunge position, the tester recorded the distance of the big toe from the wall to the nearest 0.1cm on the tape measure. Participants completed three tests per ankle, with the best of each side used as the representative value for data analysis.

**Dynamic calf strength using the eccentric-concentric calf raise test (Dennis et al., 2008)**

The participants were instructed to stand on one foot on a 15cm step with the heel off the edge of the step. They were then asked to rise onto the ball of that foot as high as possible, then slowly lower their heel while maintaining knee extension throughout the movement. The heel raise/lower cycle was repeated continuously until the participants were unable to rise through full range with the knee extended or if they experienced any pain. The recorded measure was the number of repetitions performed. A metronome set at one beat per second was used to ensure that the heel raises were performed at a standardised speed.

A practice trial was completed to ensure the participants understood what was required (1-2 repetitions only). Each leg was tested once. This test has excellent reliability (ICC = 0.99) when used in cricket players (Dennis et al., 2008).

#### 3.2.5.4 Proprioception

**Wedge test (Ituen et al., 2020)**

The participants were asked to stand facing the wall looking straight ahead with a wooden bench placed in front of them obscuring their feet from their vision should they look down. Plastic wedges of different heights were placed on the floor (1.5, 3, 4.5, 6, 9 and 12-degree angles) and presented in various pairs by the tester. The sequence of pairs was randomised but the same protocol was used for each participant (Appendix F). The tester assisted the participants in lifting first their right then their left foot to stand on a pair of wedges, after which the participants were asked to identify the wedge that felt higher, without looking down, by either lifting their right, left or both hands (should the wedges feel of equal height). Incorrect responses were scored = 0, correct = 1. The total number of correct scores was used for data analysis. Furthermore, a penalty score was awarded for every incorrect response, based on the height difference the participant was unable to detect (*Table 2*).

*Table 2. Wedge height difference and the respective penalty scores*

| Wedge degree height difference | Penalty score |
|---|---|
| **9°** | 6 |
| **6°** | 5 |
| **4.5°** | 4 |
| **3°** | 3 |
| **1.5°** | 2 |
| **0°** | 1 |

All penalty scores were added to calculate a total penalty score, which was also used for data analysis, with higher penalty scores indicating poorer proprioception. Although this test has no documented psychometric properties yet, it detected differences in proprioception in a study comparing hypermobile and non-hypermobile individuals (Ituen et al., 2020).

#### 3.2.5.5 Jumping capacity

**Countermovement jump with arm swing (CMJA) (Heishman et al., 2018)**

This test was performed on the sand and a hard indoor court. Participants were asked to perform a countermovement jump as high as they could from a standing start. This was recorded using a Samsung S8 smartphone and later analysed using the MyJump 2 app (Brooks et al., 2018). This application has excellent reliability (ICC = 0.92) when compared to data obtained from a contact mat (Coswig et al., 2019). Participants were allowed arm swing but were instructed to keep their knees extended and feet relaxed when in the air. Participants were tested three times on each surface, with 30 seconds rest between jumps. The average height (cm) was used for analysis.

**Single-leg triple hop for distance (SLTHD) test (Munro & Herrington, 2011)**

This test was performed on the sand and hard indoor court. Participants were allowed one sub-maximum effort practice trial on each leg. Participants were instructed to perform three consecutive maximal hops forwards on the same leg (arm swing allowed) and to maintain the final landing for a minimum of 2 seconds (s). The test was repeated if the participant was unable to complete a triple hop without losing balance and contacting the ground with the opposite leg. The average distance (cm) of the three trials was measured per leg for analysis (Munro & Herrington, 2011). This test has excellent reliability (ICC = 0.95) for assessing lower limb strength (Williams et al., 2017).

#### 3.2.5.6 Agility

**Modified agility T-test (MAT) (Munro & Herrington, 2011)**

The modified agility T-test (MAT) was performed on the sand and hard indoor court. Participants were required to run forwards 5 meters (m), shuffle to one side for 2.5m, back to the centre, then to the other side for 2.5m, back to the centre and then backpedal to the starting point. A practice trial at submaximal speed was given to ensure the participant understood the sequence required. The test was conducted twice (once in each direction) with the best time (s) used for data analysis. This test has excellent reliability (ICC = 0.92-0.95) (Sassi et al., 2009).

### 3.2.6 Pilot study

A pilot study was performed with two BVB and two IVB players, who consented and met the inclusion and exclusion criteria. The pilot study aimed to determine participants' understanding of the questionnaires and test instructions as well as to confirm the total time needed for testing. As anticipated, approximately 90 minutes were required for one participant to complete all the questionnaires and physical tests. The results obtained were not included in the main study. The pilot study ran seamlessly and no changes were made to the procedure. However, the layout of the data capture sheet was amended slightly for ease of data capturing (Appendix F).

### 3.2.7 Procedure

Volleyball players who responded to the information flyer and were interested in participating in the study were asked to contact the researcher. An appointment was then made to attend a testing session at the UCT Sports Centre. Testing commenced in January 2020, was on hold between March and September due the COVID lockdown, and was completed in October 2020 (lockdown level 1). Each participant was tested separately, with a maximum of three consecutive testing sessions being conducted per day. Participants were asked not to perform any physical activity or consume any alcohol on the testing day prior to testing. On arrival, participants were given the informed consent sheet (Appendix C). If they decided to consent to participate and sign the form, the screening questionnaire (Appendix B) was administered to determine eligibility to participate. Due to the COVID pandemic, additional precautions were taken to ensure the safety of all participants (Appendix I), including the use of a COVID-19 screening tool (Appendix G). No participants were screened out of the study. Participants then received the Training and Injury History questionnaire (Appendix D1 or D2) and OSTRC questionnaire (Appendix E) to complete. The researcher was present to ensure subjects' understanding of the questionnaires, though no questions were asked.

Participants were allocated to either the beach volleyball (BVB) or indoor volleyball (IVB) player group based on their playing history (*see inclusion criteria*). These two groups were subdivided into two groups using simple randomisation (BVB_i, BVB_b, IVB_i, IVB_b) for counterbalancing, to test half of each group on the indoor surface first and the other half on the beach court first.

All anthropometric measurements and physical tests were conducted solely by the researcher (a qualified physiotherapist with six years of clinical experience and thus trained to administer such tests safely and with comprehensive, standardised instructions). *Figure 1* shows the procedure followed for the subsequent physical tests.

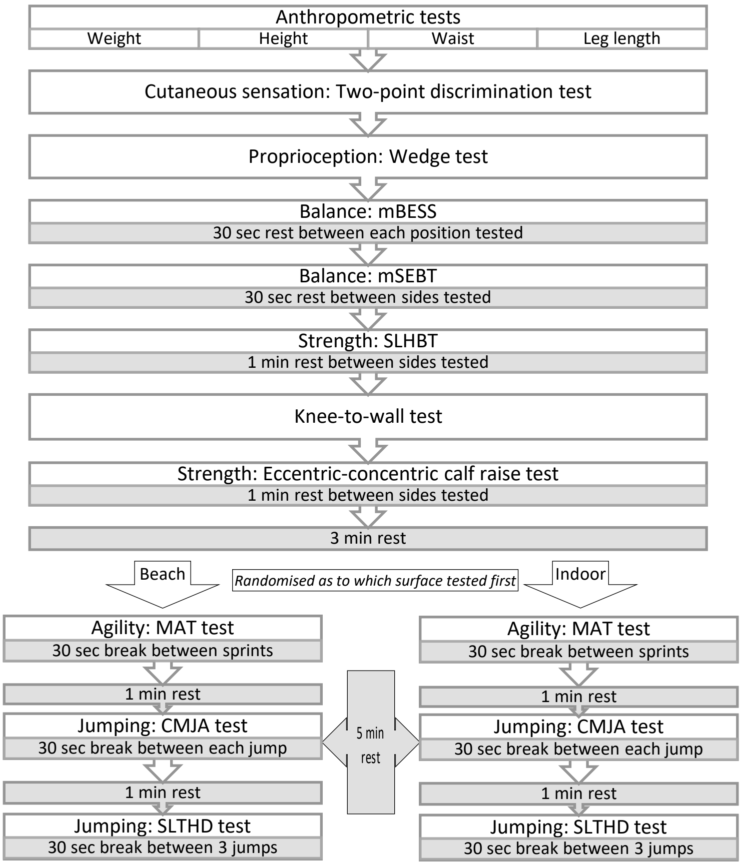



*Figure 1. Procedure physical test*

To ensure standardisation, the same BVB court was used for all the testing, and the sand was dry (no rain in the past 48 hours) and raked evenly prior to testing each new participant. Participants were given ten minutes to complete a warm-up, including a light jog at their own pace and any exercises they would normally perform before a training session. The testing area was not used by anyone else at the time of testing to ensure a quiet environment. Participants were asked to wear shorts and a light shirt and remove all socks, strapping and shoes prior to testing. The indoor tests (MAT, CMJA and SLTHD) were performed with shoes on.

#### 3.4.6.1 Post-study

Participants were provided the results of their physical tests in an Excel spreadsheet and encouraged to contact the researcher for further information if needed. Important findings were distributed to the volleyball community via the club websites and social media pages. The researcher aims to have the findings of this research published in a peer-reviewed scientific journal.

#### 3.4.6.2 Data management

Participants were numbered to protect their identity. Confidentiality was ensured by only requiring basic demographic details. Data were entered into Excel spreadsheets which were on a password-protected laptop and backed up onto password-protected, cloud-based storage as well as being uploaded to the UCT data management platform. Informed consent sheets were stored in a separate locked cupboard so that identification could not be derived. Access to data was restricted to the researchers and supervisory team.

### 3.2.8 Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS Inc., version 26 IBM Company, Armonk, NY). Data were tested for normality using the Shapiro-Wilk test. Descriptive statistics were used to present the frequency, means and standard deviations of the demographical data, training and injury history. A t-test was used to determine whether the two groups were comparable on anthropometric data. Differences between the two groups (BVB and IVB players) in proprioception, agility and jumping capacity were analysed using Mann-Whitney U and unpaired t-tests (depending on the normality of the distribution of the data). Repeated measures ANOVA were used to determine any differences in agility, jumping height or hopping distance between IVB and BVB players when tested on different surface conditions (the surface being the within-group factor and player type being the between-group factor). Effect size analysis was also reported for the physical outcome measures data, to determine the strength of any trends in differences existing between the two player groups (Lakens, 2013; Pinnington & Dawson, 2001). Correlations between proprioception and the functional tests (agility and jumping) were calculated using Pearson correlations. All numerical data were presented as the mean ± standard deviation (SD) and statistical significance was set at $p < 0.05$.

### 3.2.9 Ethical considerations

The study adhered to the research ethics guidelines of the Declaration of Helsinki (World Medical JAMA, 2013). The study protocol was submitted and approved by the Faculty of Health Sciences Human Research Ethics Committee, University of Cape Town (HREC REF: 697/ 2019) (Appendix G).

Autonomy was ensured by the willingness to participate after reading the informed consent sheet (Appendix C) and having the opportunity to ask any questions before signing or withdrawing without consequence. The informed consent sheet explained the purpose of the study, the details of the testing procedure and the potential risks and benefits. All data were treated with confidentiality and results presented in this thesis could not identify participants.

Beneficence was ensured for the individual as they received the results of their tests, highlighting any insufficiencies in their physical capabilities. No participants requested further referral. Non-maleficence was ensured as the testing procedures were all previously validated and found to present minimal risk of pain or injury to the participants. No participants reported any pain or injury during or after the testing. Justice was upheld by allowing all volleyball players to be screened for inclusion/exclusion for the study without bias or prejudice.

## 3.3 Results

### 3.3.1 Study sample

30 participants who met the inclusion criteria were recruited for the study and went on to complete the study (no participants screened out) (*Figure 2*). Participants were divided into IVB or BVB groups according to their playing history. Each group had 10 male and 5 female participants. In accordance with the priori sample size calculation (Section 3.2.3, page 23), the study had 95% statistical power.

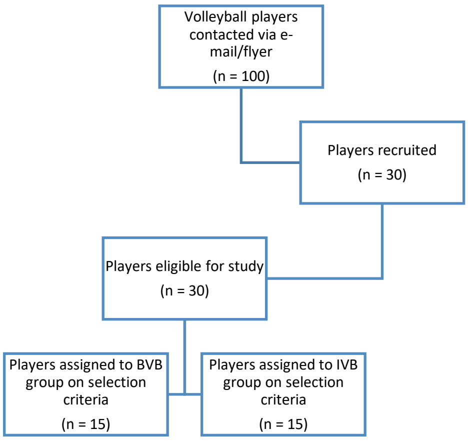



*Figure 2. Description of study sample*

### 3.3.2 Demographics and anthropometrics

The descriptive demographics of participants in the BVB and IVB groups can be seen in *Table 3*. There were no significant differences between the two groups for any of these descriptive variables except age – BVB players (M=32.6, SD=7.7) being older than IVB players (M=27.9, SD=5.4) (t = 4.28, p = <.001).

*Table 3. Descriptive characteristics of participants in the sample (n = 30), IVB (n = 15) and BVB groups (n = 15). Data are expressed as mean ± standard deviation with t- and p-values reported.*

| Variable | Sample (n=30) | IVB (n=15) | BVB (n=15) | t | p |
|---|---|---|---|---|---|
| **Age (years)** | 32.6 ± 7.7 | 27.9 ± 5.4 | 37.4 ± 6.6 | 4.28 | .0002 |
| **Height (cm)** | 183.3 ± 9.2 | 181.7 ± 9.3 | 184.9 ± 9.0 | 0.94 | .35 |
| **Mass (kg)** | 79.3 ± 16.0 | 79.7 ± 19.5 | 79.0 ± 12.4 | -0.11 | .91 |
| **Body mass index (kg/m$^2$)** | 23.5 ± 3.5 | 23.9 ± 4.4 | 23.0 ± 2.4 | -0.70 | .49 |
| **Leg length (cm)** | 104.9 ± 5.8 | 104.4 ± 6.7 | 105.4 ± 5.0 | 0.43 | .67 |
| **Waist (cm)** | 82.0 ± 12.2 | 82.7 ±15.0 | 81.3 ± 9.0 | -0.31 | .76 |

**indicates significant difference with p≤0.05*

### 3.3.1 Questionnaires: Training and Injury History & OSTRC

Data from the Training and Injury History questionnaire showed no significant differences in the total number of years that the participants had played volleyball or the amount of weekly volleyball and other training they performed. The IVB player group reported performing a significantly higher percentage of strength training (37.7% ± 22.3%), in relation to volleyball training, than the BVB group (21.3% ± 18.8%). Though not statistically significant, the BVB player group had been playing for slightly more years and trained slightly more hours of volleyball and other training per week than the IVB group. The training history of both groups is shown in *Table 4*.

*Table 4. Descriptive statistics of training history and training load of the sample (n = 30), IVB (n = 15) and BVB groups (n = 15). Data are expressed as mean ± standard deviation with t- and p-values reported.*

| Variable | Sample (n=30) | IVB (n=15) | BVB (n=15) | t | p |
|---|---|---|---|---|---|
| **Years of play** | 14.4 ± 7.2 | 12.1 ± 4.9 | 16.7 ± 8.5 | 1.79 | .08 |
| **Volleyball training (hours/week)** | 4.6 ± 2.1 | 4.0 ± 1.4 | 5.1 ± 2.5 | 1.54 | .13 |
| **Other training (hours/week)** | 6.4 ± 4.9 | 5.7 ± 5.1 | 7.1 ± 4.9 | 0.76 | .45 |
| **Percentage of training time:** | | | | | |
| **Volleyball (%)** | 47.2 ± 19.5 | 48.3 ± 19.4 | 46 ± 20.2 | -0.32 | .75 |
| **Strength (%)** | 29.5 ± 21.9 | 37.7 ± 22.3 | 21.3 ± 18.8 | -2.17 | .04* |
| **Endurance (%)** | 13.3 ±15.4 | 10.3 ± 11.7 | 16.3 ± 18.4 | 1.07 | .30 |
| **Flexibility (%)** | 4.8 ± 7.9 | 3.0 ± 6.5 | 6.7 ± 9.0 | 1.28 | .21 |
| **Other (%)** | | *none reported* | 9.7 ± 22.1 | | |

**indicates significant difference with p≤0.05*

Participants recruited for the study varied considerably in their highest level of play achieved. Because this study involved non-professional players, this was expected. As can be seen in *Table 5*, there is a fairly equal distribution of level of play in each of the two player groups.

*Table 5. Descriptive statistics of the level of play of the sample (n = 30), IVB (n = 15) and BVB groups (n = 15). Data are expressed as the frequency of the level reported.*

| Variable | Sample (n=30) | IVB (n=15) | BVB (n=15) |
|---|---|---|---|
| **Highest level of play** | | | |
| **Social** | 3 | 2 | 1 |
| **Provincial** | 9 | 4 | 5 |
| **National** | 13 | 7 | 6 |
| **International** | 5 | 2 | 3 |

Participants who had an injury causing them to stop training were not included in the study, however some participants reported areas of pain which they did not consider an injury and thus continued to train at full capacity. These current areas of pain and the respective pain scores are shown in *Table 6*. BVB players reported a higher frequency of current shoulder (4/15) and knee (4/15) pain, while there was a higher prevalence of lower back pain (2/15) in IVB players.

*Table 6. Descriptive statistics of current areas of pain for participants in the IVB (n = 15) and BVB groups (n = 15). Data are expressed as the frequency of area of pain reported and the respective pain score.*

| Area of pain | IVB (n=15) | | BVB (n=15) | |
|---|---|---|---|---|
| | Frequency | Pain score (/10) | Frequency | Pain score (/10) |
| **Shoulder** | 1 | 5 | 4 | 5,6,2,4 |
| **Cervical spine** | 1 | 3 | 1 | 6 |
| **Lumbar spine** | 2 | 2,7 | 0 | 0 |
| **Hip** | 0 | 0 | 2 | 2,2 |
| **Knee** | 0 | 0 | 4 | 6,6,8,2 |
| **Elbow** | 1 | 4 | 0 | 0 |
| **Calf** | 1 | 7 | 0 | 0 |
| **Shin** | 1 | 5 | 0 | 0 |
| **Ankle** | 1 | 3 | 1 | 5 |
| **Hand** | 0 | 0 | 1 | 1 |

Data from the OSTRC questionnaire showed similar trends: IVB players had a slightly higher frequency (6/15) and pain score (9.3 ± 15.6) for lower back pain, while BVB players had a higher frequency (7/15) and mean pain score (12.1 ± 17.9) for knee pain (*Table 7*). Due to the high variability in pain scores (as can be seen in the standard deviations), no statistics could be calculated on these values. When cross-examining the data from the injury questionnaires, we confirmed that players who reported an overuse injury on the OSTRC, were the same players who reported current areas of pain on the Training and Injury History questionnaire.

*Table 7. Descriptive statistics of overuse injury prevalence of participants in the IVB (n = 15) and BVB groups (n = 15). Data are expressed as frequencies of reported injuries and mean OSTRC scores ± standard deviation*

| **Variable** | **IVB (n=15)** | | **BVB (n=15)** | |
|---|---|---|---|---|
| | Frequency of reported injury | OSTRC[1] Severity score (0-100) | Frequency of reported injury | OSTRC Severity score (0-100) |
| **Knee** | 5 | 7.4 ± 13.9 | 7 | 12.1 ± 17.9 |
| **Lower back** | 6 | 9.3 ± 15.6 | 2 | 3.5 ± 11.4 |
| **Ankle** | 2 | 3.2 ± 8.6 | 1 | 2.5 ± 9.6 |

*[1]OSTRC: (Oslo Sports Trauma Research Centre) Overuse Injury questionnaire*

### 3.3.2 Physical measures: Two-point discrimination, balance, ROM, strength & proprioception

Analysis using the Shapiro-Wilk test found all physical measures data to be normally distributed, except data for the wedge test (number correct and penalty score) and the single-leg balance (on floor) test. Thus, Mann-Whitney U tests were used for comparative analysis of these measures, while independent samples t-tests were used to compare all other physical measures between player groups. The results indicated that the anterior reach in the Y-balance test (for right and left legs) was the only test that was significantly different between groups ($p = .027$ and $p = .002$ respectively) with a large effect size ($d = 0.85$ and $d = 1.27$ respectively). No significant differences were found for two-point discrimination, knee-to-wall ROM, wedge test, single leg balance test, SLBHT or calf raise test (*Table 8)*. Effect sizes were also calculated, investigating the strength of any trends in the differences between the two groups. There was a trend for better proprioception (scores on the wedge test), as predicted in BVB players, with a medium effect size of ($d = 0.66$; $p = .08$), indicating that the BVB group identified more differences in wedge heights correctly. It should be noted here that none of the players made errors on the wedge test when the difference in angle of inclination was greater than 1.5mm, hence these results are not listed. While not statistically significant, the BVB players consistently performed better on the wedge test, single leg bridge hold test and calf raise test. These results are reported in *Table 8*.

*Table 8. Descriptive statistics of physical measures of two-point discrimination, balance, ROM, strength and proprioception of participants in the IVB (n = 15) and BVB groups (n = 15). Data are expressed as mean ± standard deviation, with t- values, p-values and effect sizes reported. Where data were not normally distributed, medians ± IQR with U- and p-values are reported.*

| Variable | IVB (n=15) | BVB (n=15) | t | p | Cohen's d |
|---|---|---|---|---|---|
| **Two-point discrimination (mm): L** | 9.0 ± 1.8 | 9.6 ± 2.1 | 0.83 | .41 | .30 |
| **Two-point discrimination (mm): R** | 9.3 ± 1.6 | 9.3 ± 2.1 | 0.10 | .92 | 0 |
| **Knee-to-wall (cm): L** | 123.8 ± 46.3 | 130.7 ± 29.1 | 0.49 | .63 | .18 |
| **Knee-to-wall (cm): R** | 126.2 ± 47.9 | 125.1 ± 34.7 | -0.07 | .94 | .03 |
| **Wedges: Correct (score out of 22) ϟ** | 20 (19-21) | 21 (20-22) | 72 | .08 | .66 |
| **Wedges: Penalty scoreϟ** | 2 (1-4) | 1 (0-3) | 270 | .11 | .58 |
| **Error: 1.5-3mm** | 0.2 ± 0.4 | 0.1 ± 0.4 | -0.48 | .64 | .25 |
| **Error: 3-3mm** | 0.9 ± 0.9 | 0.5 ± 0.5 | -1.77 | .09 | .55 |
| **Error: 4.5-3mm** | 0.1 ± 0.3 | 0.1 ± 0.3 | 0.00 | 1.00 | 0 |
| **Error: 6-4.5mm** | 0.5 ± 0.7 | 0.2 ± 0.4 | -1.21 | .23 | .53 |
| **Error: 9-9mm** | 0.3 ± 0.5 | 0.3 ± 0.6 | 0.00 | 1.00 | 0 |
| **Single leg balance** | | | | | |
| **on floor (errors): Lϟ** | 0 (0-2) | 0 (0-1) | 128ϟ | .47 | .34 |
| **on floor (errors): Rϟ** | 0 (0-1) | 0 (0-1) | 243ϟ | .60 | .07 |
| **on foam (errors): L** | 5.0 ± 1.1 | 5.3 ± 1.4 | 0.56 | .58 | .24 |
| **on foam (errors): R** | 5.1 ± 1.4 | 5.6 ± 1.7 | 0.93 | .36 | .32 |
| **Y-balance test** | | | | | |
| **Anterior (cm): L** | 57.1 ± 7.6 | 68.6 ± 10.3 | 3.49 | .002* | 1.27 |
| **Posterior-medial (cm): L** | 95.7 ± 12.1 | 99.7 ± 10.0 | 0.99 | .33 | .36 |
| **Posterior-lateral (cm): L** | 95.8 ± 13.3 | 97.1 ± 13.2 | 0.27 | .79 | .10 |
| **Composite (cm): L** | 79.8 ± 12.1 | 84.1 ± 9.9 | 1.07 | .29 | .39 |
| **Anterior (cm): R** | 57.5 ± 7.0 | 64.6 ± 9.5 | 2.33 | .027* | .85 |
| **Posterior-medial (cm): R** | 94.9 ± 10.7 | 97.5 ± 11.6 | 0.64 | .53 | .23 |
| **Posterior-lateral (cm): R** | 98.2 ± 13.9 | 99.8 ± 9.4 | 0.37 | .71 | .13 |
| **Composite (cm): R** | 80.3 ± 10.8 | 82.9 ± 8.1 | 0.73 | .47 | .27 |
| **Single leg bridge hold test (s): L** | 118.6 ± 37.5 | 139.9 ± 57.9 | 1.19 | .24 | .44 |
| **Single leg bridge hold test (s) R** | 115.7 ± 34.9 | 135.7 ± 55.2 | 1.19 | .25 | .43 |
| **Single leg bridge hold test (s): AVRG[2]** | 117.1 ± 32.9 | 137.8 ± 53.5 | 1.27 | .21 | .47 |
| **Calf raise test (repetitions): L** | 22.5 ± 6.9 | 24.1 ± 7.8 | 0.57 | .57 | .22 |
| **Calf raise test (repetitions): R** | 22.1 ± 7.8 | 24.2 ± 7.2 | 0.75 | .46 | .28 |
| **Calf raise test (repetitions): AVRG[2]** | 22.3 ± 7.1 | 24.1 ± 6.9 | 0.70 | .49 | .26 |

**indicates significant difference with $p \leq 0.05$*

*[2]AVRG: Average of left and right legs*

*ϟindicates using Mann-Whitney U test*

When normalising variables using Z-scores (mean = 0, SD = 1) to make the scales of the different outcomes comparable, it can be seen that the BVB players have better wedge test scores (higher correct and lower penalty) and higher anterior reach scores on the Y-balance test than the IVB players (*Figure 3*).

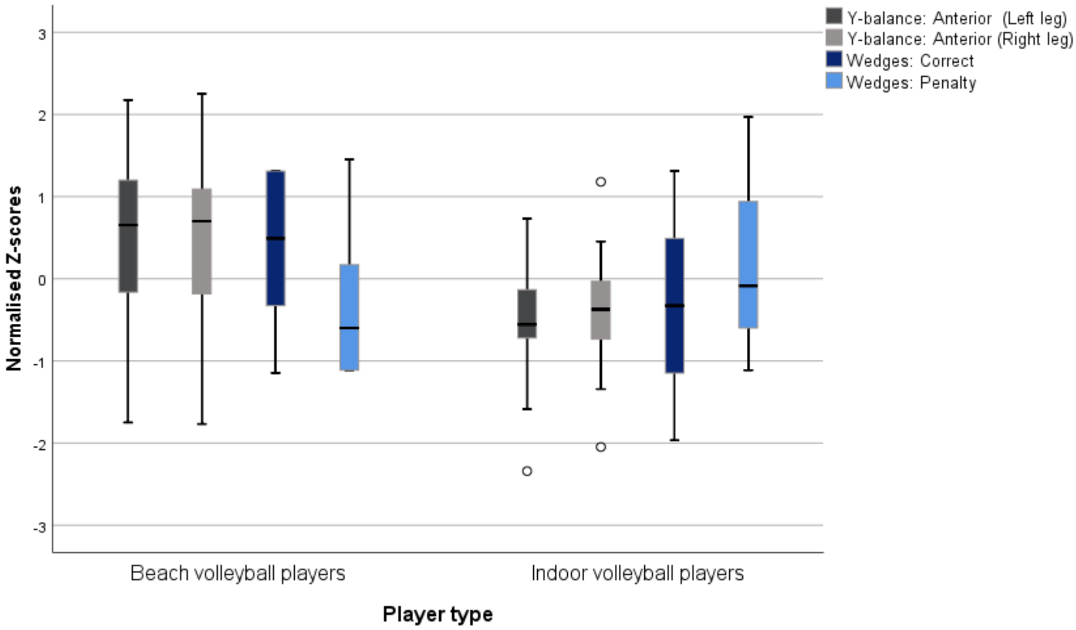



*Figure 3. Normalised Z-scores for Y-balance test (anterior reach distance) and wedge test (correct wedges and penalty scores) in BVB and IVB groups*

### 3.3.3 Jumping capacity and agility

Two main effects were investigated: The main within-group effect, namely the effect of surface on jumping and agility, and the between-group effect, namely the effect of player type on jumping and agility. Lastly, any interactions between surface and player type were examined.

A repeated-measures ANOVA determined that there was a significant main effect of surface type on mean CMJA heights (Wilks' Lambda = 0.799, $F(1,28) = 7.040$, $p = .013$) (

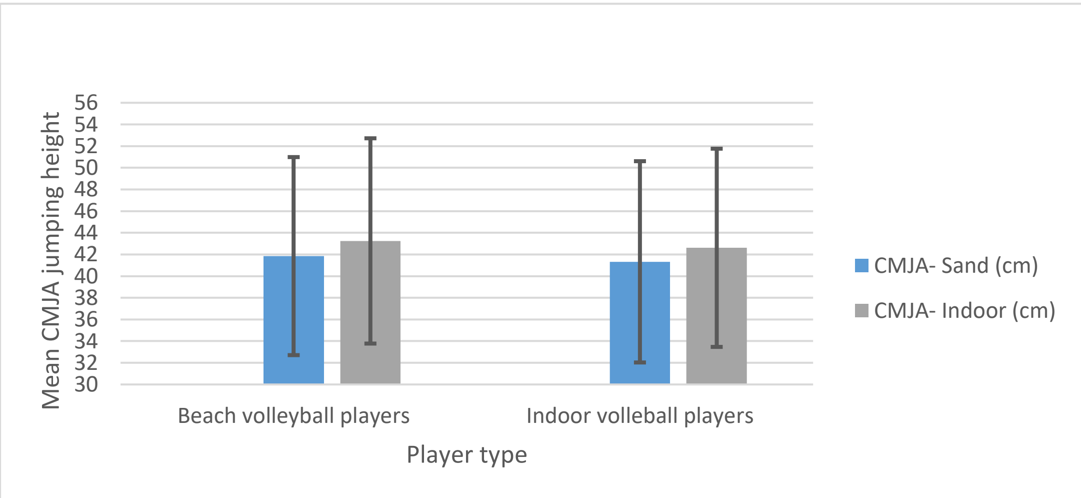


*Figure* 4), mean left leg SLTHD distances (Wilks' Lambda = 0.522, F (1,28) = 25.654, p = <.001), mean right leg SLTHD distances (Wilks' Lambda = 0.473, F (1,28) = 31.169, p = <.001) and mean average SLTHD distances (Wilks' Lambda = 0.480, F (1,28) = 30.362, p = <.001) (*Figure 5*). There was no significant effect of surface type on MAT times (Wilks' Lambda = 0.936, F (1,28) = 1.927, p = .176).

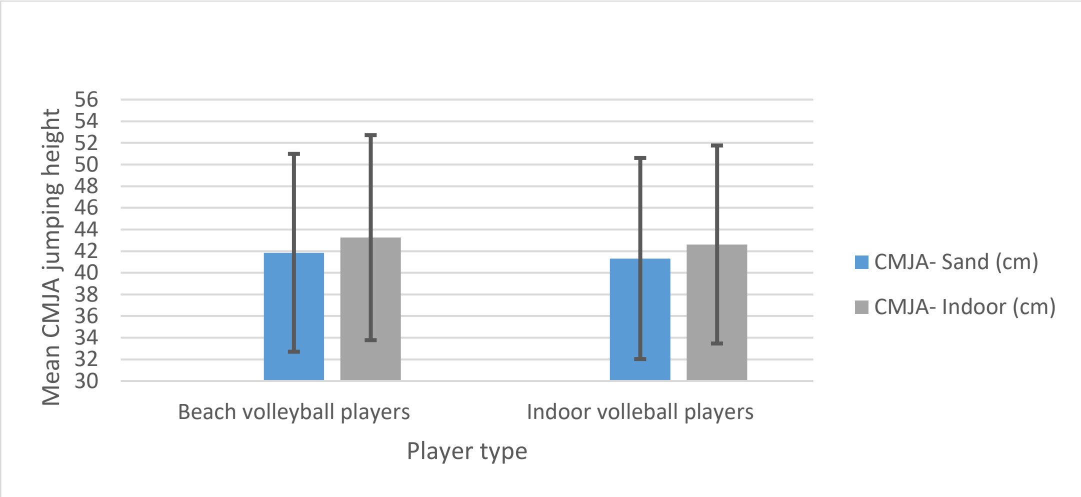



*Figure 4. Mean jumping height (measured using the countermovement jump with arm swing (CMJA)) on sand and indoor for BVB and IVB players*

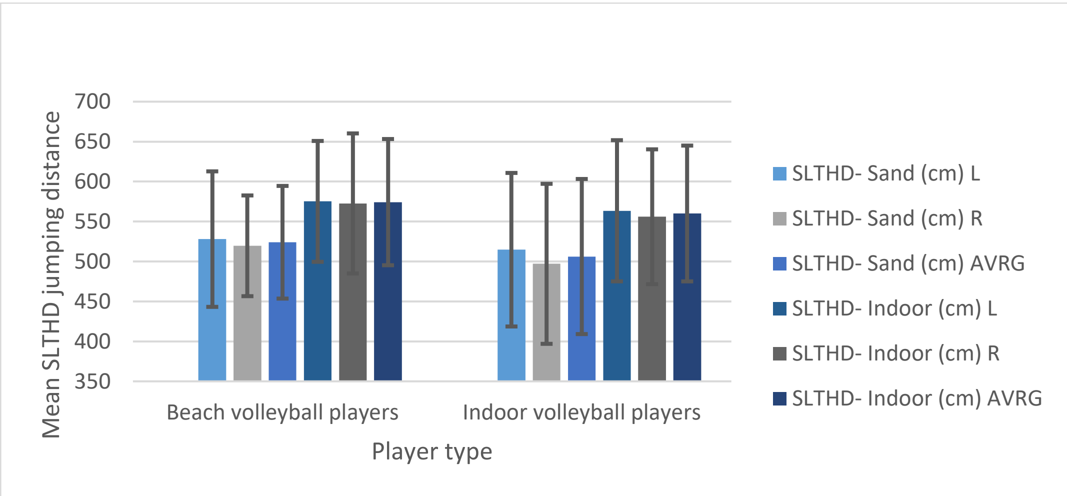



*Figure 5. Mean jumping distance (measured using the single-leg triple hop for distance (SLTHD) test) on sand and indoor for BVB and IVB players*

A between-groups comparison was done for each test and found that there were no significant main effects of group for CMJA height (p = .863), left SLTHD distance (p = .682), right SLTHD distance (p = .509), average SLTHD distance (p = .584) or MAT time (p = .621).

No surface-by-player group interactions emerged, indicating that the impact of the surface was not different between groups of players: All volleyball players ran faster, jumped higher and hopped further on the indoor floor than on the beach.

Between-group analysis using independent t-tests found that there were no significant differences on any of the agility and jumping tests. The BVB group consistently performed slightly better on the jumping tests. Notably, all volleyball players hopped further in the SLTHD test on their left leg compared to their right leg. The data from these tests are depicted in *Table 9*.

*Table 9. Descriptive statistics of agility and jumping capacity of participants in the IVB (n = 15) and BVB groups (n = 15). Data are expressed as mean ± standard deviation, with t-values, p-values and effect sizes reported.*

| Variable | IVB (n=15) | BVB (n=15) | t | p | Cohen's d |
|---|---|---|---|---|---|
| **Modified agility T-test (MAT)** | | | | | |
| **on sand (s)** | 7.1 ± 0.7 | 6.9 ± 0.7 | -0.82 | .42 | .29 |
| **on indoor (s)** | 6.9 ± 0.6 | 6.9 ± 0.6 | -0.07 | .95 | .00 |
| **Countermovement jump with arm swing (CMJA)** | | | | | |
| **on sand (cm)** | 41.3 ± 9.3 | 41.8 ± 9.1 | .16 | .88 | .05 |
| **on indoor (cm)** | 42.6 ± 9.1 | 43.2 ± 9.5 | .19 | .85 | .06 |
| **Single leg triple hop for distance (SLTHD)** | | | | | |
| **on sand (cm): L** | 514.7 ± 96.1 | 528.0 ± 84.8 | .40 | .69 | .15 |
| **on sand (cm): R** | 497.1 ± 100.1 | 519.6 ± 63.0 | .74 | .47 | .27 |
| **on sand (cm): AVRG** | 506.2 ± 97.1 | 524.1 ± 70.5 | .58 | .57 | .21 |
| **on indoor (cm): L** | 563.5 ± 88.3 | 575.2 ± 75.6 | .39 | .70 | .14 |
| **on indoor (cm): R** | 556.0 ± 84.4 | 572.7 ± 87.6 | .53 | .60 | .19 |
| **on indoor (cm): AVRG** | 560.1 ± 85.0 | 574.3 ± 79.0 | .47 | .64 | .17 |

Data published in the literature typically report means for males or females only. We therefore split our data for comparison to values in the literature. There were no significant differences between the male IVB and BVB groups (*Table 10*).

*Table 10. Descriptive statistics of agility and jumping capacity of participants in the male IVB (n = 10) and BVB groups (n = 10). Data are expressed as mean ± standard deviation, with t- and p-values reported.*

| Variable | Male IVB (n=10) | Male BVB (n=10) |
|---|---|---|
| **Modified agility T-test (MAT)** | | |
| **on sand (s)** | 6.8 ± 0.6 | 6.6 ± 0.6 |
| **on indoor (s)** | 6.5 ± 0.4 | 6.7 ± 0.5 |
| **Countermovement jump with arm swing (CMJA)** | | |
| **on sand (cm)** | 46.4 ± 6.5 | 46.9 ± 5.2 |
| **on indoor (cm)** | 47.9 ± 5.8 | 47.9 ± 7.9 |
| **Single leg triple hop for distance (SLTHD)** | | |

| | | |
|---|---|---|
| **on sand (cm): L** | 567.3 ± 37.5 | 560.6 ± 84.0 |
| **on sand (cm): R** | 555.1 ± 63.5 | 549.0 ± 51.1 |
| **on sand (cm): AVRG** | 561.5 ± 38.0 | 555.0 ± 63.5 |
| **on indoor (cm): L** | 614.2 ± 50.1 | 612.2 ± 57.2 |
| **on indoor (cm): R** | 607.0 ± 40.0 | 612.7 ± 73.2 |
| **on indoor (cm): AVRG** | 610.9 ± 43.2 | 612.8 ± 61.0 |

Due to the small sample size of female players (n = 5), no comparative statistics could be calculated for this subgroup.

*Table 11. Descriptive statistics of agility and jumping capacity of participants in the female IVB (n = 5) and BVB groups (n = 5). Data are expressed as mean ± standard deviation.*

| Variable | Female IVB (n=5) | Female BVB (n=5) |
|---|---|---|
| **Modified agility T-test (MAT)** | | |
| **on sand (s)** | 7.8 ± 0.5 | 7.5 ± 0.7 |
| **on indoor (s)** | 7.7 ± 0.1 | 7.4 ± 0.4 |
| **Countermovement jump with arm swing (CMJA)** | | |
| **on sand (cm)** | 31.2 ± 3.8 | 31.7 ± 6.2 |
| **on indoor (cm)** | 32.0 ± 1.7 | 34.0 ± 3.7 |
| **Single leg triple hop for distance (SLTHD)** | | |
| **on sand (cm): L** | 409.6 ± 91.8 | 462.8 ± 36.3 |
| **on sand (cm): R** | 381.0 ± 77.6 | 460.8 ± 39.5 |
| **on sand (cm): AVRG** | 395.6 ± 82.3 | 462.2 ± 34.0 |
| **on indoor (cm): L** | 462.0 ± 48.7 | 501.2 ± 48.9 |
| **on indoor (cm): R** | 454.0 ± 42.5 | 492.6 ± 52.8 |
| **on indoor (cm): AVRG** | 458.4 ± 41.2 | 497.2 ± 48.1 |

### 3.3.4 Correlational analyses

A Pearson's correlation coefficient was computed to assess the relationship between ankle dorsiflexion range of movement (results from the knee-to-wall test), single-leg balance (on foam and floor) and the dynamic balance results (from the Y-balance test) (*see* Table 12). A significant correlation was found between ankle dorsiflexion and anterior reach on the Y-balance test (r = .377, n = 30, p = <.05).

A Pearson's correlation coefficient was also used to assess the relationship between proprioception (results from the wedge test) and jumping height, hopping distance and agility on the sand and indoor surfaces. There was no statistically significant correlation between the variables, as can be seen in *Table 13*. There was however a strong negative correlation for agility and jumping height on an indoor surface (r = -.799, n = 30, p = <.001) and sand surface (r = -.637, n = 30, p = <.01) as well as agility and hopping distance on an indoor surface (r = -.827, n = 30, p = <.01) and sand surface (r = -.705, n = 30, p = <.01). These results indicate that players who performed faster on the agility test also jumped higher and hopped further (*see Table 13*).

There was a strong correlation found between jumping indoor and jumping on the sand between individual players ($R^2$ Linear = 0.912) (*Figure 6*).

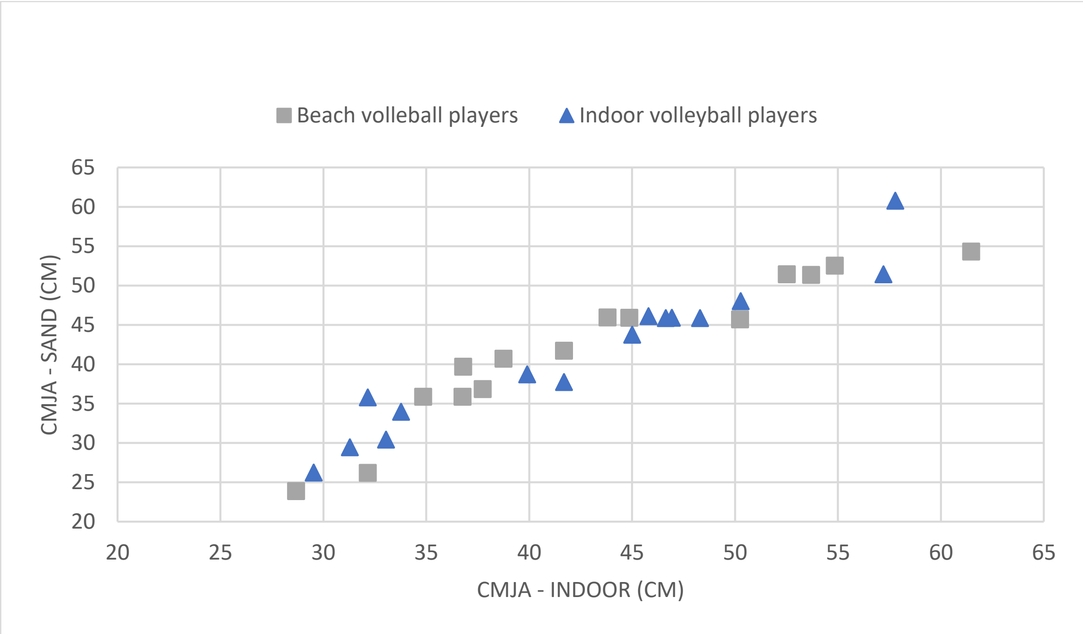



*Figure 6. Jumping heights on sand and indoor (measured using countermovement jump with arm swing (CMJA)) in beach and indoor volleyball players*

*Table 12. Correlations between dynamic balance (Y-balance test into anterior, posterior-medial and posterior-lateral reach direction and composite score), ankle dorsiflexion (knee-to-wall test) and single-leg balance (on foam and floor) and (N = 30)*

| | | Composite: Left | Composite: Right | Anterior: Left | Post-Med: Left | Post-Lat: Left | Anterior: Right | Post-Med: Right | Post-Lat: Right | Knee-to-wall: Left | Knee-to-wall: Right | SL balance: (floor) Left | SL balance: (floor) Right | SL balance: (foam) Left | SL balance: (foam) Right |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Composite: Left | Pearson Corr. | 1 | .939** | .604** | .859** | .853** | .383* | .763** | .717** | 0,050 | -0,039 | 0,132 | 0,076 | -0,038 | 0,250 |
| | Sig. (2-tailed) | | 0,000 | 0,000 | 0,000 | 0,000 | 0,037 | 0,000 | 0,000 | 0,794 | 0,840 | 0,488 | 0,690 | 0,841 | 0,183 |
| Composite: Right | Pearson Corr. | .939** | 1 | .528** | .795** | .843** | .391* | .836** | .836** | 0,007 | 0,038 | 0,289 | 0,176 | 0,063 | 0,337 |
| | Sig. (2-tailed) | 0,000 | | 0,003 | 0,000 | 0,000 | 0,033 | 0,000 | 0,000 | 0,972 | 0,841 | 0,121 | 0,353 | 0,740 | 0,069 |
| Anterior: Left | Pearson Corr. | .604** | .528** | 1 | .507** | .447* | .896** | .383* | .380* | 0,286 | 0,210 | 0,059 | 0,176 | 0,006 | 0,122 |
| | Sig. (2-tailed) | 0,000 | 0,003 | | 0,004 | 0,013 | 0,000 | 0,037 | 0,039 | 0,126 | 0,265 | 0,757 | 0,352 | 0,974 | 0,522 |
| Post-Med: Left | Pearson Corr. | .859** | .795** | .507** | 1 | .856** | 0,320 | .842** | .786** | 0,219 | 0,130 | 0,106 | 0,025 | 0,057 | .407* |
| | Sig. (2-tailed) | 0,000 | 0,000 | 0,004 | | 0,000 | 0,084 | 0,000 | 0,000 | 0,245 | 0,492 | 0,576 | 0,895 | 0,765 | 0,026 |
| Post-Lat: Left | Pearson Corr. | .853** | .843** | .447* | .856** | 1 | 0,333 | .887** | .841** | 0,076 | 0,027 | 0,185 | 0,079 | -0,069 | 0,236 |
| | Sig. (2-tailed) | 0,000 | 0,000 | 0,013 | 0,000 | | 0,072 | 0,000 | 0,000 | 0,690 | 0,886 | 0,326 | 0,678 | 0,718 | 0,210 |
| Anterior: Right | Pearson Corr. | .383* | .391* | .896** | 0,320 | 0,333 | 1 | 0,277 | 0,313 | 0,288 | .377* | 0,020 | 0,174 | -0,030 | 0,070 |
| | Sig. (2-tailed) | 0,037 | 0,033 | 0,000 | 0,084 | 0,072 | | 0,139 | 0,093 | 0,123 | 0,040 | 0,915 | 0,356 | 0,874 | 0,712 |
| Post-Med: Right | Pearson Corr. | .763** | .836** | .383* | .842** | .887** | 0,277 | 1 | .828** | 0,086 | 0,121 | 0,303 | 0,212 | 0,154 | .390* |
| | Sig. (2-tailed) | 0,000 | 0,000 | 0,037 | 0,000 | 0,000 | 0,139 | | 0,000 | 0,651 | 0,525 | 0,103 | 0,261 | 0,415 | 0,033 |
| Post-Lat: Right | Pearson Corr. | .717** | .836** | .380* | .786** | .841** | 0,313 | .828** | 1 | 0,123 | 0,163 | .386* | 0,164 | 0,122 | .442* |
| | Sig. (2-tailed) | 0,000 | 0,000 | 0,039 | 0,000 | 0,000 | 0,093 | 0,000 | | 0,517 | 0,390 | 0,035 | 0,386 | 0,519 | 0,014 |
| Knee-to-wall: Left | Pearson Corr. | 0,050 | 0,007 | 0,286 | 0,219 | 0,076 | 0,288 | 0,086 | 0,123 | 1 | .829** | 0,009 | -0,153 | 0,024 | 0,056 |
| | Sig. (2-tailed) | 0,794 | 0,972 | 0,126 | 0,245 | 0,690 | 0,123 | 0,651 | 0,517 | | 0,000 | 0,962 | 0,420 | 0,900 | 0,769 |
| Knee-to-wall: Right | Pearson Corr. | -0,039 | 0,038 | 0,210 | 0,130 | 0,027 | .377* | 0,121 | 0,163 | .829** | 1 | -0,012 | -0,107 | 0,059 | 0,173 |
| | Sig. (2-tailed) | 0,840 | 0,841 | 0,265 | 0,492 | 0,886 | 0,040 | 0,525 | 0,390 | 0,000 | | 0,949 | 0,574 | 0,758 | 0,360 |
| SL balance: (floor) Left | Pearson Corr. | 0,132 | 0,289 | 0,059 | 0,106 | 0,185 | 0,020 | 0,303 | .386* | 0,009 | -0,012 | 1 | .378* | .395* | 0,302 |
| | Sig. (2-tailed) | 0,488 | 0,121 | 0,757 | 0,576 | 0,326 | 0,915 | 0,103 | 0,035 | 0,962 | 0,949 | | 0,039 | 0,031 | 0,105 |
| SL balance: (floor) Right | Pearson Corr. | 0,076 | 0,176 | 0,176 | 0,025 | 0,079 | 0,174 | 0,212 | 0,164 | -0,153 | -0,107 | .378* | 1 | 0,221 | .461* |
| | Sig. (2-tailed) | 0,690 | 0,353 | 0,352 | 0,895 | 0,678 | 0,356 | 0,261 | 0,386 | 0,420 | 0,574 | 0,039 | | 0,240 | 0,010 |
| SL balance: (foam) Left | Pearson Corr. | -0,038 | 0,063 | 0,006 | 0,057 | -0,069 | -0,030 | 0,154 | 0,122 | 0,024 | 0,059 | .395* | 0,221 | 1 | .391* |
| | Sig. (2-tailed) | 0,841 | 0,740 | 0,974 | 0,765 | 0,718 | 0,874 | 0,415 | 0,519 | 0,900 | 0,758 | 0,031 | 0,240 | | 0,032 |
| SL balance: (foam) Right | Pearson Corr. | 0,250 | 0,337 | 0,122 | .407* | 0,236 | 0,070 | .390* | .442* | 0,056 | 0,173 | 0,302 | .461* | .391* | 1 |
| | Sig. (2-tailed) | 0,183 | 0,069 | 0,522 | 0,026 | 0,210 | 0,712 | 0,033 | 0,014 | 0,769 | 0,360 | 0,105 | 0,010 | 0,032 | |

*** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).*

*Table 13. Correlations between proprioception (wedge test and two-point discrimination test (TPD)) and jumping height (CMJA test), hopping distance (SLTHD test) and agility (MAT test) (N = 30)*

| | | **Wedges: Correct** | **TPD: Left** | **TPD: Right** | **MAT - Sand** | **MAT - Indoor** | **CMJA - Sand** | **CMJA - Indoor** | **SLTHD - Sand Left** | **SLTHD - Sand Right** | **SLTHD - Indoor Left** | **SLTHD - Indoor Right** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wedges: Correct** | Pearson Corr. | 1 | 0,221 | 0,285 | 0,193 | 0,082 | 0,007 | -0,078 | -0,136 | -0,133 | -0,030 | -0,011 |
| | Sig. (2-tailed) | | 0,240 | 0,126 | 0,306 | 0,667 | 0,969 | 0,681 | 0,473 | 0,482 | 0,876 | 0,953 |
| **TPD: Left** | Pearson Corr. | 0,221 | 1 | .791** | -0,209 | -0,191 | 0,352 | 0,303 | .436* | .373* | 0,321 | 0,222 |
| | Sig. (2-tailed) | 0,240 | | 0,000 | 0,267 | 0,311 | 0,057 | 0,103 | 0,016 | 0,043 | 0,084 | 0,239 |
| **TPD: Right** | Pearson Corr. | 0,285 | .791** | 1 | -0,201 | -0,160 | .506** | .444* | .491** | 0,318 | .381* | 0,207 |
| | Sig. (2-tailed) | 0,126 | 0,000 | | 0,286 | 0,397 | 0,004 | 0,014 | 0,006 | 0,087 | 0,038 | 0,273 |
| **MAT – Sand** | Pearson Corr. | 0,193 | -0,209 | -0,201 | 1 | .807** | -.637** | -.685** | -.705** | -.688** | -.692** | -.616** |
| | Sig. (2-tailed) | 0,306 | 0,267 | 0,286 | | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **MAT - Indoor** | Pearson Corr. | 0,082 | -0,191 | -0,160 | .807** | 1 | -.730** | -.799** | -.610** | -.743** | -.777** | -.827** |
| | Sig. (2-tailed) | 0,667 | 0,311 | 0,397 | 0,000 | | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **CMJA – Sand** | Pearson Corr. | 0,007 | 0,352 | .506** | -.637** | -.730** | 1 | .955** | .691** | .679** | .781** | .715** |
| | Sig. (2-tailed) | 0,969 | 0,057 | 0,004 | 0,000 | 0,000 | | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| **CMJA - Indoor** | Pearson Corr. | -0,078 | 0,303 | .444* | -.685** | -.799** | .955** | 1 | .682** | .693** | .808** | .749** |
| | Sig. (2-tailed) | 0,681 | 0,103 | 0,014 | 0,000 | 0,000 | 0,000 | | 0,000 | 0,000 | 0,000 | 0,000 |
| **SLTHD - Sand Left** | Pearson Corr. | -0,136 | .436* | .491** | -.705** | -.610** | .691** | .682** | 1 | .895** | .825** | .638** |
| | Sig. (2-tailed) | 0,473 | 0,016 | 0,006 | 0,000 | 0,000 | 0,000 | 0,000 | | 0,000 | 0,000 | 0,000 |
| **SLTHD - Sand Right** | Pearson Corr. | -0,133 | .373* | 0,318 | -.688** | -.743** | .679** | .693** | .895** | 1 | .830** | .793** |
| | Sig. (2-tailed) | 0,482 | 0,043 | 0,087 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | | 0,000 | 0,000 |
| **SLTHD - Indoor Left** | Pearson Corr. | -0,030 | 0,321 | .381* | -.692** | -.777** | .781** | .808** | .825** | .830** | 1 | .901** |
| | Sig. (2-tailed) | 0,876 | 0,084 | 0,038 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | | 0,000 |
| **SLTHD - Indoor Right** | Pearson Corr. | -0,011 | 0,222 | 0,207 | -.616** | -.827** | .715** | .749** | .638** | .793** | .901** | 1 |
| | Sig. (2-tailed) | 0,953 | 0,239 | 0,273 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | |

*** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).*

## 3.4 Discussion

Our aim of this exploratory study was to compare functional lower limb range, balance, proprioception and strength, agility and jumping capacity between non-professional BVB and IVB players. The study found no significant differences in most of the measures tested. The hypothesis was that BVB players would have improved physical capacity due to habitually training on a more challenging surface. Our results found that although the BVB players did consistently perform better on the tests, these differences were not significant (Section 3.3.2. *Table 8* and *Table 10*), except for the anterior reach on the Y-balance test (for left and right leg).

### 3.4.1 Demographics and anthropometrics

This exploratory study had a sample size of 15 BVB and 15 IVB players. Other studies investigating the effects of training on different surfaces on performance had total sample sizes varying between 11 and 45 participants (Arazi et al., 2014; Balasas et al., 2018; Giatsis et al., 2018; Gortsila, 2013; Mirzaei et al., 2013). No studies could be found specifically comparing BVB and IVB players. The descriptive characteristics of the participants in this study showed that the two groups were similar in height, mass, BMI, leg length and waist circumference (Section 3.3.2, *Table 3*). These anthropometric measures are comparable with measures documented in the literature for IVB and BVB players (Balasas et al., 2013; Bishop, 2003; Giatsis et al., 2018; Kulling et al., 2014; Palao et al., 2014; Vaverka et al., 2016). Age was the only significant difference in demographics between the IVB (27.9 ± 5.4) and BVB (37.4 ± 6.6) groups ($p = <.001$). Published literature confirms the trend that BVB players are older than IVB players, but the mean BVB player age reported (30.3 ± 5.3) is still lower than our sample (Palao, Gutierrez, & Frideres, 2008; Palao et al., 2014). The mean age for IVB players (22.1 ± 3.6) was however also reportedly lower than our sample (Migliorini et al., 2019) by a similar margin.

### 3.4.2 Questionnaires: Training and Injury History & OSTRC

Both player groups consisted of healthy participants, who had similar training histories (Section 3.3.3, page Table 434). Our sample performed notably fewer weekly hours of volleyball training (4.6 ± 2.1) compared to training loads published for volleyball players in the literature (8 - 18.5 hours per week) (Balasas et al., 2013; Kulling et al., 2014). This could have had a significant impact on the outcomes of the functional measures tested in this study. The results of the Training and Injury History, and OSTRC questionnaires indicate that the participants in the BVB group had been playing for slightly more years (16.7 ± 8.5) than the IVB group (12.1 ± 4.9) by a mean of 4.6 years ($p = .08$). This can be attributed to the fact that our BVB group was significantly older than the IVB group. The IVB group performed a significantly higher percentage of strength training in relation to volleyball training (37.7 ± 22.3) compared to the BVB group (21.3 ± 18.8) (p = .04). While the importance of integrating strength training for volleyball players is emphasised in the literature, no specific dosages or recommendations regarding the frequency and duration of such training in relation to volleyball training could be found (Lehnert et al., 2017). This discrepancy in strength training may also be attributed to the fact that data collection was done during the COVID pandemic, where IVB players had only started training again two months prior to data collection and had supplemented their exercise programme with more strength training.

While the pattern of injuries indicated in our sample is comparable to that found in the literature, it should be noted that due to the demands of the study, there was an element of selection bias and the actual injury prevalence in the volleyball population is likely to be higher, as many injured players would not have been recruited to partake in this physically demanding study. Authors reported knee injuries to be most prevalent in beach and indoor volleyball players (Jimenez-Olmedo & Penichet-Tomás, 2015; Migliorini et al., 2019). In our study, the BVB sample reported knee and shoulder overuse injuries most frequently, while IVB players had a higher prevalence of lower back pain (Section 3.3.1 Table 5. Descriptive statistics of the level of play of the sample (n = 30), IVB (n = 15) and BVB groups (n = 15). Data are expressed as the frequency of the level reported.*Table 5* and *Table 6)*. It should also be taken into consideration, when comparing outcomes of the physical tests to reported norms (Section 3.4.3 and 3.4.4), that most studies exclude participants with any current overuse injuries. Not excluding these participants would potentially have negatively affected the outcomes achieved in our study.

### 3.4.3 Physical measures: Two-point discrimination, proprioception, balance, ROM, strength

This study was based on the idea that better proprioception leads to improved balance and performance (Clark et al., 2015). The rationale for hypothesising that BVB players would have better proprioception than IVB players is that they habitually train on the sand, an unstable surface, thereby challenging their proprioception. The wedge test showed a ceiling effect, with 47% of participants scoring 21 or 22 correct wedges (correct wedges: BVB 20.8 ± 1.1; IVB 20.0 ± 1.3; p = .07 & penalty score: BVB 1.6 ± 1.7; IVB 2.7 ± 2.1; p = .11). As mentioned above, two-point discrimination (TPD) is also considered an outcome measure indicating proprioception (Duysens et al., 2000; Franco et al., 2012). Our study did not find any significant differences in TPD measures between groups or any correlation between results of the wedge test and TPD measures. However, TPD was significantly correlated to jumping capacity (Section 3.3.4 *Table 13*). Again, while any cause for such correlation is speculative, the fact that BVB players train barefoot may improve their TPD (as is seen for sensitivity to vibration (Schlee et al., 2007)) which may, in turn, contribute to functional outcomes.

An independent-samples t-test found that the BVB players had a significantly larger anterior reach for left (68.6 ± 10.3) and right (64.6 ± 9.5) legs in the Y-balance test compared to IVB players (left: 57.1 ± 7.6; right: 57.5 ± 7.0) ($p = .002$; $p = .027$). The ability to maintain balance on one leg while reaching the other leg in another direction, is considered by some authors to also be a measure of proprioception (Plisky et al., 2009). Due to the design of this study, no concrete mechanisms for this difference may be drawn. It is however hypothesised that as BVB players train barefoot and as such may develop larger dorsiflexion ROM and improved proprioception and can therefor achieve a larger lower limb reaching capacity measured by the Y-balance test. Studies investigating shod versus barefoot runners have found that training without shoes on, causes athletes to utilise a larger dorsiflexion ROM (LeBlanc & Ferkranus, 2018), which would, in turn, allow for a greater anterior reach on the Y-balance test. While no significant difference between the groups was found in our study, the BVB players had a mean dorsiflexion ROM 7mm greater than the IVB players (Section 3.3.2 *Table 8*: Knee-to-wall test).

When comparing the composite scores achieved by our sample on the Y-balance test (81.9 ± 11.1; 81.6 ± 9.5 for left and right legs respectively) to norms in the literature, our sample achieved less than the recommended 94% composite score, thought to reduce the risk of injury (Hudson, Garrison, & Pollard, 2016). Again, this is likely related to the recreational level of players recruited in this study.

It was further believed that BVB players would do better on the strength tests. This improved performance on strength tests has been said to be an adaptation to training on the sand, which requires for force production (Mirzaei et al., 2013). BVB players challenge their neuromusculoskeletal system more by jumping on a sand surface, where much more energy is absorbed by the ground, thus making it harder to jump (Kibele et al., 2014). The results of the single-leg bridge hold test (AVRG BVB: 137.8 ± 53.5; IVB: 117.1 ± 32.9; $p = .21$) and calf raise test (AVRG BVB: 24.1 ± 6.9; IVB: 22.3 ± 7.1; $p = .49$) found that again, while BVB players performed better than IVB players, this was not a statistically significant difference. The IVB players were however found to be performing more strength training at the time of their testing. This could have improved their results and thus reduce the difference evident between the two groups (Section 3.3.1 *Table 4*).

### 3.4.4 Jumping capacity and agility

The results of the agility and jumping tests showed no significant differences between the two groups, though the BVB group marginally outperformed the IVB group on all measures (Section 3.3.2 *Table 9*). This is despite the fact that IVB players were recorded to be doing a higher percentage of strength training, which is known to positively influence jumping capacity (Zech et al., 2010).

The repeated-measures analyses showed that surface type had a significant effect on jumping height ($p = .013$) and jumping distance ($p = <.001$) but not on agility ($p = .176$). Specifically, our results suggest that when volleyball players jump on the sand, they jump significantly lower than on an indoor court (Section 3.3.2 *Figure 5*). This finding has also been published by Giatsis et al. (2018), who investigated CMJA heights on rigid and sand surfaces and found that BVB players adopted similar patterns on both surfaces, but that the softer sand surface absorbed energy more than a rigid surface resulting in a lower jump height. A possible reason for the agility measure to not also be consistently faster on the hard surface is that participants reported more apprehension with sudden stops and direction changes required by the modified agility T-test (MAT) on an indoor surface versus on sand, where they could dig their foot into the sand when changing direction. This may have levelled out the advantage of running on a hard surface, as only a small percentage of the test was running forwards with cutting movements taking more time. The times recorded by males for the MAT on the indoor surface (6.5-6.7s) were only marginally slower than reported in the literature (6.25-6.28s). Similarly, our female participants (7.4-7.7s) scored in line with reported times (7.26-7.29s) (Sassi et al., 2009). No data could be found for the MAT used on the sand.

When comparing our results of the CMJA to published literature, we split our sample by sex, so as to only compare male jumping height to articles published. Vaverka et al. (2016) found that elite male IVB players in the Czech Republic had a CMJA height of 52.2 ± 8.8 cm. Our male IVB players had a CMJA height of 47.9 ± 5.8 cm. It must be noted again that our group had varying levels of play and were classified as currently non-professional players. Ruffieux, Walchli, Kim, and Taube (2020) conducted a study on non-professional female IVB players using a jump-training intervention. The authors recorded CMJA heights of 32.7 ± 4.7 cm and 37.8 ± 4.1 cm (pre- and post-training respectively). The pre-training CMJA measures are comparable to our female IVB group (32.0 ± 1.7 cm).

Between-group comparison found that IVB and BVB players were not different in agility ($p = .176$), jumping height ($p = .863$) or hopping distance ($p = .584$) on either surface. This suggests that a biomechanical effect, rather than training specificity or a training effect, plays a larger role in determining functional outcome measures in volleyball players (Schubert et al., 2008).

Overall, our study found BVB players to have better functional outcomes, though largely not significant. When considering a correlation between proprioception and functional measures, we only found a correlation between TPD and jumping capacity. This may have been due to our chosen proprioception test (wedge test) not being sensitive enough in this study population (well-conditioned players), resulting in a ceiling effect. This test was chosen due to its reproducibility in clinical practice, however further studies may need to investigate how to make the test more effective in detecting minor variations in proprioception.

### 3.4.5 Limitations of the study

Disadvantages from our cross-sectional study design were that no causations could be inferred from a study that was not longitudinal. Thus, while causal mechanisms for the differences between groups (or lack thereof) found in this study may be theorised, further research is needed to confirm these ideas.

This study was the first to investigate differences in functional capacity between IVB and BVB players, making the design of the study relatively novel. It was an exploratory study with a sample size of 15 BVB and 15 IVB players. When conducting power calculations post hoc, this only provided a statistical power of 45%. While trends and tendencies could be noted between groups, these were not of a significant difference. Based on the effect size of 0.66 for the wedge test, each group needed 26 participants to reach a power of 95%. By recruiting a larger sample size, trends observed between groups that were not significant in this study may be picked up more sensitively. However, differences between groups requiring a very large sample size may not have clinical relevance. Although every effort was made to recruit from a large pool of players, our study relied on volunteers. Consequently, our sample may not have been a true representative of the actual population of volleyball players in the Western Cape. When discussing injury prevalence seen in our sample, this data has limited generalisability and may similarly not be representative of the volleyball population due to the fact that most players with injuries would not continue to play and as such would have been excluded from this study.

As discussed, although our groups were not significantly different on most demographic measures, there was still a large variability in the level of these non-professional players, making them a non-homogeneous group. Furthermore, players with current overuse injuries, which did not stop them from training, were not excluded from our study. These factors may have contributed to the variance in results obtained. By investigating a group with a more similar level of play, excluding players with any current areas of pain and limiting the group to only one sex, data collected would be more comparable in terms of functional performance.

As with any observational study, participants may have varied their normal action due to performing experimental tasks under experimental conditions. While every effort was made to motivate participants equally, this may have been perceived differently by different athletes. A potential confounding factor was, was the actual time of data collection in relation to the volleyball season. This could not be controlled for, and may have influenced the amount of training currently being performed by the players. The majority of the BVB players were tested at the end of their playing season, and, due to the COVID pandemic, the majority of the IVB players were tested in their off-season.

Lastly, while players were allocated to groups based on their volleyball training history, there was no control of any other training performed by the groups. This means that the IVB group may have performed other proprioception exercises (e.g. Bosu ball at the gym), which may have confounded the results.

### 3.4.6 Recommendations for future research

The data gathered in this study may provide the basis for future randomised control trials to investigate causality between proprioceptive training and functional performance and/or injury prevention. A recommended approach would be to test two groups (IVB and BVB players) at baseline for injury prevalence and functional capacity, as was done in this study, but then follow the groups throughout a season, performing the same tests during and after the season to monitor for any changes and relate these to any injuries suffered. Alternatively, future studies could use an intervention, based on proprioceptive and plyometric training, to ascertain the effects of this on jumping capacity in IVB and BVB players. It is therefore hoped that this study could provide a base for further investigation into the benefits of training on different surfaces for volleyball players.

# CHAPTER FOUR: SUMMARY AND CONCLUSION

In beach and indoor volleyball, jumping capacity and agility are two of the most important components needed to excel as a player (Sheppard et al., 2008). Methods of improving these skills are constantly being challenged and updated (Giatsis et al., 2018). Intervention programs tested in randomised control trials using sand training, have shown to improve cardiovascular fitness (Balasas et al., 2013), lower limb strength (Balasas et al., 2018), jumping height (Impellizzeri et al., 2008) and agility (Gortsila, 2013).

While proprioceptive training is thought to reduce the risk of injury and improve performance (Nagai et al., 2018; Ribeiro et al., 2008; Roijezon et al., 2015), there is no consensus as to which proprioception exercise best achieves these goals (Clark et al., 2015). There is currently no known research demonstrating the use of sand training to improve proprioception. Furthermore, whether proprioception is linked to performance such as jumping capacity and agility has yet to be investigated.

Our overall aim, therefore, was to compare proprioception, functional lower limb capacity, agility and jumping capacity on two different surfaces, between non-professional BVB and IVB players. Based on the evidence provided in this thesis, the study objectives as described in Section 1.2.2 (page 2) may be answered as follows:

1 *To compare lower limb functional capabilities of BVB and IVB players (measured using a two-point discrimination test, modified balance error scoring system (mBESS), modified star excursion balance test (mSEBT), knee-to-wall test, single leg hamstring bridge test (SLHBT) and eccentric-concentric calf raise test respectively).*
2 *To assess differences in jumping capacity (measured using countermovement jump with arm swing (CMJA), single-leg triple hop for distance (SLTHD)) and agility (measured using modified agility T-test (MAT)) on two surfaces, indoor and sand, between BVB and IVB players.*

Our study found that BVB players did not perform significantly better on the tests for functional lower limb capacity than IVB players. A small sample size, non-homogenous group and high variability in results, could account for this finding. The exceptions were the anterior reach on the Y-balance test (for left and right legs), where BVB players had a significantly greater reach distance than IVB players. It is hypothesised that this may be due to the increased court movement and flexibility required from BVB players, due to the smaller number of players on the court (two versus six on an indoor court). The results of the agility and jumping tests also showed no significant differences between the two groups, though the BVB group marginally outperformed the IVB group on all measures (Section 3.3.2 *Table 9*).

3 *To assess the relationship between measures of functional capacity, proprioception, jumping capacity and agility and in both groups*.

A significant main effect was found for surface within-groups for jumping capacity. This was expected, as it has been well-researched that jumping on sand absorbs more of the energy produced by the lower limbs, resulting in a lower or shorter jump.

No significant main effects were found for CMJA height, SLTHD distance or MAT time between groups. While the BVB group consistently performed slightly better on the jumping tests than the IVB players, no surface by player group interactions emerged, indicating that the impact of the surface was not different between groups of players: All volleyball players ran faster, jumped higher and hopped further on the indoor floor than on the sand. This suggests that a biomechanical effect had an influence on performance measures, rather than task-specific training or pure force production.

4 *To outline the prevalence of injuries in the two groups (BVB and IVB) using retrospective analysis from data obtained by means of the Training and Injury History questionnaire and the OSTRC (Oslo Sports Trauma Research Centre) questionnaire.*

The pattern of injuries noted in the sample in this study is comparable to that noted in the literature: Authors reported knee injuries to be most prevalent in beach and indoor volleyball players (Jimenez-Olmedo & Penichet-Tomás, 2015; Migliorini et al., 2019). In our study, the BVB sample reported knee and shoulder injuries most frequently, while IVB players had a higher prevalence of lower back pain (Section 3.3.1 Table 5 and Table 6).

In conclusion, the aim of this exploratory study was to compare functional lower limb range, balance, proprioception and strength, agility and jumping capacity between non-professional BVB and IVB players. The study found no significant differences in most of the measures tested. The hypothesis was that BVB players would have improved physical capacity due to habitually training on a more challenging surface. Our results found that although the BVB players did consistently perform better on the tests, these differences were not significant (Section 3.3.2. *Table 8* and *Table 10*) except for the anterior reach on the Y-balance test (for left and right legs).

# CHAPTER FIVE: REFERENCES


Alvim, F. C., Lucareli, P. R. G., & Menegaldo, L. L. (2018). Predicting muscle forces during the propulsion phase of single leg triple hop test. *Gait and Posture, 59*, 298-303. doi:10.1016/j.gaitpost.2017.07.038

Aman, J. E., Elangovan, N., Yeh, I. L., & Konczak, J. (2014). The effectiveness of proprioceptive training for improving motor function: a systematic review. *Frontiers in Human Neuroscience, 8*, 1075. doi:10.3389/fnhum.2014.01075

Arazi, H., Mohammadi, M., & Asadi, A. (2014). Muscular adaptations to depth jump plyometric training: Comparison of sand vs. land surface. *Interventional Medicine and Applied Science, 6*(3), 125-130. doi:10.1556/IMAS.6.2014.3.5

Ashton-Miller, J. A., Wojtys, E. M., Huston, L. J., & Fry-Welch, D. (2001). Can proprioception really be improved by exercises? *Knee Surgery, Sports Traumatology, Arthroscopy, 9*(3), 128-136. doi:10.1007/s001670100208

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine, 39*(6), 324-329. doi:10.1136/bjsm.2005.018341

Bahr, R., & Reeser, J. C. (2003). Injuries among World-Class Professional Beach Volleyball Players: The Fédération Internationale de Volleyball Beach Volleyball Injury Study. *The American Journal of Sports Medicine, 31*(1), 119-125. doi:10.1177/03635465030310010401

Balasas, D., Christoulas, K., Stefanidis, P., Vamvakoudis, E., & Bampouras, T. (2018). The effect of beach volleyball training on muscle performance of indoor volleyball players. *Journal of Sports Medicine and Physical Fi ness, 58*, 1240-1246.

Balasas, D., Van Makoudis, E., Christoula, K., Stefanidis, P., & Evangelia, P. (2013). The effect of beach volleyball training on running economy and VO2max of indoor volleyball players. *Journal of Physical Education and Sport, 13*, 33-38. doi:10.7752/jpes.2013.01006

Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research, 21*, 1192–1196.

Behm, D. G., & Colado, J. C. (2012). The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *The International Journal of Sports Physical Therapy, 7*, 226-241.

Bell, D. R., Guskiewicz, K. M., Clark, M. A., & Padua, D. A. (2011). Systematic review of the balance error scoring system. *Sports Health, 3*(3), 287-295. doi:10.1177/1941738111403122

Binnie, M. J., Dawson, B., Arnot, M. A., Pinnington, H., Landers, G., & Peeling, P. (2014). Effect of sand versus grass training surfaces during an 8-week pre-season conditioning programme in team sport athletes. *Journal of Sports Sciences, 32*(11), 1001-1012. doi:10.1080/02640414.2013.879333

Binnie, M. J., Dawson, B., Pinnington, H., Landers, G., & Peeling, P. (2014). Sand training: a review of current research and practical applications. *Journal of Sports Sciences, 32*, 8-16. doi:10.1080/02640414.2013.805239

Bishop, D. (2003). A comparison between land and sand-based tests for beach volleyball assessment. *Journal of Sports Medicine and Physical Fitness, 43*, 418-423.

Boccolini, G., Brazzit, A., Bonfanti, L., & Alberti, G. (2013). Using balance training to improve the performance of youth basketball players. *Sport Sciences for Health, 9*(2), 37-42. doi:10.1007/s11332-013-0143-z

Brooks, E., Benson, A., & Bruce, L. (2018). NOVEL TECHNOLOGIES FOUND TO BE VALID AND RELIABLE FOR THE MEASUREMENT OF VERTICAL JUMP HEIGHT WITH JUMP-AND-REACH TESTING. *Journal of Strength and Conditioning Research, 32*.

Brown, H., Dawson, B., Binnie, M. J., Pinnington, H., Sim, M., Clemons, T. D., & Peeling, P. (2017). Sand training: Exercise-induced muscle damage and inflammatory responses to matched-intensity exercise. *European Journal of Sport Science, 17*(6), 741-747. doi:10.1080/17461391.2017.1304998

Butowicz, C. M., Ebaugh, D., Noehren, B., & Silfi, S. P. (2016). Validation of two clinical measures of core stablity. *The International Journal of Sports Physical Therapy, 11*, 15-23.

Butowicz, C. M., Pontillo, M., Ebaugh, D., & Silfies, S. P. (2019). Comprehensive movement system screening tool (MSST) for athletes: Development and measurement properties. *Brazilian Journal of Physical Therapy*. doi:10.1016/j.bjpt.2019.10.002

Cashin, A. G., & McAuley, J. H. (2017). Measuring two-point discrimination threshold with a caliper. *Journal of Physiotherapy, 63*(3), 186. doi:10.1016/j.jphys.2017.04.005

Clark, N., Roijezon, U., & Treleaven, J. (2015). Proprioception in musculoskeletal rehabilitation. Part 2: Clinical assessment and intervention. *Manual Therapy, 20*(3), 378-387. doi:10.1016/j.math.2015.01.009

Clarsen, B., Myklebust, G., & Bahr, R. (2013). Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *British Journal of Sports Medicine, 47*(8), 495-502. doi:10.1136/bjsports-2012-091524

Collins, D. F., Refshauge, K. M., Todd, G., & Gandevia, S. C. (2005). Cutaneous Receptors Contribute to Kinesthesia at the Index Finger, Elbow, and Knee. *Journal of Neurophysiology, 94*, 1699-1706.

Coswig, V., Silva, A., Barbalho, M., Faria, F. R., Nogueira, C. D., Borges, M., . . . Gorla, J. I. (2019). Assessing the Validity of the MyJump2 App for Measuring Different Jumps in Professional Cerebral Palsy Football Players: An Experimental Study. *JMIR Mhealth Uhealth, 7*(1), e11099. doi:10.2196/11099

Coughlan, G. F., Delahunt, E., O'Sullivan, E., Fullam, K., Green, B. S., & Caulfield, B. M. (2014). Star Excursion Balance Test performance and application in elite junior rugby union players. *Physical Therapy in Sport 15*(4), 249-253. doi:10.1016/j.ptsp.2013.11.005

Cressey, E., West, C., Tibero, D., Kraemer, W., & Mares, C. (2007). The effects of ten weeks of lower-body unstable surface training on markers of atheletic performance. *Journal of Strength and Conditioning Research, 21*, 561-567.

Davies, S. E. H. (2002). Strength and power characteristics of elite South African beach volleyball players. *S.A. Journal for Research in Sport, Physical Education and Recreation, 24*(1), 29-40.

Dennis, R. J., Finch, C. F., Elliott, B. C., & Farhart, P. J. (2008). The reliability of musculoskeletal screening tests used in cricket. *Physical Therapy in Sport 9*(1), 25-33. doi:10.1016/j.ptsp.2007.09.004

Donatelli, R., Dimond, D., & Holland, M. (2012). Sport-specific biomechanics of spinal injuries in the athlete (throwing athletes, rotational sports, and contact-collision sports). *Clinics in Sports Medicine, 31*(3), 381-396. doi:10.1016/j.csm.2012.03.003

Driller, M., Tavares, F., McMaster, D., & O'Donnell, S. (2017). Assessing a smartphone application to measure counter-movement jumps in recreational athletes. *International Journal of Sports Science & Coaching, 12*(5), 661-664. doi:10.1177/1747954117727846

Duysens, J., Clarac, F., & Cruse, H. (2000). Load-Regulating Mechanisms in Gait and Posture: Comparative Aspects. *Physiological Reviews, 80*, 83-133.

Evarts, E. V. (1981). Sherrington's concept of proprioception. *Trends in Neurosciences, 4*, 44-46. doi:10.1016/0166-2236(81)90016-3

Finch, C. F., & Cook, J. (2014). Categorising sports injuries in epidemiological studies: the subsequent injury categorisation (SIC) model to address multiple, recurrent and exacerbation of injuries. *British Journal of Sports Medicine, 48*(17), 1276-1280. doi:10.1136/bjsports-2012-091729

Finley, J., Dhaher, Y., & Perreault, E. (2012). Contributions of feed-forward and feedback strategies at the human ankle during control of unstable loads. *Experimental Brain Research, 217*, 53-66. doi:10.1007/s00221-011-2972-9

Franco, P. G., Bohrer, R. C. D., & Rodacki, A. L. F. (2012). Intra-observer reproducibility of the feet soles two-point discrimination test in asymptomatic elderly and young individuals. *Revista Brasileira de Fisioterapia, 16*.

Gabbe, B., Finch, C., Bennell, K., & Wajswelner, H. (2003). How valid is a self reported 12 month sports injury history? *British Journal of Sports Medicine, 37*, 545-547.

Gallardo-Fuentes, F., GALLARDO-FUENTES, J., RAMI´REZ-CAMPILLO, R., BALSALOBRE-FERNANDEZ, C., MARTINEZ, C., CANIUQUEO, A., . . . IZQUIERDO, M. (2015). INTERSESSION AND INTRASESSION RELIABILITY AND VALIDITY OF THE MY JUMP APP FOR MEASURING DIFFERENT JUMP ACTIONS IN TRAINED MALE AND FEMALE ATHLETES. *Journal of Strength and Conditioning Research, 30*.

Gandevia, S. C., Smith, J. L., Crawford, M., Proske, U., & Taylor, J. L. (2006). Motor commands contribute to human position sense. *The Journal of Physiology, 571*(3), 703-710. doi:10.1113/jphysiol.2005.103093

Garbenytė-Apolinskienė, T., Šiupšinskas, L., Salatkaitė, S., Gudas, R., & Radvila, R. (2018). The effect of integrated training program on functional movements patterns, dynamic stability, biomechanics, and muscle strength of lower limbs in elite young basketball players. *Sport Sciences for Health, 14*(2), 245-250. doi:10.1007/s11332-017-0409-y

Giatsis, G., Panoutsakopoulos, V., & Kollias, I. A. (2018). Biomechanical differences of arm swing countermovement jumps on sand and rigid surface performed by elite beach volleyball players. *Journal of Sports Sciences, 36*(9), 997-1008. doi:10.1080/02640414.2017.1348614

Göktepe, M., Çakır, E., Göktepe, M. M., & Şenel, Ö. (2019). Effect of Maximal Anaerobic Loading on Lower Extremity Proprioceptive Sense in Soccer Players. *Journal of Education and Training Studies, 7*(2). doi:10.11114/jets.v7i2.3768

Gortsila, E. (2013). Effect of Training Surface on Agility and Passing Skills of Prepubescent Female Volleyball Players. *Journal of Sports Medicine & Doping Studies, 03*(02). doi:10.4172/2161-0673.1000128

Gottlieb, G., & Agarwal, G. (1973). Modulation of postural reflexes by voluntary movement. *Journal of Neurology, Neurosurgery and Psychiatry, 36*, 540-546.

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *Journal of athletic training, 47*(3), 339. doi:10.4085/1062-6050-47.3.08

Gruber, M., Gruber, S., Beck, S., & Gollhofer, A. (2007). Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *Journal of Strength and Conditioning Research, 21*, 274–282.

H Meeuwisse, W., Tyreman, H., Hagel, B., & Emery, C. (2007). *A Dynamic Model of Etiology in Sport Injury: The Recursive Nature of Risk and Causation* (Vol. 17).

Hamilton, R. T., Shultz, S. J., Schmitz, R. J., & Perrin, D. H. J. J. o. a. t. (2008). Triple-hop distance as a valid predictor of lower limb strength and power. *43*(2), 144-151.

Han, J., Waddington, G., Adams, R., & Anson, J. (2013). Ability to discriminate movements at multiple joints around the body: global or site-specific. *Perceptual and Motor Skills, 116*(1), 59-68. doi:10.2466/24.10.23.PMS.116.1.59-68

Han, J., Waddington, G., Adams, R., Anson, J., & Liu, Y. (2016). Assessing proprioception: A critical review of methods. *J Sport Health Sci, 5*(1), 80-90. doi:10.1016/j.jshs.2014.10.004

Han, J., Waddington, G., Anson, J., & Adams, R. (2015). Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability. *Journal of Science and Medicine in Sport, 18*(1), 77-81. doi:10.1016/j.jsams.2013.11.013

Hebert-Losier, K., Wessman, C., Alricsson, M., & Svantesson, U. (2017). Updated reliability and normative values for the standing heel-rise test in healthy adults. *Physiotherapy, 103*(4), 446-452. doi:10.1016/j.physio.2017.03.002

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A., & Bemben, M. G. (2018). Countermovement jump reliability performed with and without an arm swing in NCSS devision 1 intercollegiate basketball players. *Journal of Strength and Conditioning Research, 34*, 546-558.

Hillier, S., Immink, M., & Thewlis, D. (2015). Assessing Proprioception: A Systematic Review of Possibilities. *Neurorehabilitation and Neural Repair, 29*(10), 933-949. doi:10.1177/1545968315573055

Hoch, M. C., Staton, G. S., & McKeon, P. O. (2011). Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport, 14*(1), 90-92. doi:10.1016/j.jsams.2010.08.001

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Medicine, 41*, 221-232.

Hubscher, M., Zech, A., Pfeifer, K., Hansel, F., Vogt, L., & Banzer, W. (2010). Neuromuscular training for sports injury prevention: a systematic review. *Medicine and Science in Sports and Exercise, 42*(3), 413-421. doi:10.1249/MSS.0b013e3181b88d37

Hudson, C., Garrison, J. C., & Pollard, K. (2016). Y-balance normative data for female collegiate volleyball players. *Physical Therapy in Sport 22*, 61-65. doi:10.1016/j.ptsp.2016.05.009

Hunt, T. N., Ferrara, M. S., Bornstein, R. A., & Baumgartner, T. A. (2009). The Reliability of the Modified Balance Error Scoring System. *Clinical Journal of Sport Medicine, 19*.

Iglesias-Caamaño, M., Carballo-López, J., Álvarez-Yates, T., Cuba-Dorado, A., & García-García, O. (2018). Intrasession Reliability of the Tests to Determine Lateral Asymmetry and Performance in Volleyball Players. *Symmetry, 10*(9). doi:10.3390/sym10090416

Impellizzeri, F. M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S., & Wisloff, U. (2008). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine, 42*(1), 42-46. doi:10.1136/bjsm.2007.038497

Ituen, O. A., Smits-Engelsman, B., Ferguson, G., & Duysens, J. (2020). Judging heel height: A new test for proprioception while standing reveals that young hypermobile children perform better than controls. *Gait and Posture, 75*, 8-13. doi:10.1016/j.gaitpost.2019.09.012

JAMA. (2013). *World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects*. Fortaleza, Brazil: JAMA

James, L. P., Kelly, V. G., & Beckman, E. M. (2014). Injury risk management plan for volleyball athletes. *Sports Medicine, 44*(9), 1185-1195. doi:10.1007/s40279-014-0203-9

Jimenez-Olmedo, J. M., & Penichet-Tomás, A. (2015). Injuries and pathologies in beach volleyball players: A systematic review. *Journal of Human Sport and Exercise, 10*(4). doi:10.14198/jhse.2015.104.09

Kibele, A., Classen, C., Muehlbauer, T., Granacher, U., & Behm, D. G. (2014). Metastability in plyometric training on unstable surfaces: a pilot study. *BMC Sports Science, Medicine, and Rehabilitation, 6*.

Kilic, O., Maas, M., Verhagen, E., Zwerver, J., & Gouttebarge, V. (2017). Incidence, aetiology and prevention of musculoskeletal injuries in volleyball: A systematic review of the literature. *Eur J Sport Sci, 17*(6), 765-793. doi:10.1080/17461391.2017.1306114

Konor, M. M., Morton, S., Eckerson, J. M., & Grindstaff, T. L. (2012). RELIABILITY OF THREE MEASURES OF ANKLE DORSIFLEXION RANGE OF MOTION. *The International Journal of Sports Physical Therapy, 7*.

Krakauer, J. W., Hadjiosif, A. M., Xu, J., Wong, A. L., & Haith, A. M. (2019). Motor Learning. *Comprehensive Physiology, 9*(2), 613-663. doi:10.1002/cphy.c170043

Kulling, F. A., Florianz, H., Reepschlager, B., Gasser, J., Jost, B., & Lajtai, G. (2014). High Prevalence of Disc Degeneration and Spondylolysis in the Lumbar Spine of Professional Beach Volleyball Players. *Orthop J Sports Med, 2*(4), 2325967114528862. doi:10.1177/2325967114528862

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology, 4*, 863. doi:10.3389/fpsyg.2013.00863

LeBlanc, M., & Ferkranus, H. (2018). Lower Extremity Joint Kinematics of Shod, Barefoot, and Simulated Barefoot Treadmill Running. *International Journal of Exercise Science, 11*, 717-729.

Lehnert, M., Sigmund, M., Lipinska, P., Varekova, R., Hroch, M., Xaverova, Z., . . . Zmijewski, P. (2017). Training-induced changes in physical performance can be achieved without body mass reduction after eight week of strength and injury prevention oriented programme in volleyball female players. *Biology of Sport, 34*(2), 205-213. doi:10.5114/biolsport.2017.65995

Lorentzen, J., Willerslev-Olsen, M., Huche Larsen, H., Svane, C., Forman, C., Frisk, R., . . . Nielsen, J. B. (2018). Feedforward neural control of toe walking in humans. *Journal of Physiology, 596*(11), 2159-2172. doi:10.1113/JP275539

Loudon, J. K., Reiman, M. P., & Sylvain, J. (2014). The efficacy of manual joint mobilisation/manipulation in treatment of lateral ankle sprains: a systematic review. *British Journal of Sports Medicine, 48*(5), 365-370. doi:10.1136/bjsports-2013-092763

Macrum, E., Bell, D. R., Boling, M., Lewek, M., & Padua, D. (2012). Effect of Limiting Ankle-Dorsiflexion Range of Motion on Lower Extremity Kinematics and Muscle-Activation Patterns during a Squat. *Journal of Sport Rehabilitation, 21*(2), 144-150. doi:10.1123/jsr.21.2.144

Magal, M., & Riebe, D. (2016). New Preparticipation Health Screening Recommendations: What Exercise Professionals Need to Know. *ACSM's Health & Fitness Journal, 20*.

Magalhães, J., Inácio, M., Oliveira, E., Ribeiro, J. C., & Ascensão, A. (2011). Physiological and neuromuscular impact of beach-volleyball with reference to fatigue and recovery. *The Journal of sports medicine and physical fitness, 51*(1), 66-73.

Malliaras, P., Cook, J. L., & Kent, P. (2006). Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. *Journal of Science and Medicine in Sport, 9*(4), 304-309. doi:10.1016/j.jsams.2006.03.015

Markovic, G., & Mikulic, P. (2010). Neuro-Musculoskeletal and Performance Adaptations to Lower-Extremity Plyometric Training. *Sports Medicine, 40*, 859-895.

Marquez, G., Aguado, X., Alegre, L. M., & Fernandez-Del-Olmo, M. (2013). Neuromechanical adaptation induced by jumping on an elastic surface. *Journal of Electromyography and Kinesiology, 23*(1), 62-69. doi:10.1016/j.jelekin.2012.06.012

Medeiros, A. I. A., Palao, J. M., Marcelino, R., & Mesquita, I. (2014). Revisão sistemática sobre a performance desportiva no voleibol de praia a partir da análise do jogo. *Revista Brasileira de Cineantropometria e Desempenho Humano, 16*(6). doi:10.5007/1980-0037.2014v16n6p698

Migliorini, F., Rath, B., Tingart, M., Niewiera, M., Colarossi, G., Baroncini, A., & Eschweiler, J. (2019). Injuries among volleyball players: a comprehensive survey of the literature. *Sport Sciences for Health, 15*(2), 281-293. doi:10.1007/s11332-019-00549-x

Mirzaei, B., Norasteh, A. A., & Asadi, A. (2013). Neuromuscular adaptations to plyometric training: depth jump vs. countermovement jump on sand. *Sport Sciences for Health, 9*, 145-149. doi:10.1007/s11332-013-0161-x

Moritz, C. T., & Farley, C. T. (2004). Passive dynamics change leg mechanics for an unexpected surface during human hopping. *Journal of Applied Physiology, 97*, 1313-1322.

Mornieux, G., Gehring, D., Tokuno, C., Gollhofer, A., & Taube, W. (2014). Changes in leg kinematics in response to unpredictability in lateral jump execution. *European Journal of Sport Science, 14*(7), 678-685. doi:10.1080/17461391.2014.894577

Mouthon, A., & Taube, W. (2019). Intracortical Inhibition Increases during Postural Task Execution in Response to Balance Training. *Neuroscience, 401*, 35-42. doi:10.1016/j.neuroscience.2019.01.007

Munro, A. G., & Herrington, L. C. (2011). Bewteen-session reliability of four op tests and the agility T-test. *The Journal of Strength and Conditioning Research, 25*.

Murphy, D., Connolly, D., & Beynnon, B. (2003). Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine, 37*.

Nagai, T., Schilaty, N. D., Strauss, J. D., Crowley, E. M., & Hewett, T. E. (2018). Analysis of Lower Extremity Proprioception for Anterior Cruciate Ligament Injury Prevention: Current Opinion. *Sports Medicine, 48*(6), 1303-1309. doi:10.1007/s40279-018-0889-1

Negra, Y., Chaabene, H., Sammoud, S., Bouguezzi, R., Mkaouer, B., Hachana, Y., & Granacher, U. (2017). Effects Of Plyometric Training On Components Of Physical Fitness In Prepuberal Male Soccer Athletes: The Role Of Surface Instability. *Journal of Strength and Conditioning Research, 31*, 3295–3304.

Oliveira, W. K., Jesus, K. d., Andrade, A. D., Nakamura, F. Y., Assumpção, C. O., & Medeiros, A. I. (2018). Monitoring training load in beach volleyball players: a case study with an Olympic team. *Motriz: Revista de Educação Física, 24*(1). doi:10.1590/s1980-6574201800010004

Ozinga, S. J., Alberts, J. L., Linder, S., Koop, M. M., Dey, T., Figler, R., . . . Cruickshank, J. (2018). Normative Performance on the Balance Error Scoring System by Youth, High School, and Collegiate Athletes. *Journal of athletic training, 53*.

Palao, J. M., Gutierrez, D., & Frideres, J. E. (2008). Height, weight, Body Mass Index, and age in beach volleyball players in relation to level and position. *Journal of Sports Medicine and Physical Fitness, 48*, 466-471.

Palao, J. M., Valadés, D., Manzanares, P., & Ortega, E. (2014). Physical actions and work-rest time in men's beach volleyball. *Motriz: Revista de Educação Física, 20*(3), 257-261. doi:10.1590/s1980-65742014000300003

Pinnington, H., & Dawson, B. (2001). The Energy Cost of Running on Grass Compared to Soft Dry Beach Sand. *Journal of Science and Medicine in Sport, 4*(416-430).

Pinnington, H., Lloyd, D., Besier, T., & Dawson, B. (2005). Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. *European Journal of Applied Physiology, 94*(3), 242-253. doi:10.1007/s00421-005-1323-6

Plisky, P. J., Gorman, P., Butler, R., Kiesel, K., Underwood, F. B., & Elkins, B. (2009). The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. *North American Journal of Sports Physical Therapy, 4*.

Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic and Sports Physical Therapy, 36*(12), 911-919. doi:10.2519/jospt.2006.2244

Powden, C. J., Hoch, J. M., & Hoch, M. C. (2015). Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. *Manual Therapy, 20*(4), 524-532. doi:10.1016/j.math.2015.01.004

Prilutsyky, B. I., & Zatsiosky, V. M. (1994). Tendon action of two-joint muscles: Transfer of mechanical energy between joints during jumping, landing, and running. *Journal of Biomechanics, 27*, 25-34.

Proske, U., & Gandevia, S. C. (2012). The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiological Reviews, 92*(4), 1651-1697. doi:10.1152/physrev.00048.2011

Rago, V., Brito, J., Figueiredo, P., Carvalho, T., Fernandes, T., Fonseca, P., & Rebelo, A. (2018). Countermovement Jump Analysis Using Different Portable Devices: Implications for Field Testing. *Sports (Basel), 6*(3). doi:10.3390/sports6030091

Rawlinson, A. J. (2016). *A cross sectional study to determine whether there are central changes in rugby players who have sustained recurrant ankle inuries.* (Degree of Master of Philosophy in Exercise and Sports Physiotherapy), University of Cape Town,

Reeser, J. C., Joy, E. A., Porucznik, C. A., Berg, R. L., Colliver, E. B., & Willick, S. E. (2010). Risk factors for volleyball-related shoulder pain and dysfunction. *PM R, 2*(1), 27-36. doi:10.1016/j.pmrj.2009.11.010

Reeser, J. C., Verhagen, E., Briner, W. W., Askeland, T. I., & Bahr, R. (2006). Strategies for the prevention of volleyball related injuries. *British Journal of Sports Medicine, 40*(7), 594-600; discussion 599-600. doi:10.1136/bjsm.2005.018234

Ribeiro, F., Santos, F., Gonçalves, P., & Oliveira, J. (2008). Effects of volleyball match-induced fatigue on knee joint position sense. *European Journal of Sport Science, 8*(6), 397-402. doi:10.1080/02614360802373060

Roijezon, U., Clark, N. C., & Treleaven, J. (2015). Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. *Manual Therapy, 20*(3), 368-377. doi:10.1016/j.math.2015.01.008

Ruffieux, J., Walchli, M., Kim, K. M., & Taube, W. (2020). Countermovement Jump Training Is More Effective Than Drop Jump Training in Enhancing Jump Height in Non-professional Female Volleyball Players. *Frontiers in Physiology, 11*, 231. doi:10.3389/fphys.2020.00231

Salgado, E., Ribeiro, F., & Oliveira, J. (2015). Joint-position sense is altered by football pre-participation warm-up exercise and match induced fatigue. *Knee, 22*(3), 243-248. doi:10.1016/j.knee.2014.10.002

Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N., Mahfoudhi, M. E., & Gharbi, Z. (2009). Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. *Journal of Strength and Conditioning Research, 23*(6), 1644-1651. doi:10.1519/JSC.0b013e3181b425d2

Schlee, G., Sterzing, T., & Milani, T. L. (2007). *Influence Of Footwear On Foot Sensitivity: A Comparison Between Barefoot And Shod Sports*. Paper presented at the Next Level Concepts, Beijing.

Schubert, M., Beck, S., Taube, W., Amtage, F., Faist, M., & Gruber, M. (2008). Balance training and ballistic strength training are associated with task-specific corticospinal adaptations. *European Journal of Neuroscience, 27*(8), 2007-2018. doi:10.1111/j.1460-9568.2008.06186.x

Seminati, E., & Minetti, A. E. (2013). Overuse in volleyball training/practice: A review on shoulder and spine-related injuries. *Eur J Sport Sci, 13*(6), 732-743. doi:10.1080/17461391.2013.773090

Shadmehr, R., Smith, M. A., & Krakauer, J. W. (2010). Error correction, sensory prediction, and adaptation in motor control. *Annual Review of Neuroscience, 33*, 89-108. doi:10.1146/annurev-neuro-060909-153135

Sheppard, J. M., Cronin, J., Gabbett, T. J., McGuigan, M., Extebarria, N., & Newton, R. (2008). Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *Journal of Strength and Conditioning Research, 22*, 758-765.

Sheppard, J. M., Gabbett, T. J., & Riggs, M. P. (2013). Indoor and Beach Volleyball Players. In *Physiological Tests for Elite Athletes* (pp. 475-486).

Son, C., Stewart, A., Ward, J., & Farrar, K. (2018). Lower Body Strength-Training Versus Proprioceptive Exercises on Vertical Jump Capacity: A Feasibility Study. *Journal of Chiropractic Medicine, 17*(1), 7-15. doi:10.1016/j.jcm.2017.10.007

Stillman, B. C. (2002). Making Sense of Proprioception. *Physiotherapy, 88*(11), 667-676. doi:10.1016/s0031-9406(05)60109-5

Stillman, B. C., & McMeeken, J. M. (2001). The role of weightbearing in the clinical assessment of knee joint position sense. *Australian Journal of Physiotherapy, 47*(4), 247-253. doi:10.1016/s0004-9514(14)60272-5

Taube, W., Gollhofer, A., & Lauber, B. (2020). Training-, muscle- and task-specific up- and downregulation of cortical inhibitory processes. *European Journal of Neuroscience, 51*(6), 1428-1440. doi:10.1111/ejn.14538

Taube, W., Gruber, M., & Gollhofer, A. (2008). Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiologica, 193*(2), 101-116. doi:10.1111/j.1748-1716.2008.01850.x

Tramel, W., Lockie, R. G., Lindsay, K. G., & Dawes, J. J. (2019). Associations between Absolute and Relative Lower Body Strength to Measures of Power and Change of Direction Speed in Division II Female Volleyball Players. *Sports, 7*(7). doi:10.3390/sports7070160

Valagussa, G., Meroni, R., Cantarelli, F., Molteni, L., Galbiati, L., & Cerri, C. (2016). Two point discrimination in lower limbs in healthy people: Average values and influence of gender, dominance, height and BMI. *Manual Therapy, 25*. doi:10.1016/j.math.2016.05.164

van der Krogt, M. M., de Graaf, W. W., Farley, C. T., Moritz, C. T., Casius, L. J. R., & Bobbert, M. F. (2009). Robust passive dynamics of the musculoskeletal system compensate for unexpected

surface changes during human hopping. *Journal of Applied Physiology, 107*(3), 801-808. doi:10.1152/japplphysiol.91189.2008
van Lieshout, R., Reijneveld, E. A. E., van den Berg, S. M., Haerkens, G. M., Koenders, N. H., de Leeuw, A. J., . . . Stukstette, M. J. (2016). Reproducibility of the modified Star Excursion Balance Test composite and specific reach direction scores. *The International Journal of Sports Physical Therapy, 21*, 356-365.
Vaverka, F., Jandacka, D., Zahradnik, D., Uchytil, J., Farana, R., Supej, M., & Vodicar, J. (2016). Effect of an Arm Swing on Countermovement Vertical Jump Performance in Elite Volleyball Players. *Journal of Human Kinetics, 53*, 41-50. doi:10.1515/hukin-2016-0009
Verhagen, E., van der Beek, A., Twisk, J., Bouter, L., Bahr, R., & van Mechelen, W. (2004). The Effect of a Proprioceptive Balance Board Training Program for the Prevention of Ankle Sprains. *The American Journal of Sports Medicine, 32*.
Viseux, F., Lemaire, A., Barbier, F., Charpentier, P., Leteneur, S., & Villeneuve, P. (2019). How can the stimulation of plantar cutaneous receptors improve postural control? Review and clinical commentary. *Clinical Neurophysiology, 49*(3), 263-268. doi:10.1016/j.neucli.2018.12.006
Williams III, D. S. B., Murray, N. G., & Powell, D. W. (2016). Athletes who train on unstable compared to stable surfaces exhibit unique postural control strategies in response to balance perturbations. *Journal of Sport and Health Science, 5*(1), 70-76. doi:10.1016/j.jshs.2016.01.010
Williams, M., Dott, A., & Dawes, J. (2017). The Single Leg Triple Hop for Distance Test. *National Strength and Conditioning Association, 39*.
Yang, N., Waddington, G., Adams, R., & Han, J. (2019). Age-related changes in proprioception of the ankle complex across the lifespan. *Journal of Sport and Health Science, 8*(6), 548-554. doi:10.1016/j.jshs.2019.06.003
Yingling, V. R., Castro, D. A., Duong, J. T., Malpartida, F. J., Usher, J. R., & O, J. (2018). The reliability of vertical jump tests between the Vertec and My Jump phone application. *PeerJ, 6*, e4669. doi:10.7717/peerj.4669
Zech, A., Hubscher, M., Vogt, L., Banzer, W., Hansel, F., & Pfeifer, K. (2010). Balance Training for Neuromuscular Control and Performance Enhancement: A Systematic Review. *Journal of athletic training, 45*, 392–403.
Zemkova, E., & Hamar, D. (2018). Sport-Specific Assessment of the Effectiveness of Neuromuscular Training in Young Athletes. *Frontiers in Physiology, 9*, 264. doi:10.3389/fphys.2018.00264

APPENDIX A: Recruitment flyer

Dear volleyball player

I am a Sports & Exercise Physiotherapy Masters student researching differences between indoor and beach volleyball players. I would like to measure balance, strength, agility and jumping height on a sand and indoor court and compare the results between the two types of players. The study has been approved by the UCT Human Research Ethics Committee (HREC REF: 697/2019).

If interested, you will be required to attend a session at UCT Lower Campus Beach volleyball court, Woolsack road, Mowbray. The session will be broken down into two parts.

- Part 1: Completing 3 questionnaires about your training and injury history.
- Part 2: Measuring body weight, height and waist circumference and testing your balance, strength, agility and jumping height

The session will take approximately 90 minutes. None of these tests are invasive or harmful. All information obtained from you will be kept strictly confidential, and your name will not be associated with the information that appears in the research. You will be required to be videotaped for some of the tests for analysis of your movement.

Anyone interested in participating should:

- Be over the age of 18 years old
- Play either indoor or beach volleyball for more than 12 months
- Not have had previous surgery after which you have not been cleared by your doctor to return to full sport participation
- Take part in physical activity for 30 minutes at least 3 times a week
- Not have any injury or condition in the past 6 weeks that caused you to stop playing volleyball

The benefits of taking part in the study include having a free functional physical assessment done by a qualified physiotherapist. You will be reimbursed for your travel costs to attend the testing session (R3.25/km).

Please note that your participation in this study is completely voluntary. Should you wish to withdraw from the study you may do so at any point without any consequences.

If you are interested in participating in this study, and for additional information, please contact me via cell: 082 348 3526 or e-mail: chrissyvh@live.co.za

Many thanks
Chrissy Glossop-von Hirschfeld (Researcher)
Cell: 082 348 3526
E-mail: chrissyvh@live.co.za

## APPENDIX B: Exercise Pre-participation Health Screening questionnaire for exercise professionals

Assess your client health needs by marking all true statements.

**Step 1**

**SYMPTOMS**
**Does your client experience:**
_ chest discomfort with exertion
_ unreasonable breathlessness
_ dizziness, fainting, blackouts
_ ankle swelling
_ unpleasant awareness of a forceful, rapid or irregular heartbeat
_ burning or cramping sensation in your lower legs when walking short distance

If you **did** mark any of the statements under the symptoms, **STOP**, your client should seek medical clearance before engaging in or resuming exercise. Your client may need to a use a facility with **medically qualified staff.**

If you **did not** mark any symptoms, continue to steps 2 and 3.

**Step 2**

**CURRENT ACTIVITY**
Does your client currently perform planned, structured physical activity at least 30 min at moderate intensity on at least 3 days per week for at least the last 3 months?

☐ Yes ☐ No

Continue to Step 3

**Step 3**

**MEDICAL CONDITIONS**
Has your client had or do they currently have:
_ a heart attack
_ heart surgery, cardiac catheterisation, or coronary angioplasty
_ pacemaker/implantable cardiac defibrillator/rhythm disturbance
_ heart valve disease
_ heart failure
_ heart transplantation
_ congenital heart disease
_ diabetes
_ renal disease

Evaluating Step 2 and 3:

- If you **did not mark any of the statements in Step 3**, medical clearance is not necessary.
- If you marked Step 2 “**yes**” and **marked any of the statements in Step 3**, your client may continue to exercise at light to moderate intensity without medical clearance. Medical clearance recommended before engaging in vigorous exercise.
- If you marked Step 2 “**no**” and **marked any of the statements in Step 3**, medical clearance is recommended. Your client may need to a use a facility with **medically qualified staff.**

(Magal & Riebe, 2016)

APPENDIX C: Informed consent

Department of Health and Rehabilitation Sciences
Faculty of Health Sciences
Divisions of Communications Sciences and Disorders, Nursing and Midwifery, Occupational Therapy, Physiotherapy
F45 Old Main Building, Groote Schuur Hospital,
Observatory 7925
Tel: +27 (0) 21 406 6401 Fax: +27 (0) 21 406 6323
Internet: www.uct.ac.za

**Proprioception, agility and jumping capacity in beach versus indoor volleyball players**

Dear participant,

I am Chrissy Glossop-von Hirschfeld and I am completing my MSc in Exercise and Sport Physiotherapy at the University of Cape Town. I am doing a study to compare the differences in balance, agility and jumping height in beach and indoor volleyball players. This research study has been given ethics approval by the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC REF: 697/2019).

Why is this study being done?
There is very little research on training load and injury in volleyball in South Africa. Internationally, the injury rate in beach volleyball players is lower than in indoor players. A big factor that can lead to injury is not having good balance and strength. Because beach volleyball players train on sand, this might train their balance and leg strength better than indoor players.

The information from this study will be used to complete a mini-dissertation as part of the Masters in Sports & Exercise Physiotherapy degree from the University of Cape Town.

What is being done?
The study will look at your individual training and injury history and use physical tests (e.g. balance and jumping) to measure your strength, balance, agility and flexibility. We will use this information to compare the results of these tests between indoor and beach volleyball players.

What is required of you?
If you decide to take part in this study, you will be asked to offer 90 minutes of your time to attend a session at the UCT Lower Campus Beach volleyball court, Woolsack Road, Mowbray.

Here you will be asked to read this letter carefully, ask any questions you may have and sign the informed consent section below if you still wish to take part in the study.

The physical testing session will be done in two parts:

Part 1:

- Filling out three questionnaires: To check that you are medically fit to take part in the study and get information on your volleyball training and any injuries you have had.

Part 2:

- Height, weight and waist measurements: A scale will be used to measure your body weight. A tape measure will be used to measure height and waist circumference.

- Sensation testing: You will be asked to lie on a physiotherapy plinth on your stomach with your eyes closed. A calliper will be used to touch the sole of your foot. You will be asked to say “one” if it feels like one point or “two” if it feels like two points. This will be done on both feet.

- Proprioception: You will be asked to stand with each foot on a plastic wedge with different heights. Without looking down, you must decide which wedge is higher (left or right).

- Static balance: You will be asked to balance on a foam block with your hands on your hips and eyes closed. Each foot will be tested three times.

- Dynamic balance:  You will be asked to stand on one foot, while reaching the other foot forwards and backwards as far as possible without losing your balance. Each leg will be tested three times.

- Knee-to-wall test: You will be asked to lunge forwards facing a wall, getting your knee to touch the wall without lifting your heel. The distance between your toe and the wall will be measured. Each foot is tested three times.

- Single leg hamstring bridge test: You will be asked to lie on your back with your knees bent, lift your hips and straighten one leg and hold this position as long as you can. Each leg will be tested twice.

- Calf raise test: You will be asked to stand on the edge of a step on one leg. You are then asked to lift you heel as high as possible, then slowly lower your heel all the way down. This will be done in time with a metronome as many times as you can. Each leg will be tested once.

- Triple single leg hop for distance test: You will be asked hop forwards three times on one leg as far as you can. Each leg is tested three times on the beach court and three times on the indoor court.

- Modified agility T-test: You will be asked to run forwards, shuffle sideways and backwards in a T-shape around cones as fast as you can. The test is done once on the beach court and once on the indoor court.

- Vertical jump test: You will be asked to jump as high as you can while being videoed by the researcher. This test will be done three times on the beach court and three times on the indoor court.

None of these tests are invasive or harmful.

What are the risks and discomforts of this study?
There may be minimal discomfort from the physical tests, similar to what you may feel during a volleyball training session. It is possible that you may feel delayed onset muscle soreness (DOMS) in your legs, particularly your calves, in the two days following testing. If you suffer any injury during the testing, you will be referred to the proper health care professional immediately.

What happens if I injure myself during the research?
UCT offers a no-fault insurance that covers all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury in accordance with the Association of the British Pharmaceutical Industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected.

Are there any benefits to you for being in the study?
The benefits of taking part in the study include having a free physical assessment done by a qualified physiotherapist. You will receive an e-mail of all the results of your testing in an information pack at the end of the study. This information may highlight areas that you can work on to improve your volleyball game.

What other choices do you have?
Participation in this study is completely voluntary. You may choose not to take part in this study, and this decision will not affect you in any way. If you decide to take part, you are free to change your mind and stop at any time without any penalty.
Please note that you will not be paid for your participation in this study. However you will be reimbursed for your travel costs to attend the testing session (R3.25/km).

Confidentiality
All information obtained will be kept strictly confidential and your name will not be linked with the information that appears in the research. Any reports or publications about the study will not identify you or any other study participant.

Will the results of the research be shared with you?
The final results of this study may only be available in a year and a half (beginning 2021) and can be sent to you if requested. Feedback on the results of the study will be sent to the coaches and clubs in the form of overall statistics for your interest.

Questions?
If you have any concerns or questions, please feel free to contact me or one of my supervisors:

| | | |
|---|---|---|
| Supervisor: | Prof Bouwien Smits-Engelsman | bouwienengelsman@icloud.com |
| Co-supervisor: | Dr Gillian Ferguson | gillian.ferguson@uct.ac.za |
| Researcher: | Christine Glossop-von Hirschfeld<br>082 348 3526 | chrissyvh@live.co.za |

If you have any ethical questions or concerns about your rights as a research participant, please contact The Faculty of Health Sciences Human Research Ethics Committee on 021 406 6338.

I understand that a study titled "*Proprioception, agility and jumping capacity in beach versus indoor volleyball players*" will be conducted by Chrissy Glossop-von Hirschfeld through the University of Cape Town. I understand that my participation will advance the medical and scientific knowledge related to volleyball in South Africa.

I have read the above and am satisfied with my understanding of the study, its possible benefits, risks and alternatives. My questions about the study have been answered. I hereby voluntarily consent to participate in the research study as described. I understand that I may freely withdraw from this study at any point without further question. I have been offered copies of this consent form.

____________________________________________________________
Signature of participant Date

____________________________________________________________
Name of participant (printed) Signature of researcher

Kind Regards
Chrissy Glossop-von Hirschfeld

APPENDIX D.1: Training and Injury History questionnaire: Beach volleyball player

<table>
<tr><td colspan="4">Part A: Basic Details</td></tr>
<tr><td>Participant number</td><td colspan="3"></td></tr>
<tr><td>Name</td><td colspan="3"></td></tr>
<tr><td>E-mail address</td><td colspan="3"></td></tr>
<tr><td>DOB</td><td colspan="3">yyyy-mm-dd</td></tr>
<tr><td>Height</td><td colspan="3">cm</td></tr>
<tr><td>Weight</td><td colspan="3">kg</td></tr>
<tr><td>Dominant hand</td><td colspan="2">Left</td><td>Right</td></tr>
<tr><td>Position</td><td>Blocker</td><td>Defender - Back court</td><td>Universal - no specialisation</td></tr>
</table>

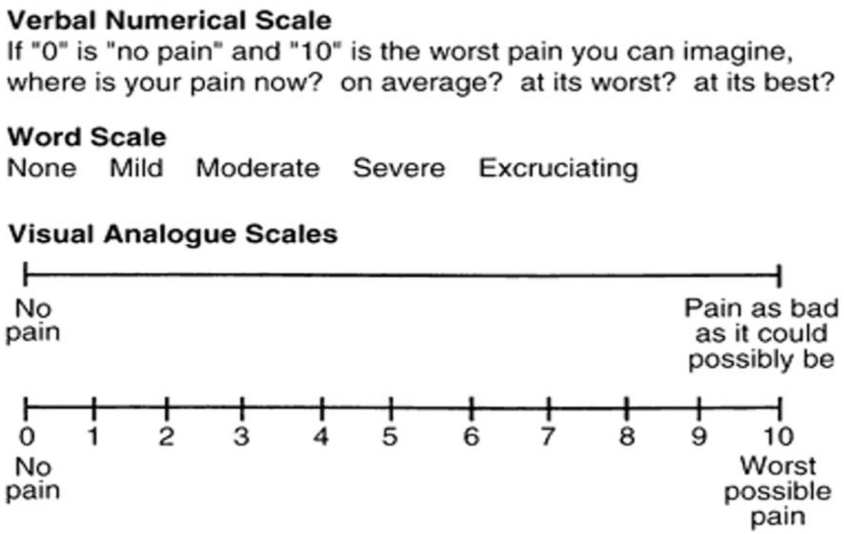
<table>
<tr><td colspan="7">Part B: Volleyball Training History</td></tr>
<tr><td>How many years have you played beach volleyball for?</td><td colspan="6"></td></tr>
<tr><td>What is the highest level of BVB you have achieved?</td><td>Social/Recreational</td><td colspan="2">Provincial</td><td colspan="2">National</td><td>International</td></tr>
<tr><td>On average, how many days a week do you train beach volleyball?</td><td colspan="6">days/week</td></tr>
<tr><td>On average, how many hours a week do you train beach volleyball?</td><td colspan="6">hours/week</td></tr>
<tr><td>Do you do any other training besides beach volleyball?</td><td colspan="3">Yes</td><td colspan="3">No</td></tr>
<tr><td rowspan="2">If yes, please indicate what types of training you perform and the percentage of training.</td><td>Beach volleyball training on the beach</td><td>%</td><td>Strength training</td><td>%</td><td>Endurance training (eg. running, cycling)</td><td>%</td></tr>
<tr><td>Flexibility / agility training</td><td>%</td><td>Other training ____________</td><td>%</td><td colspan="2"></td></tr>
<tr><td>Do you currently or have you ever played indoor volleyball?</td><td colspan="2">Yes, currently</td><td colspan="2">Yes, used to</td><td colspan="2">No, never</td></tr>
</table>

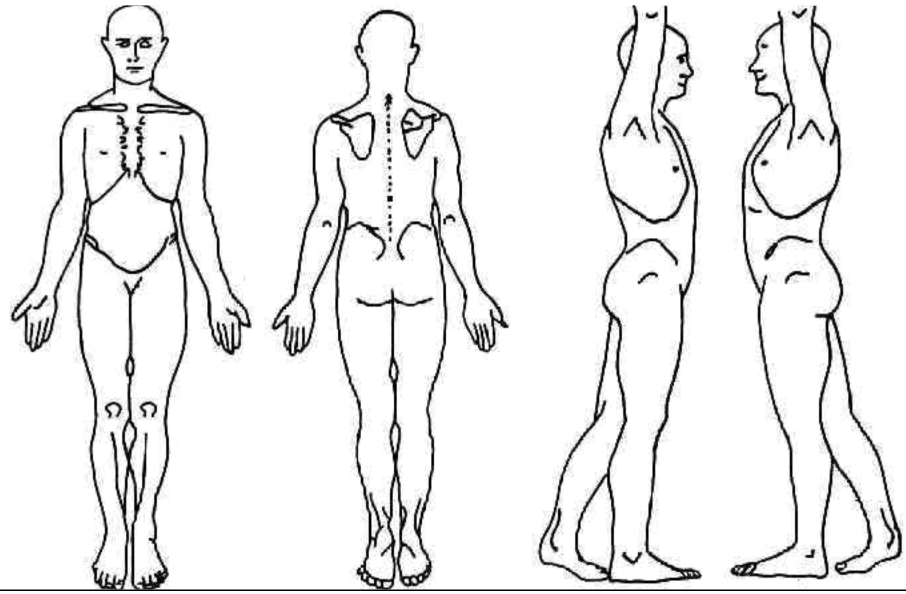
| | |
|---|---|
| If yes, on average how many days a week do/did you play indoor volleyball? | days/week |
| If yes, on average how hours a week do/did you play indoor volleyball? | hours/week |

| Section D: Injury History | | | |
|---|---|---|---|
| Have you sustained any injury over previous 12 months? | Yes:<br>If Yes, How many? : ____________ | No | |
| Areas affected: (If more than one injury per area, indicate how many with a number) | Head | Elbow | Hamstring |
| | Neck | Forearm | Quadriceps |
| | Face | Wrist | Knee |
| | Front chest | Finger | Shin |
| | Back chest | Lower back | Achilles |
| | Shoulder | Hip | Ankle |
| | Upper arm | Thigh | Foot |
| | Other Specify: ________________________ | | |
| Structures injured? | Muscle | Ligament | Joint |
| | Tendon | Bone | Other Specify:______________ |
| Areas affected by Re-injury: | | | |
| Please indicate how your injury was treated to date? (you can tick more than one) | Rest | Tablets | Cortisone injection |
| | Stretches | Strengthening exercises | Equipment change |
| | Physiotherapy | Surgery | Orthotics/Bracing |
| | Other Specify: ________________________ | | |
| Length of time from injury to return to full training? | | | |
| Current Injuries: | Yes | No | |
| Areas affected: | Head | Elbow | Hamstring |
| | Neck | Forearm | Quadriceps |
| | Face | Wrist | Knee |

| | | | |
|---|---|---|---|
| | Front chest | Finger | Shin |
| | Back chest | Lower back | Achilles |
| | Shoulder | Hip | Ankle |
| | Upper arm | Thigh | Foot |
| | Other Specify: ________________________ | | |

Indicate on diagram where injuries are and severity out of 10.



APPENDIX D.2: Training and Injury History questionnaire: Indoor volleyball player

<table>
<tr><td colspan="4">Part A: Basic Details</td></tr>
<tr><td>Participant number</td><td colspan="3"></td></tr>
<tr><td>Name</td><td colspan="3"></td></tr>
<tr><td>E-mail address</td><td colspan="3"></td></tr>
<tr><td>DOB</td><td colspan="3">yyyy-mm-dd</td></tr>
<tr><td>Height</td><td colspan="3">cm</td></tr>
<tr><td>Weight</td><td colspan="3">kg</td></tr>
<tr><td>Dominant hand</td><td>Left</td><td colspan="2">Right</td></tr>
<tr><td rowspan="2">Position</td><td>Outside</td><td>Middle</td><td>Setter</td></tr>
<tr><td>Utility</td><td>Libero</td><td>No specialisation</td></tr>
</table>

<table>
<tr><td colspan="7">Part B: Volleyball Training History</td></tr>
<tr><td>How many years have you played volleyball for?</td><td colspan="6"></td></tr>
<tr><td>What is the highest level of volleyball you have achieved?</td><td colspan="2">Social/Recreational</td><td colspan="2">Provincial</td><td>National</td><td>Internat<br>al</td></tr>
<tr><td>On average, how many days a week do you train volleyball?</td><td colspan="6">days/week</td></tr>
<tr><td>On average, how many hours a week do you train volleyball?</td><td colspan="6">hours/week</td></tr>
<tr><td>Do you do any other training besides volleyball?</td><td colspan="3">Yes</td><td colspan="3">No</td></tr>
<tr><td rowspan="2">If yes, please indicate what types of training you perform and the percentage of training.</td><td>Volleyball training</td><td>%</td><td>Strength training</td><td>%</td><td>Endurance training (eg. running, cycling)</td><td>%</td></tr>
<tr><td>Flexibility / agility training</td><td>%</td><td>Other training ______________</td><td>%</td><td colspan="2"></td></tr>
</table>

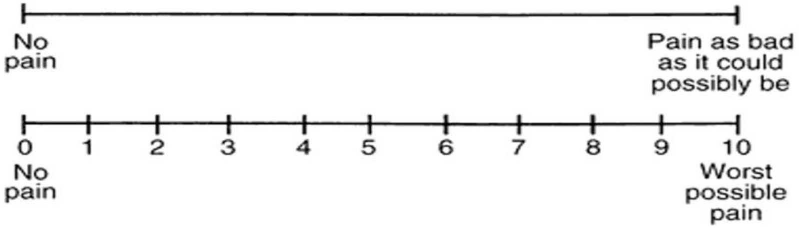
| Section D: Injury History | | | | |
|---|---|---|---|---|
| Have you sustained any injury over previous 12 months? | Yes:<br>If Yes, How many? : _____________ | | No | |
| Areas affected: (If more than one injury per area, indicate how many with a number) | Head | Elbow | | Hamstring |
| | Neck | Forearm | | Quadriceps |
| | Face | Wrist | | Knee |
| | Front chest | Finger | | Shin |
| | Back chest | Lower back | | Achilles |
| | Shoulder | Hip | | Ankle |
| | Upper arm | Thigh | | Foot |
| | Other Specify: __________________________ | | | |
| Structures injured? | Muscle | Ligament | | Joint |
| | Tendon | Bone | | Other Specify:__________ |
| Areas affected by Re-injury: | | | | |
| Please indicate how your injury was treated to date? (you can tick more than one) | Rest | Tablets | | Cortisone injection |
| | Stretches | Strengthening exercises | | Equipment change |
| | Physiotherapy | Surgery | | Orthotics/Bracing |
| | Other Specify: __________________________ | | | |
| Length of time from injury to return to full training? | | | | |
| Current Injuries: | Yes | | No | |
| Areas affected: | Head | Elbow | | Hamstring |
| | Neck | Forearm | | Quadriceps |
| | Face | Wrist | | Knee |
| | Front chest | Finger | | Shin |
| | Back chest | Lower back | | Achilles |
| | Shoulder | Hip | | Ankle |
| | Upper arm | Thigh | | Foot |
| | Other Specify: __________________________ | | | |

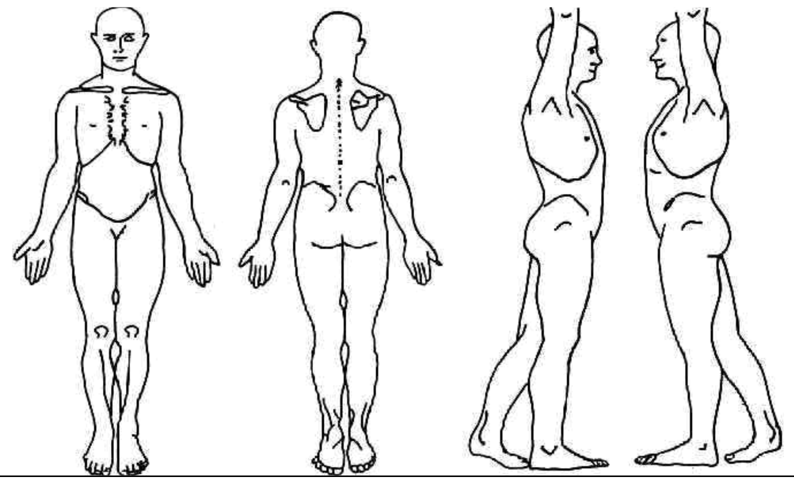
Indicate on diagram where injuries are and severity out of 10.

**Verbal Numerical Scale**
If "0" is "no pain" and "10" is the worst pain you can imagine, where is your pain now? on average? at its worst? at its best?

**Word Scale**
None Mild Moderate Severe Excruciating

**Visual Analogue Scales**



## APPENDIX E: OSTRC (Oslo Sports Trauma Research Centre) Overuse Injury Questionnaire

Part 1: Knee Problems

Please answer all the questions regardless of whether or not you have problems with your knees. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "knee problems" refers to pain, ache, stiffness, swelling, instablity/giving way, locking or other complaints related to one or both knees.

Question 1

*Have you had any difficulties participating in normal training and competition due to knee problems during the past week?*

- ☐ Full participation without knee problems
- ☐ Full participation, but with knee problems
- ☐ Reduced participation due to knee problems
- ☐ Cannot participate due to knee problems

Question 2

*To what extent have you reduced your training volume due to knee problems in the past week?*

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

*To what extent have knee problems affected your performance in the past week?*

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

*To what extent have you experienced knee pain related to your sport during the past week?*

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain

Part 2: Lower back Problems

Please answer all the questions regardless of whether or not you have problems in your lower back. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "lower back problems" refers to pain, ache, stiffness or other problems in your lower back.

Question 1

*Have you had any difficulties participating in normal training and competition due to lower back problems during the past week?*

- ☐ Full participation without lower back problems
- ☐ Full participation, but with lower back problems
- ☐ Reduced participation due to lower back problems
- ☐ Cannot participate due to lower back problems

Question 2

*To what extent have you reduced your training volume due to lower back problems in the past week?*

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

*To what extent have lower back problems affected your performance in the past week?*

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

*To what extent have you experienced lower back pain related to your sport during the past week?*

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain

Part 3: Ankle Problems

Please answer all the questions regardless of wether or not you have problems with your ankles. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term “ankle problems” refers to pain, ache, stiffness, swelling, instablity/giving way or other complaints related to one or both ankles.

Question 1

*Have you had any difficulties participating in normal training and competition due to ankle problems during the past week?*

- ☐ Full participation without ankle problems
- ☐ Full participation, but with ankle problems
- ☐ Reduced participation due to ankle problems
- ☐ Cannot participate due to ankle problems

Question 2

*To what extent have you reduced your training volume due to ankle problems in the past week?*

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

*To what extent have ankle problems affected your performance in the past week?*

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

*To what extent have you experienced ankle pain related to your sport during the past week?*

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain

APPENDIX F: Score sheet

Participant number:

Anthropometry

| | |
|---|---|
| Body mass: | kg |
| Height: | cm |
| Waist circumference: | cm |

| | | | |
|---|---|---|---|
| Leg length | Left cm | Right cm | Average: cm |

TPD

| | Left | Right |
|---|---|---|
| Distance of calliper: Moving inwards | mm | mm |
| Distance of calliper: Moving outwards | mm | mm |

Wedge test

| | Left | Right | Response 1=correct 0=incorrect |
|---|---|---|---|
| 1 | 9 | 12 | |
| 2 | 3 | 9 | |
| 3 | 3 | 3 | |
| 4 | 1.5 | 3 | |
| 5 | 6 | 1.5 | |
| 6 | 9 | 6 | |
| 7 | 9 | 9 | |
| 8 | 4.5 | 9 | |
| 9 | 3 | 3 | |
| 10 | 12 | 3 | |
| 11 | 6 | 12 | |
| 12 | 4.5 | 6 | |
| 13 | 9 | 4.5 | |
| 14 | 6 | 9 | |
| 15 | 1.5 | 6 | |
| 16 | 4.5 | 3 | |
| 17 | 6 | 4.5 | |
| 18 | 3 | 6 | |
| 19 | 9 | 3 | |
| 20 | 9 | 9 | |
| 21 | 3 | 9 | |
| 22 | 9 | 3 | |
| TOTAL | | | /22 |

Knee-to-wall test

| Distance | Left | Right |
|---|---|---|
| 1 | mm | mm |
| 2 | mm | mm |
| 3 | mm | mm |
| AVERAGE | mm | mm |

mSEBT

| | | 1 | 2 | 3 | Best distance |
|---|---|---|---|---|---|
| Anterior | Left | cm | cm | cm | cm |
| | Right | cm | cm | cm | cm |
| Posteromedial | Left | cm | cm | cm | cm |
| | Right | cm | cm | cm | cm |
| Posterolateral | Left | cm | cm | cm | cm |
| | Right | cm | cm | cm | cm |

Single Leg Bridge Hold Test (SLBHT)

| | Time held |
|---|---|
| Left | s |
| Right | s |

mBESS

| | | 1 | 2 | 3 | Best score |
|---|---|---|---|---|---|
| Tandem on ground | Left leg behind | | | | |
| | Right leg behind | | | | |
| Tandem on foam | Left leg behind | | | | |
| | Right leg behind | | | | |
| Single leg on ground | Left | | | | |
| | Right | | | | |
| Single leg on foam | Left | | | | |
| | Right | | | | |

Eccentric-concentric calf raise test

| | Left | Right |
|---|---|---|
| Repetitions | | |

Modified Agility T-test (MAT)

| | 1 | 2 | Best time |
|---|---|---|---|
| SAND | | | s |
| INDOOR | | | s |

Single leg triple hop for distance (THD) test

| SAND | 1 | 2 | 3 | Average distance |
|---|---|---|---|---|
| Left | cm | cm | cm | cm |
| Right | cm | cm | cm | cm |
| Average distance | | | | cm |

| INDOOR | 1 | 2 | 3 | Average distance |
|---|---|---|---|---|
| Left | cm | cm | cm | cm |
| Right | cm | cm | cm | cm |
| Average distance | | | | cm |

Countermovement jump test with arm swing

| | SAND | INDOOR |
|---|---|---|
| 1 | cm | cm |
| 2 | cm | cm |
| 3 | cm | cm |
| Average height | cm | cm |

APPENDIX G: COVID Screening Tool

## SCREENING TOOL FOR COVID -19

**Name**: ________________________________

**Cellphone Number:** ______________________

| No. | CONDITION / SYMPTOM | YES | NO |
|---|---|---|---|
| **A** | **SYMPTOM CHECK** | | |
| **1** | Are you suffering from fever / high temperature or temperature fluctuations? | | |
| **2** | Do you have a dry cough? | | |
| **3** | Do you have a sore throat? | | |
| **4** | Do you have redness of eyes? | | |
| **5** | Do you experience shortness of breath / difficulty in breathing? | | |
| **6** | Have you got unusual body aches / muscle pain? | | |
| **7** | Do you experience a loss of smell / taste? | | |
| **8** | Are you nauseous and/or do you experience unusual vomiting? | | |
| **9** | Have you got diarrhoea? | | |
| **10** | Do you suffer from fatigue / physical weakness / tiredness? | | |
| **B** | **CONTACT / EXPOSURE RISK** | | |
| **1** | Have you been exposed to someone diagnosed with COVID-19 or had recent contact with someone who is self-isolating whilst waiting for a COVID-19 test result? | | |
| **2** | Have you worked in or attended a healthcare facility where patients with SARS-CoV-2 infections are being treated? | | |
| **3** | Have you travelled outside of South Africa in the past 14 days or been in contact with somebody that has travelled internationally to a high risk area within the past month? | | |
| **4** | Have you been in quarantine / self-isolation for the past 14 days? | | |
| **C** | **OTHER RISK FACTORS** | | |
| **1** | Do you suffer from any pre-existing medical condition / chronic illness that may have compromised your immune system, i.e. respiratory disease, diabetes, heart disease, or any other chronic illness that could compromise one's immune system? | | |
| **2** | Are you 65 years of age or older? | | |

I hereby attest that the information provided above is a true reflection of my screening results. Should I experience any COVID-related symptoms within 14 days of the testing session, I will alert the researcher (Chrissy Glossop-von Hirschfeld – 082 348 3526).

**Signature**: ___________________________________ **Date**: ________________________

APPENDIX H: HREC letter of approval

**UNIVERSITY OF CAPE TOWN**
**Faculty of Health Sciences**
**Human Research Ethics Committee**

**Room E53-46 Old Main Building**
**Groote Schuur Hospital**
**Observatory 7925**
**Telephone** [021] 406 6492
**Email:** sumayah.ariefdien@uct.ac.za
**Website:** www.health.uct.ac.za/fhs/research/humanethics/forms

01 November 2019

**HREC REF: 697/2019**

**Dr G Ferguson**
Health & Rehab Sciecnes
Division of Physiotherapy
F-45, OMB

Dear Dr Ferguson

**PROJECT TITLE: PROPRIOCEPTION, AGILITY AND JUMPING CAPACITY IN BEACH VERSUS INDOOR VOLLEYBALL PLAYERS (MSC DEGREE - MRS CHRISTINE GLOSSOP-VON HIRSCHFELD)**

Thank you for your response letter dated 29 October 2019, addressing the issues raised by the Human Research Ethics Committee (HREC).

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

**Approval is granted for one year until the 30 November 2020.**

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

***The HREC acknowledge that the student: Mrs Christine Glossop-Von Hirschfeld will also be involved in this study.***

**Please quote the HREC REF in all your correspondence.**

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

Signature Removed

PROFESSOR M BLOCKMAN
**CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE**

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

HREC 697/2019

## APPENDIX I: Protocol amendments due to COVID

15 September 2020

### Summary of amendments to research protocol for data collection – COVID-19 circumstances

PROJECT TITLE: Proprioception, agility and jumping capacity in beach versus indoor volleyball players (HREC 697/2019)

- Researcher (me) to complete online *Higher Health HealthCheck* daily prior to testing sessions
- Participants to be screened using the COVID-19 questionnaire (see attached) prior to testing
- Participants and researcher (me) to wear a mask throughout the testing
- All participants tested individually
- Testing sessions to be conducted at least 30 minutes apart
- Participants to bring their own water bottle, pen and sweat towel
- All equipment and surfaces touched by participants and investigator to be thoroughly disinfected after each session (using alcohol 70% v/v spray)
- Should participants experience any COVID-related symptoms in the 14 days following testing, they are asked to contact the researcher (me) immediately so that she may imitate contact tracing and arrange for testing as deemed necessary once alerting the Department of Health COVID-19 24-Hour Hotline (0800 029 999)

Signature Removed

C Glossop-von Hirschfeld (MSc student)

Signature Removed

Dr G Ferguson (Supervisor)

APPENDIX J: Turnitin report

1/15/2021 Turnitin

# turn off anonymous marking

Please state reason for turning off Anonymous Marking for:
**Warning: Administrator has access to this information. This setting is permanent.**

Signature Removed

submit
Cancel

## Turnitin Originality Report

Student Papers: 48%

Processed on: 15-Jan-2021 16:14 SAST
ID: 1488057670
Word Count: 29071
Submitted: 1

vhrchr002:Chrissy_MSc_Thesis.docx
By Chrissy Glossop-Von Hirschfeld

| Similarity Index | Similarity by Source |
|---|---|
| 53% | Internet Sources: 20% |
| | Publications: 9% |

23% match (student papers from 17-Aug-2020)
Class: 40?96231-9c1?-4c7f-9b57-64f9e17b9c93
Assignment: AHS5051W Literature Review
Paper ID: 1370617992

16% match (student papers from 02-Sep-2019)
Class: f479df9d-859b-48f0-93f9-bda03856e44b
Assignment: Step 2 Proposal for Review Departmental Divisional
Paper ID: 1166344915

2% match (student papers from 17-Dec-2020)
Submitted to Queen Mary and Westfield College on 2020-12-17

1% match (Internet from 05-Feb-2017)
https://protect-za.mimecast.com/s/Aoa4CgjgrZSy2noDSNCdOY

1% match ()
https://protect-za.mimecast.com/s/cdk1Cr0gw9lDm7GATVvPiO

< 1% match (Internet from 11-Jun-2013)
https://protect-za.mimecast.com/s/P6vmCygxAZfZlo3WSyGOfS

< 1% match (student papers from 28-Jun-2019)
Submitted to University of Cape Town on 2019-06-28

< 1% match ()
https://protect-za.mimecast.com/s/pt7fCwfyBrSnNkWLuCEBYi

< 1% match (Internet from 11-Nov-2020)
https://protect-za.mimecast.com/s/BBPvCxGzD1UfXD3Ilfcs2/