Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players

by

Charné Britz

A dissertation submitted in partial fulfilment of the requirements for the degree MSc Sport Science (Biomechanics)

Division of Biokinetics and Sport Science

Department of Physiology

Faculty of Health Sciences

University of Pretoria

Supervisor: Dr Helen Bayne

Co-supervisor: Mr James Clark

2023

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences
Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

PLAGIARISM DECLARATION

Full Name: **Charné Britz**

Student number: **U14017327**

Degree: **MSc Sport Science**

Title of thesis: **Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players**

I declare that this thesis/dissertation is my own original work. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements.

I understand what plagiarism is and am aware of university policy and implications in this regard.

Signature: Date: 31/08/2023

ACKNOWLEDGEMENTS

I want to extend my appreciation to the following people and institutions, whose assistance and support with this dissertation has been invaluable to me:

Dr H. Bayne, my supervisor, Department of Physiology, University of Pretoria, for guiding me through every step of this dissertation with her knowledge, patience, persistence and subtle persuasions and encouragements. I'm extremely grateful for the opportunity I had to work with her and to learn from her.

Mr J. Clark, my co-supervisor, Department of Physiology, University of Pretoria, for being the sound board, for patiently enduring with me, and for his expertise and encouragement in supervising this study.

Sport, Exercise Medicine, and Lifestyle Institute (SEMLI), University of Pretoria, for their support and resources to complete this study.

TuksSport, TuksNetball club and the TuksNetball team, for their support and volunteering to participate in the study, and for the use of their facilities and equipment involved in this study.

To my husband, Werner, for his continual support and love in everything that he has done for me while I was doing this study.

TABLE OF CONTENTS

List of symbols and abbreviations

IMU	inertial measurement unit
COD	change of direction
BAI-1	Bilateral Asymmetry Index-1
ISQ	isometric squat
IMTP	isometric midthigh pull
PF	peak force
CMJ	countermovement jump
GRF	ground reaction force
DJ	drop jump
GCT	ground contact time
JH	jump height
RSI	reactive strength index
ICC	intraclass correlation coefficient
CV	coefficient of variation
CI	confidence intervals
HIS	high intensity steps
MIS	medium intensity steps
LIS	low intensity steps
DB	diagonal bound and stick
CB	continuous straight-line bounding
LBD	loose-ball drill
DD	deflection drill
RS	repeated sprints
2 v 2	small-sided half-court game
SD	standard deviation
FISQ	peak vertical force of the ISQ
FCMJ	peak force during the CMJ take-off phase
FDJ	peak force during the DJ rebound take-off
SI	symmetry index
SEMLI	Sport, Exercise Medicine and Lifestyle Institute
GPS	global positioning system
LPS	local positioning system

List of tables

Abstract

Title: Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players

Inter-limb asymmetry, the ratio that represents the performance comparison between two limbs, has been quantified during lower body plyometric, ballistic and isometric strength assessments. Asymmetries vary across different tasks and performance metrics, making asymmetries very task specific and metric dependent. In addition, inertial measurement units (IMUs) have recently developed into a popular tool to quantify training load and inter-limb differences in a sport-specific environment. The reliability of a measure shows its reproducibility across repeated trials. Any assessment requires a high reliability to ensure low measurement error. Measurement studies assessing inter-limb differences have generally shown acceptable within- and between-session reliability for observed performance measures. However, recent research investigating the within- and between-session reliability of the actual derived asymmetry value found this to be highly variable and unreliable.

This measurement study aimed to investigate the within-day and between-day reliability of force metrics and inter-limb force asymmetry during unilateral and bilateral variations of isometric, ballistic and plyometric laboratory-based strength assessments. A second aim was to investigate the between-day reliability of IMU-derived impact load and impact load asymmetry during sport-specific drills. During the netball pre-season, 25 healthy female university netball players (mean ± SD age: 20 ± 1.7, stature: 177.6 ± 7.0 cm, mass: 69.9 ± 8.3 kg) participated in this study. Testing consisted of four days. On Day 1 participants performed three trials of both unilateral and bilateral variations of the drop jump (DJ), countermovement jump (CMJ), and isometric squat (ISQ). On Day 2 participants performed six routine warm-up drills with IMUs attached to the shin to measure the frequency and intensity of ground contacts experienced. Day 1 and Day 2 was repeated on Day 3 and Day 4. Inter-limb asymmetries were quantified for peak force in the drop jump, countermovement jump and isometric squat. For the field-based assessments inter-limb asymmetry was quantified for impact load. The coefficient of variation (CV) and intraclass correlation coefficient (ICC) was determined for each participant for all performance and asymmetry metrics to define the within-and between-day reliability.

Good to excellent within- and between-day reliability was seen for all force metrics for both variations of the strength assessments. Relative within- and between-day reliability for force asymmetry variables during the bilateral strength tests ranged from good to excellent (ICC: 0.89 – 0.94). For the unilateral strength assessments relative within- and between-day reliability were poor to moderate (ICC: 016 – 0.67). Absolute within- and between-day reliability for all force asymmetry variables were unacceptable (CV: 26.4 – 645.5%). During the sport-specific drills, moderate relative reliability (ICC: 0.50 – 0.60) and unacceptable agreement (CV: 13 – 19%) were seen for impact load in all the controlled drills. When considering all the drills together, impact load reliability was moderate (ICC: 0.58 – 0.60), with a CV of 11%. In all the sport-specific drills impact load asymmetry was inconsistent between days and showed very poor between-day reliability (CV: 44.3 – 422.6%; ICC: -0.21 – 0.15).

Performance variables used to quantify inter-limb asymmetries are reliable within- and between sessions, however, high variability is seen when considering the reliability of asymmetry measures. When describing, comparing, or tracking lower limb asymmetries during unilateral and bilateral strength assessments, as well as during sport specific drills, practitioners should carefully consider test selection, and metric- and asymmetry reliability. Practitioners should not only look at the ecological validity of a specific test to create an asymmetry profile of an athlete, but also consider the reliability and variability of the test, test metrics and asymmetry measures.

Key words: inter-limb asymmetry, reliability, variable, inertial measurement unit (IMU), court sport, team sports, impact load, wearables

Chapter 1: Introduction

1.1 Background

The difference in performance or capacity between two limbs can be defined as inter-limb asymmetry.[1-2] Inter-limb asymmetries are usually reported as a percentage difference comparing one limb to another (in terms of dominance, preference, strength or left vs. right) and can be linked to natural asymmetry of the anatomy, previous injuries, positional demands of the sport, training experience and/or limb preference.[2-4] Strength and power asymmetries have been a topic of interest because of the potential effect it might have on injury and performance.[5] This effect could be due to altered motor behaviours causing dysfunctional or inefficient task performance and/or the inability of the weaker limb to produce and absorb similar force outputs compared to the stronger limb.[1-3,6] Varying magnitudes of inter-limb asymmetry have been reported in the literature across different population groups, various sporting codes and injury status, and evidence suggests that larger inter-limb strength imbalances are often associated with performance detriments in jumping, sprinting and change of direction.[1] Strength asymmetries of 10-15% or more are often considered as problematic, however, due to the task-, metric- and population-specific nature of asymmetry, a more recent perspective questions the use of pre-determined thresholds, and it is suggested that an individual approach to asymmetry that takes sample-specific thresholds and individual variability into account, should be considered.[1]

1.2 Rationale

Test validity and reliability are two fundamental concepts in athlete testing and profiling.[7] It is of vital importance to determine whether the test measures what it was designed to measure (validity) and whether the test outcomes are repeatable (reliability).[7] Research shows that there is a lack of association between asymmetry scores across different tasks which indicates the task specificity of inter-limb asymmetry.[8-9] To show the full picture of an athlete's asymmetry profile, multiple tasks and tests might be required.[9] Inter-limb asymmetries have been quantified through a multitude of laboratory-based tests and test metrics.[9-12] These tests provides invaluable information, but when looking at inter-limb differences to explore underlying injury risk or to inform an athlete's return to play, it is possible that most of these tests might not detect underlying imbalances in limb function or mechanics that might only be noticeable during sport-specific movements.[13] Thus, measuring inter-limb differences during actual play or sports manoeuvres may be of much more value.[13] The rise of comfortable, inexpensive wearable shin-mounted inertial measurement units (IMUs) is making it possible to quantify surrogate measures of mechanical load experienced by the lower extremities, providing more ecologically valid metrics while athletes are in their sport-specific environments.[13-14]

The degree of measurement repeatability, reproducibility or consistency can be described as the reliability of a measurement.[7] Knowing the within- and between-session reliability for different assessments, devices and output measures is important for practitioners to make informed decisions about inter-limb differences. Existing literature often reports on the reliability of the output measures achieved during specific tasks, and these typically show good within- and between-session reliability.[15] However, these studies rarely report on the reliability of the asymmetry ratio itself.[15-16] Asymmetry research has mostly focused on laboratory-based strength assessments, and little is known about impact load and impact load asymmetries during sport specific drills, especially in court-based sports. Quantifying asymmetries during sport specific manoeuvres, along with both unilateral and bilateral variations of different strength assessments (isometric, ballistic and plyometric) might be a comprehensive way to create an asymmetry profile for an athlete. However, practitioners should understand the variability of inter-limb asymmetry ratios as longitudinal monitoring and interpretation can only be done when the within- and between-session reliability for the asymmetry ratio is known.

1.3 Research problem

In sport, some presence of inter-limb asymmetries is to be expected and research has focused on the effects of inter-limb asymmetry on athletic performance and injury risk. Research highlights that the magnitude and direction of asymmetries are highly variable across different tests and performance metrics because of its task sensitivity.[4]

Recent research investigated the reliability of the tests and performance metrics used to quantify inter-limb asymmetries during specific tests,[17] however, the reliability of the actual inter-limb asymmetry has only been looked at in a handful of studies.[15-16,18] To calculate force production asymmetry, simultaneously collected force-time data from two adjacent force plates is used in the equation.[16] Much of the recent research evaluates the reliability of the single-side force-time data, but does not evaluate the reliability of the asymmetry measure.[16]Understanding the within- and between-session reliability of performance and asymmetry metrics in unilateral and bilateral lower body laboratory strength assessments is needed to guide practitioners to select a precise and repeatable tool (or multiple tools) to accurately quantify meaningful inter-limb asymmetries of which the magnitude and direction can be monitored longitudinally.

Knowing that inter-limb asymmetries are so task specific, it might be more ecologically valid to assess and monitor inter-limb differences while the athlete is doing sport-specific manoeuvres. This can be done using wearable technology such as shin mounted IMUs. Information on the reliability of accelerometer derived metrics, like impact load, captured with IMUs during sport specific movements in team- and court-based sport, is very little. It is thus important to evaluate whether metrics are reliable to accurately track mechanical load across sessions. It is also important to understand the reliability of the asymmetry value quantified using these IMU-derived metrics across sessions, as this information has performance implications and might guide return-to-play decisions.

1.4 Aim and objectives

The aim of this study was to investigate the within- and between-session reliability of lower limb force asymmetry during laboratory strength tests, and the between-session reliability of impact load and impact load asymmetry during sport-specific drills in netball players.

The objectives of the study were to:

- Quantify inter-limb force asymmetry during unilateral and bilateral isometric, ballistic and plyometric lower body strength tests on a dual force plate.
- Quantify impact load experienced for each lower limb during netball-specific tasks using shin-mounted IMUs and quantify inter-limb impact load asymmetry during these tasks.
- Determine the between-session reliability for inter-limb force asymmetries observed in unilateral and bilateral isometric, ballistic and plyometric strength tests.
- Determine the between-session reliability of impact load and inter-limb impact load asymmetries observed during netball-specific tasks.

The study was a cross-sectional, non-experimental cohort study during which inter-limb strength and mechanical load asymmetries was quantified. Within-and between session reliability was established for inter-limb peak force asymmetries during the laboratory strength assessments, and between-session reliability was established for impact load and impact load asymmetries.

1.5 Outline of the dissertation

The remainder of the dissertation consists of:

- Chapter 2: A literature review regarding the identification, calculation, and reliability of lower body inter-limb asymmetry during strength assessments and sport-specific tasks.
- Chapter 3: An experimental study in draft manuscript format with introduction, methods, results, and discussion sections to potentially submit to the Eur J Sport Sci.
- Chapter 4: A summative discussion of the research results along with study limitations and recommendations for future research.

Chapter 2: Literature Review

2.1 Introduction

Sport participation places heavy physical demands on athletes.[19] Many sports are characterized by rapid unilateral actions like jumping and change of direction (COD) tasks that are performed repeatedly and may lead to bilateral differences in range of motion, force production capability, and neuromuscular adaptations of the lower extremities.[3,19] Bilateral differences or inter-limb asymmetry in strength and power has been a topic of interest because of the potential effect it has on injury and performance.[1-3,6] Inter-limb strength asymmetry has been suggested to be a potential risk factor for injury and/or poor performance due to altered motor behaviours causing dysfunctional or inefficient task performance, and the inability of the weaker limb to produce and/or absorb similar amounts of force compared to the stronger limb.[3,6]

2.2 Inter-limb asymmetry

Inter-limb asymmetry can be defined as the difference in strength or performance when comparing two limbs or muscle groups, and is usually reported as a percentage difference of one limb in respect to the other.[1-2] Inter-limb asymmetries have been examined across a variety of physical competencies such as strength, power, dynamic balance and leg stiffness.[2] These inter-limb differences can be linked to natural asymmetry of the anatomy, previous injuries, positional demands of the sport, training experience and limb preference.[3]

Varying magnitudes of inter-limb asymmetry have been reported in the literature across sexes, age groups, sports and injury status.[1] Asymmetries can be interpreted as a scalar variable (magnitude only) or a vector variable (magnitude and direction).[16] The magnitude of the inter-limb asymmetry is not the only factor that affects the interpretation of the asymmetry measurement, but the direction of the asymmetry should also be considered.[18] The direction of asymmetry refers to the limb that performs superiorly in a specific task.[5] With a vector variable the value from zero represents the magnitude of the asymmetry, and a positive or negative value indicates the direction of the asymmetry.[16]

Asymmetries of >15% have often been considered as problematic and research has highlighted that athletes with asymmetries above this threshold have been associated with higher injury incidence.[1-2] Literature recommends that practitioners conduct frequent evaluations throughout a training cycle to evaluate inter-limb differences to ensure their athletes or patients are below this arbitrary "high risk" threshold that may increase their subsequent injury risk.[18] It has been suggested that lower injury incidences and a safer return to play after injury may be associated with lower inter-limb asymmetry.[18] Furthermore it has also been suggested that larger imbalances in strength negatively affect performance in jumping tasks, sprinting and COD.[1,18] Baseline between-limb comparisons are particularly useful before an injury occurs, because practitioners can monitor functional improvements during any subsequent rehabilitation from an injury to ensure acceptable and comparable performance levels are reached before the athlete return to sport.[20]

Multiple classifications have been used to define limb differences in terms of dominance, preference, strength or left vs. right.[2-4] It is difficult to predict which limb is dominant and existing literature demonstrates different methods to select the dominant limb, including the preferred kicking leg, leading foot when climbing stairs or the leg used to regain balance.[3-4] When presented with a motor task, athletes will preferentially use one side of their body and this is known as laterality, lateral preference, handedness or "skill" dominance.[21] However, poor levels of agreement exist between perceived limb dominance and highest score attained as many athletes do not perform better with the self-selected dominant leg.[3-4] The direction of the inter-limb asymmetry is likely to be influenced by skill dominance or handedness, but the way the inter-limb asymmetry manifests will depend on the demand of the task that is being performed.[21] Asymmetry equations utilize a reference value, like a dominant leg in terms of strength or preference, highest score attained and/or left or right distinction, and precision on defining limb dominance is very important and must be specific to the task that is being assessed.[4] Therefore, practitioners should clearly define how limbs are categorized when calculating inter-limb asymmetries as this will have an effect on the outcome.[21] It is of utmost importance to use the same reference leg when looking at asymmetry data longitudinally, because the stronger or dominant limb might not remain the stronger or dominant limb in repeated measures, resulting in a lack of clarity in the results.[1] Practitioners should identify and define a reference leg that can always be used and tracked over time, and additionally apply a logical 'IF' function to identify the direction of asymmetry without compromising the magnitude of the score.[1]

2.3 Calculating inter-limb asymmetry

Inter-limb asymmetries can be identified through bilateral or unilateral tasks, depending on the needs of the athlete or sport.[11] To accurately quantify asymmetry it is important to select the appropriate equation to calculate the inter-limb differences for the specific metrics obtained through the test.[11] Asymmetries assessed via bilateral and unilateral tasks should be calculated differently because the set-up of the task is completely different in how the non-test leg is affecting the unilateral task and how weight distribution and loading mechanics affects a bilateral task.[16]

During a bilateral, weight-bearing test both limbs support the body's mass and perform work that contributes to the outcome. A variety of metrics can be obtained for each limb individually during such tests and inter-limb differences should always be presented in relation to the sum total of the reported metric.[11] Previous studies have utilised a range of equations to calculate inter-limb asymmetry, but it has been demonstrated that the bilateral asymmetry index-1 (BAI-1) [(dominant leg – non-dominant leg)/(sum total) x 100] and symmetry index (SI) [(high-low)/total x 100] are the only equations that produce an accurate output during bilateral tests.[11] The SI defines limbs using highest and lowest values and practitioners should be mindful that the limb with the highest score might change due to injury or training and competition requirements.[11] During a unilateral test the non-test leg doesn't contribute to the performance outcome of the tested leg and it is assumed to provide a more accurate representation of "true" inter-limb asymmetries in lower limb capacity.[11] The percentage difference method expresses the difference between two values as a fraction of 100% [100/(max value) x (min value) x (-1) +100] and has been shown to be the appropriate equation to accurately calculate inter-limb asymmetries from unilateral tests.[11] The bilateral strength asymmetry equation [(stronger limb – weaker limb)/stronger limb x 100] has also been suggested as being appropriate.[11]

During testing protocols three trials are typically encouraged and asymmetry scores can be calculated from the best trial or the average of all the trials performed during the test.[12] Bishop et al.[12] compared inter-limb asymmetry calculated from the best trial and from the average score of three trials on both limbs during unilateral strength and jump assessments and only found a significant difference between sessions for impulse asymmetry during the isometric squat (ISQ). However, considering the variable nature of asymmetry the two methods should not be used interchangeably, and it is suggested that the average of all trials might be considered the most appropriate for calculating inter-limb differences.[12]

Many methods exist to quantify inter-limb asymmetries. When selecting the appropriate test it is important to consider the requirements of the athlete within the context of their sport, the usefulness of the test in how it is associated with a higher injury risk or reductions in performance, availability of testing equipment, practitioner's ability to conduct the test, and the reliability of the chosen test.[4,11] For bilateral inter-limb asymmetry quantification the BAI-1 and SI are both appropriate equations to accurately quantify asymmetry, and the percentage difference method is suitable to calculate asymmetries from unilateral tests.

2.4 Inter-limb strength assessments

Strength has been defined as the ability to produce a maximal amount of force, developed during voluntary muscle contraction under a given set of circumstances.[22] Strength has dynamic, isometric and reactive qualities.[23-24] Dynamic strength qualities can be seen in ballistic movements which require athletes to rapidly move their body or limbs to the point of take-off or release by accelerating throughout the entire range of motion.[25] Isometric strength is the ability to produce maximal force against a stationary resistance.[24] Reactive strength is the ability to generate a propulsive concentric force after braking efficiently and absorbing eccentric forces within specific time frames.[23] Plyometric movements utilise reactive strength, are characterized by rapid stretch-shortening cycle muscle actions and are typically performed with body mass and/or little to no extra resistance.[25] In athletes, maximal force generating capabilities are commonly evaluated and monitored with the aim to create an athletic profile, establish performance levels, and to keep track of training effects on performance.[24] The prevalence of inter-limb strength asymmetry has been reported during a variety of strength-based assessments and the back squat, ISQ or isometric midthigh pull (IMTP), and isokinetic knee flexion and extension are all assessments that adequately identify inter-limb strength differences.[4,9] Previous research suggests that lower limb strength imbalances are prevalent in cutting and pivoting sports such as basketball, soccer and volleyball.[3] By comparing the unilateral neuromuscular capacity of the lower limbs, practitioners gain important insights related to performance, injury risk reduction, rehabilitation and return to play programs.[3]

Lower limb inter-limb strength asymmetries can be quantified with unilateral or bilateral tasks.[11] In team sports, athletes undertake various unilateral actions (such as running and COD), and it seems more ecologically valid to assess inter-limb asymmetry unilaterally, while in other sports a bilateral assessment might be more task specific.[4] A battery of tests may be required to accurately screen for the presence of inter-limb strength differences because of task sensitivity across a range of physical competencies.[4]

2.4.1 Unilateral and bilateral isometric tasks

Performance in isometric strength assessments is typically quantified using some form of dynamometer. Tests that are performed with the athlete standing on a force plate permit the generation of force-time curves that provide practitioners with a useful indication of athletes' maximal force generating capacity and ability to produce maximal force in minimal time.[17,24,26] These types of tests are popular because of the ease of test administration and data analysis processes, and greater task control than one repetition maximum tests, which allows for lower injury risk and performance variability, that subsequently leads to higher test-retest reliability.[27] Variables of interest to the practitioner may include peak force (PF), rate of force development and impulse.[4,27]

The IMTP and ISQ are closed-chain tasks commonly performed on a force platform that is rigged with a custom built isometric rack.[24] The set-up position for the IMTP (130-140° knee angle, upright trunk) replicates the strongest and most powerful position during weightlifting movements such as the clean or snatch, the second pull position, where the athlete is able to generate the highest forces and velocities.[26] When comparing the IMTP and the ISQ, the main differences between the two tasks are the exclusion of the upper limbs and the cueing of the task ("push" instead of "pull" for the ISQ).[26] Knee and hip angles for the ISQ ranged from 90° to 150° in previous studies.[24]

The ISQ and IMTP have been used in a number of studies to investigate the prevalence of force production asymmetries,[4] where bilateral tasks are performed with the athlete standing with their feet on two adjacent force plates.[16] Literature reports larger inter-limb differences in weaker and female athletes.[28]

Bailey et al.[19] assessed bilateral inter-limb PF asymmetry in an IMTP and its effect on jumping performance. The average inter-limb asymmetry for PF was 6.6% and were negatively correlated with jump variables, indicating that as asymmetry measures increased, jump performance decreased.[19] Hart et al.[29] compared inter-limb strength difference quantified through bilateral and unilateral ISQ with lean mass asymmetry and kicking accuracy in 32 football players, and found a positive interaction between lower limb strength, lean mass, bilateral symmetry and kicking performance.

Brady et al.[26] found significant differences between PF, relative PF and allometrically scaled PF, with the ISQ producing significantly ($P < 0.05$) higher results compared to the IMTP. ISQ may be the preferred test if practitioners are looking to measure athletes' true maximum strength, especially among females, as it may be a truer reflection of an athlete's maximal lower-limb strength compared with IMTP.[26]

Bishop et al.[17] found that inter-limb asymmetries quantified during a unilateral ISQ varied across metrics, emphasising their task-specific nature. Negative correlations could be seen between asymmetry scores and performance measures, indicating that the larger the asymmetry is, less force or rate of force development occurs.[17]

Isometric testing protocols have many advantages; however, some limitations are that a force-measuring device is required to collect strength data, and its relationship to athletic performance is not as strong when compared to dynamic strength assessments.[27] Muscular expressions of strength and power are contextually specific, and the deliberate selection of exact joints angles and body positions in isometric testing protocols that honour positional specificity will still be useful to provide important information with regards to an athlete's maximal voluntary force production capabilitites.[27]

2.4.2 Unilateral and bilateral ballistic tasks

Practitioners often include jump tests as part of their routine performance assessment protocols because they are easy to implement and time-efficient.[8] Compared to clinical strength assessments, they are more sport specific in that they mimic the closed-chain, dynamic movements experienced in sports.[20,30] Jumping tasks provide a functional and valid assessment of an athlete's lower body power capacity, and better jump performance is directly correlated with faster multidirectional speed tests.[31] The countermovement jump (CMJ) is utilised to monitor long-term changes in performance, and short-term changes in neuromuscular readiness and fatigue.[30] It is commonly performed on dual force plates that are synchronized to simultaneously monitor the force-time curve of each individual limb, allowing the identification of individual lower-limb force contributions and the ability to calculate inter-limb asymmetries.[30]

Both the unilateral and bilateral variations of the CMJ have been used to quantify side-to-side differences of the lower limbs.[9] Inter-limb asymmetries quantified with bilateral and unilateral CMJ variations seems to be unrelated, with unilateral CMJ representing a better indicator of each limb's individual capacity and bilateral CMJ providing a better understanding of between-limb compensatory strategies.[15] Benjanuvatra et al.[20] found that inter-limb asymmetries in ground reaction forces (GRF) during a bilateral CMJ were inconsistent with a unilateral CMJ, where the bilateral variation is influenced by limb-loading coordination and the asymmetry seen is not necessarily determined by strength and power differences, but rather asymmetric motor commands or central nervous system neural drive.[20] Fort-Vanmeerhaege et al.[3] performed unilateral CMJ on volleyball and basketball players to identify inter-limb neuromuscular asymmetry, calculated between the dominant and non-dominant limb, as well as the stronger vs the weaker limb. Inter-limb asymmetries for dominant vs non-dominant ranged from 9.31% (males) to 12.84% (females), and when comparing strong vs weaker limb asymmetries ranged from 10.49% (males) to 14.26% (females).[3] Bishop et al.[32] showed that unilateral CMJ resulted in jump height asymmetries of 12.5%, the greatest side-to-side difference compared with all other jump tests in female soccer players. These vertical asymmetries were associated with reduced jump performance.[32] It has been suggested that the heightened instability associated with unilateral jumping tasks may make these tests the preferred option when quantifying inter-limb differences.[32] However, it will ultimately depend on the client's needs and needs of the sport. Considering that unilateral and bilateral asymmetries in GRF during a CMJ are unrelated, it might be justified to perform both bilateral and unilateral jump variations in a testing battery to assess inter-limb asymmetry in ballistic strength.[33]

2.4.3 Unilateral and bilateral plyometric tasks

The drop jump is an assessment whereby participants start by standing on a box and are required to step off with their designated test leg and subsequently land on that leg (or both, depending on the DJ variation performed) and upon landing jump as high as possible with as little ground contact time as possible.[12] Recorded metrics for unilateral DJ can include but are not limited to jump height (JH), ground contact time (GCT) and reactive strength index (RSI).[34] Bishop et al.[34] found mean asymmetry values from 6.51-11.49% for JH, 6.55-6.85% for GCT, and 5.95-10.37% for RSI for the unilateral DJ in male soccer and cricket players. They also found significant positive correlations between JH and RSI asymmetries during the unilateral DJ and 5-0-5 times, which indicated that larger asymmetries were associated with slower COD speeds.[34] Bishop et al.[8] found similar results in that JH and RSI asymmetry correlated significantly with 10-m and 30-

m sprint, as well as 5-0-5 COD performance, with larger asymmetries indicating slower sprint and COD times.[8]

In recent literature where asymmetry scores quantified across multiple tests were compared, poor levels of agreement between the asymmetry scores can be seen.[8] According to Bishop et al.[8] there were no significant relationships between asymmetry scores during the CMJ, DJ and COD task, which emphasises the independent nature of jumping and COD asymmetry scores. Bishop et al.[9] also found poor levels of agreement for the direction of asymmetry in elite youth female soccer players during unilateral squat jump, CMJ and DJ.

The lack of association between asymmetry scores in different tasks indicates the variable nature and task specificity of inter-limb asymmetry.[8-9] Thus, when aiming to quantify inter-limb asymmetry, multiple tests might be necessary to show the full picture of an athlete's symmetry profile.[9]

2.5 Reliability of performance measures and inter-limb asymmetry during lower limb strength tests

A basic requirement for any assessment is a high reliability.[15] Reliability makes reference to how repeatable, reproducible or how consistent a test or test outcome is.[7] The test-retest reliability needs to be determined in order for practitioners to be able to assess changes in performance; otherwise practitioners can't confidently state whether an athlete has truly improved in a test or not.[7] Various statistics can be used to quantify the reliability of a test outcome measure.[7] Absolute test reliability can be quantified with the standard error of measurement (SEM) expressed as a percentage of the mean to provide a within- or between-day coefficient of variation (CV).[7,24,26] Relative test reliability can be described by the intraclass correlation coefficient (ICC).[7] The ICC informs about the consistency of the test and the CV is an estimate of typical error in a measurement.[24] In sports science there are no predetermined standards set for measurements of reliability, but a threshold of an ICC ≥ 0.8 and a CV ≤ 10% have most commonly been used in the literature.[26] Test reliability can be affected by many factors such as how test instructions are provided to the athlete, which type of equipment or technology is used and or which calculation method is used.[7] In order to understand whether changes in test performance are "real" and not just the result of measurement error or variation, reliability measures are needed to determine the noise of a test.[7]

2.5.1 Reliability of unilateral and bilateral isometric tasks

With an ICC ≥ 0.92 and CV ≤ 5%, PF is by far the most reliable variable reported in the literature for the bilateral IMTP.[26] Dos'Santos et al.[28] found that bilateral and unilateral IMTP PF demonstrated high within-session reliability (ICC: 0.94, CV: 4.7-5.5%). Bilateral and unilateral IMTP impulse showed lower reliability and greater variability (ICC: 0.81-0.88, CV: 7.7-11.8%).[28]

Compared to the IMTP, research on the reliability of the ISQ is limited, but results show that PF is generally the most reliable variable (ICC ≥ 0.97) for the ISQ as well.[26] Hart et al.[27] found that PF had good reliability during bilateral and unilateral variations of the ISQ (CV < 4.7%; ICC > 0.96). Bishop et al.[12] reported good to excellent within-session relative reliability (ICC: 0.94-0.96) and low variability (CV:4.9-5.4%), and good to excellent between-session reliability (ICC: 0.86-0.93; CV: 6.4-7.7%) for PF during the unilateral ISQ. Similar to previous research Bishop et al.[17] also reported good reliability for PF during the unilateral ISQ (ICC: 0.93-0.93; CV: 5.4-5.7%). Bishop et al.[17] highlighted the metric-specific nature of inter-limb asymmetries in that asymmetry scores varied across test metrics derived from the GRF during the unilateral ISQ. When using the unilateral ISQ to assess inter-limb force production asymmetries, PF may be the only variable to use with absolute certainty because of its good reliability.[17]

2.5.2 Reliability of unilateral and bilateral ballistic tasks

The CMJ can be performed with or without an arm swing.[30] Heisman et al.[30] purposed to establish the inter- and intra-session relative and absolute reliability of force-time metrics used to quantify inter-limb asymmetry obtained during a CMJ with and without arm swing. During both protocols most metrics had an acceptable relative and absolute inter- and intra-session reliability (ICC > 0.70; CV < 10%), and they found that the CMJ protocol influences the variability of the inter-limb symmetries.[30] Bishop et al. [12] found that PF and jump height during the unilateral CMJ showed good to excellent within-session reliability and acceptable within-session variability (ICC: 0.81-0.93; CV ≤ 5.8%). Between-session reliability was good and acceptable for all variables (ICC: 0.78-0.85; CV ≤ 6.3%).[12]

2.5.3 Reliability of unilateral and bilateral plyometric tasks

Within- and between-session reliability for the unilateral DJ showed good to excellent reliability and acceptable variability in a study by Bishop et al.[12] (ICC: 0.78-0.94; CV < 8.1%). In another study by Bishop et al.[9] PF on the left leg during a unilateral DJ was the only metric that showed slightly higher variability (CV: 11.08%). In the same study ICC values for PF, JH, concentric impulse and peak power during the unilateral DJ were moderate to excellent (ICC: 0.59-0.96).[9] The DJ is a less innate task and technically more challenging, and the more advanced nature of the jump might be the reason for the slightly lower reliability scores when compared to a CMJ.[12]

2.5.4 Reliability of asymmetry during lower body strength tests

Recent research has reported on the reliability of the performance variables achieved during specific tasks, but rarely report on the reliability of the asymmetry measure itself.[15-16] The CV provides practitioners with an indication of typical error between trials during testing.[11] For an asymmetry to be considered "real" the asymmetry scores should be more than the variability of the test.[1,11] CV values of less than 10% have been considered acceptable.[11] Inter-limb differences may be more variable than the CVs of the constituent variables because the SD is greater than the mean, which makes the asymmetry metric CVs near or greater than 100%.[16] Thus, any variability in the asymmetry measure will be missed if the reliability of the single-leg performance variables is the only reliability reported on in asymmetry studies.[16]

In a recent study Perez-Castilla et al.[15] compared the between-session reliability of single-leg performance and inter-limb asymmetry variables between unilateral and bilateral CMJs and found that most performance variables and asymmetry variables during the bilateral CMJ presented an acceptable reliability, however, the asymmetry variables during the unilateral CMJ always showed unacceptable reliability.[15] Bailey et al.[16] evaluated the reliability of PF inter-limb asymmetry metrics as scalar (magnitude only) and vector (asymmetry magnitude and direction) quantities during a CMJ. Relative reliability assessed through ICC has been shown to be good-to-excellent, with the scalar asymmetry metric producing the lowest value.[16] However, very poor absolute reliability was prevalent for both scalar and vector asymmetry metrics (CV: 36.2-1497.1%).[16]

Scarce literature exists that adequately evaluates the reliability of asymmetry measures, and the abovementioned studies demonstrate the limited between-session reliability of asymmetries determined form strength assessments.[1] When considering the results of asymmetry assessments practitioners should use caution, as they may not be as reliable as they are often portrayed, asymmetry is very task and metric specific, and caution should also be applied because of the inconsistency in the magnitude and direction of asymmetry between sessions.[1,16]

2.6 Field-based assessment of lower limb load and inter-limb asymmetry

Most tests to quantify asymmetry are not representative of the functional demands of the sport, and may mask underlying imbalances in limb function during sport-specific movements.[13] When exploring injury risk and return to play, measuring inter-limb differences during actual play or sports manoeuvres may be valuable.[13]

It is now possible to measure impacts experienced by the lower extremities with inertial measurement units (IMUs).[14] This wearable piece of micro-technology is light, moveable, affordable and easy to use with many athletes.[13] When using IMUs, surrogate measures of the mechanical load experienced during sport-specific movements are provided, which offers more ecologically valid measures of impact while athletes are in their sport-specific environments.[14] Upper trunk-mounted IMUs have most commonly been used, but it has been shown that IMUs attached to the lower limbs were able to quantify impact magnitudes more directly.[13] While the torso mounted accelerometers reliably estimate external load metrics during sporting movements, this measure is non-specific to the lower limbs and does not provide a direct measure of lower limb impact load.[14]

Tibial accelerometery has been shown to be sensitive to changes in running speed and technique, and GRF loading rate.[35] IMeasureU Blue Trident triaxial tibial accelerometer units combined with IMU Step data processing dashboard automatically generates external biomechanical load metrics and provides step count, impact load, bone stimulus, and number of high (HIS), medium (MIS) and low intensity steps (LIS).[35] Bone stimulus is an exponentially weighted metric that incorporates the number of cycles and load magnitude to model tibial response to cyclic mechanical loading.[35] The sum of the peak resultant acceleration in g experienced during each step is defined as impact load, and this is directly proportional to the intensity of impacts and the number of steps.[35] These metrics have been used to predict bone stress injuries in runners, to modify altered running patterns post-injury, as well as to aid clinical assessments of field-based rehabilitation in team sports such as soccer.[35] IMUs are able to measure athletes' performance in a way that doesn't hinder movement, can provide instant feedback in the training environment with user-friendly applications on a smart device, and can be used for technical analysis.[36]

2.7 Reliability of field-based assessments of lower limb load and inter-limb asymmetry

To make informed decisions about inter-limb differences it is important for practitioners to know that a device and output measures are reliable and valid within- and between-sessions. Armitage et al.[35] investigated the inter-unit reliability of IMUs during five sport specific tasks (Yo-Yo Intermittent Recovery Test Level 2, straight line sprint, V-drill, 90° cut and acceleration drill, zig-zag running circuit) and found excellent (ICC: 0.90 – 0.98) inter-unit reliability for step count, LIS, HIS and bone stimulus metrics. All other metrics were good (ICC: 0.83-0.86) except for impact load during the Yo-Yo.[35] During a treadmill run at four different speed zones Sheerin et al.[37] reported excellent between session reliability in peak tibial acceleration. Burland et al.[14] found excellent between-session reliability with ICC values ranging between 0.75-0.89 for cumulative impact load during acceleration-deceleration, plant and cut and COD tasks.

With the good to excellent inter-unit and inter-session reliability seen in previous studies, practitioners can have greater confidence when evaluating training load based on step frequency and magnitude.[35] Although these findings offer information about the reliability of IMU Step metrics across repeated sessions, between-session reliability for impact load asymmetry has yet to be explored.

2.8 Asymmetry and its relevance to netball

Netball is an intermittent court-based (30.5 x 15.25 m) team sport that is characterised by frequent high intensity movements.[38] Netball matches consist of four 15-minute quarters in which players change the intensity of activity every 6 seconds, performing 25 to 202 running bouts and 5 to 81 sprints.[38] Players are not allowed to run with the ball in hand and players often perform cutting, dodging, COD, leaping and bounding movements to receive and distribute the ball while also evading opposition.[38] These accelerations and decelerations, abrupt landings and explosive jumps impose high GRF on the lower body.[38] During training and competition the demands of dissipating and generating high forces imposes mechanical stress on the musculoskeletal system which is directly related to tissue damage and repair.[39] It has been suggested that in female netball players these high GRF coupled with incorrect landing techniques are a primary cause of lower body injuries.[38]

It is good practice to assess and profile athletes to identify those predisposed to injury.[40] In netball, several studies have employed lower limb motor-performance tests that includes various single-leg hop and balance tests.[40] Previous studies have also found positional differences in movement patterns and skill requirements when describing activity profiles and physiological demands with notational methods for describing time-motion data.[41] The use of Global Positioning Systems (GPS), Local Positioning Systems (LPS), heart rate monitoring, and IMUs (accelerometers, gyroscopes and magnetometers) have become increasingly popular for examining activity profiles in netball, and have allowed for more detailed analysis of distance, speed and non-locomotor activities (like jumping) experienced during matches and training, as well as impact and body load.[41-42] In most of the studies external load was quantified with the use of the accelerometery derived metric PlayerLoad™.[42] To the authors' knowledge there is currently no research on impact load and impact load asymmetry seen in netball players.

2.9 Summary

The current pool of research agrees that asymmetry is a very intricate topic. The various strength and jumping tasks and their associated performance metrics have proven to be reliable within- and between testing sessions; however, inter-limb asymmetries appear to be very task-, metric- and population specific. Special consideration should be given to how the inter-limb differences are calculated based on whether the task was performed unilaterally or bilaterally. Very little agreement exists between inter-limb asymmetry quantified during bilateral and unilateral variations of the same task. In order to create an inter-limb asymmetry profile for athletes it is important to include both unilateral and bilateral variations of different tasks (isometric, ballistic and plyometric) to see the full picture.

Current asymmetry studies are predominantly focused on inter-limb differences in strength assessments, and little is known about impact load asymmetries during sport specific drills in court-based team sports. The use of IMUs might be able to highlight inter-limb asymmetries during sports manoeuvres. This is of importance to the practitioner as evidence suggests that asymmetries are task- and metric-dependent, which highlights the need to quantify asymmetries during sport specific manoeuvres. Although IMU-derived tibial acceleration metrics obtained during running tasks and soccer specific drills demonstrated good reliability in previous studies, the between-session reliability of these metrics has not been investigated for court-based team sports yet. Calculating asymmetry ratios from these metrics can provide objective data to inform return-to-play, performance, and programming decisions but the between-session reliability of the asymmetry ratios quantified from these metrics has not been studied yet.

Even though most of the tools and metrics available to quantify inter-limb asymmetries seem to be reliable within- and between sessions, the within- and between-session reliability of the asymmetry scores themselves have only been reported for asymmetry quantified during the unilateral and bilateral variations of the CMJ and broad jump, and isometric and eccentric hamstring strength assessments. There is therefore a need to assess within- and between-session reliability of asymmetry quantified during other lower limb strength assessments, for different athletic (sport) populations, as research indicates that there is a high amount of variability in inter-limb asymmetry and the high reliability of the constituent performance metrics may have inflated the utility of between-limb comparisons.

Chapter 3: Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players

3.1 Introduction

Inter-limb asymmetry is measured as a ratio that compares the performance or function between two limbs, and is usually reported as a percentage difference of one limb with respect to the other.[2] Asymmetry measures can be quantified as scalars or vectors.[16] When an asymmetry measure is defined as a vector, the distance from zero represents the magnitude of the asymmetry, and the direction of the asymmetry is indicated by the value being positive or negative.[16] The direction of asymmetry refers to the limb that is stronger or favoured during a specific test, task or metric.[9] Inter-limb strength asymmetry has been shown to negatively affect performance tasks such as change of direction speed, jump height, and sport-specific skills such as kicking accuracy.[2,4] At present, no specific thresholds exist for reduced performance, but athletes with asymmetries of >15% may have an increased injury risk.[4] A further challenge in understanding inter-limb asymmetries in athletes is that they are task dependent.[4,9]

Isometric, ballistic and plyometric strength testing methods are often used to quantify asymmetries when assessing the physical performance characteristics of athletes.[10,28] In particular, as lower limb functional performance is of interest to strength and conditioning coaches, tests such as the isometric squat (ISQ) and mid-thigh pull,[12] countermovement jump (CMJ) and drop jumps (DJ) are commonly used. Both bilateral and unilateral testing variations can and have been used to quantify inter-limb asymmetries, with athletes performing the tests on force platforms.[11-12] During a unilateral assessment the task is performed with each limb sequentially placed on a force platform, while during a bilateral assessment a dual force-plate system is used, and each limb is placed on a separate plate in a bipodal stance.[17] Assessments on force platforms permit the acquisition of force-time curves and provides practitioners with a useful indication of athletes' force production and rate of force development capabilities.[9,12] This provides additional metrics such as peak and mean force, and impulse, that allow for some interpretation of the athlete's strategy while performing a task rather than only outcome measures such as jump height.[43]

Sport training and competition impose mechanical load on the musculoskeletal system.[39] Athletes that participate in high-intensity intermittent court-based sports such as netball experience a significant amount of braking and propulsive forces as they must attenuate high forces from impact with the ground to decelerate, and generate high forces to push away from the ground to accelerate.[43] Monitoring the number of ground impacts has been suggested to quantify the mechanical load that the lower limbs experience and the associated injury risk.[43] However, the magnitude of the forces experienced needs to be known rather than just the number of impacts to more accurately quantify the external load experienced by the musculoskeletal system.[43] It is now possible to measure the frequency and intensity of ground contacts with the use of skin-mounted inertial measurement units (IMU) on the tibia.[43-44] The advantage of IMUs are that they can be worn while athletes are in their sporting environment and provide more ecologically valid measures of impact.[35] Although the IMU metrics do not measure load at the tissue level, they may nevertheless be useful to provide objective measures of step counts, impact magnitude and cumulative load exposure. These metrics can also be monitored and compared between limbs to provide an asymmetry measure.[14]

A basic requirement for any performance assessment is high reliability.[45] This refers to the reproducibility of measured values when an assessment is repeated for the same individual.[4] The reliability of asymmetry metrics is critical to ensure that practitioners can quantify and compare inter-limb differences between repetitions and sessions.[15] Much of the recent strength asymmetry literature has been limited to evaluating the reliability of single-limb force-time variables that are used to calculate asymmetry ratios.[16] Although such measures typically demonstrate good reliability,[15] the reliability of derived asymmetry ratios using unilateral CMJs has been shown to be poor,[15] while for bilateral CMJs the evidence for asymmetry reliability is mixed.[15-16]. Similarly, good reliability has been demonstrated for step count and tibial acceleration metrics acquired from IMUs during running-based tasks,[14,37] but the reliability of asymmetry ratios calculated from these metrics has yet to be studied.

Therefore, there is a need to examine the within-session and between-session reliability of inter-limb asymmetry variables in commonly used unilateral and bilateral strength assessments to determine how consistent asymmetry magnitude and direction are within and between sessions.[14,35] In addition, the between-session reliability of impact load asymmetry measures needs to be investigated, particularly since IMUs have become more widely used and popularised for this purpose. Thus, the aim of this study was to investigate the within-day and between-day reliability of inter-limb asymmetry variables during unilateral and bilateral lower body strength assessments, as well as in step impact asymmetry during sport-specific drills in court-based athletes.

3.2 Methods

3.2.1 Participants

Twenty-five female university netball players (mean ± SD age: 20 ± 1.7, stature: 177.6 ± 7.0 cm, mass: 69.9 ± 8.3 kg) volunteered for this study. All participants were healthy and without any reported injuries for the three months prior to sampling. This study was approved by the

University of Pretoria's Faculty of Health Sciences Research Ethics Committee (503/2020). All participants were informed of the risks and benefits associated with participation and participants provided informed consent to participate in this study (Annexure H).

3.2.2 Procedures

Data collection was conducted during the netball pre-season while standard netball training continued as normal. Netball training consisted of a 60-minute court-based, tactical team training in the evening after testing on day 1 and day 3 of testing, with no additional training on days 2 and 4. Participants attended a familiarisation session one week before any data collection. Testing was then conducted over four days. Day 1 consisted of laboratory-based plyometric, ballistic and isometric strength assessments. Day 2 consisted of field-based netball-specific tasks in an indoor multi-purpose sports facility. The strength assessments of day 1 and the netball-specific tasks of day 2 were repeated on days 3 and 4, respectively. On day 1 participants were asked to complete an injury history questionnaire, measures of stature (Seca 217 portable stadiometer) and mass (Tanita Body Analyser BF-350) were recorded, and body fat percentage was estimated using bioelectrical impendence. A standardised dynamic warm-up consisting of movements such as leg swings, bodyweight squats and lunges, ankle-, hip- and knee mobility was performed before testing on each day.

A. Laboratory-based strength assessments (Day 1 and 3):

After the dynamic warm-up participants performed bilateral and unilateral variations of the isometric squat (ISQ), countermovement jump (CMJ) and drop jump (DJ). The tests were performed with the participants standing on two adjacent force plates (JM6090-06, Bertec, USA) sampling at 1000 Hz. The force plates were zeroed prior to each test, and force-time data was acquired and analysed using ForceDecks software (Vald Performance, Australia). The tests were conducted in the following order: CMJ, DJ and ISQ, and in each instance first the bilateral and then the unilateral variation of the test was administered. After a ~2-s still standing period to obtain a body weight measurement, participants were instructed to conduct the test. Three trials were conducted for bilateral and unilateral variations, with a 30-s rest period between trials and one- to two minutes' rest between sets of trials.

- *Bilateral and unilateral CMJ.* Participants were instructed to stand on the force plates with their hands on their hips. Their hands were required to remain in the same position throughout the test. Participants were instructed to jump as high as possible. Throughout the flight phase the test leg (or both legs for the bilateral variation) remained fully extended before landing back onto the force plate, returning to the starting position. The non-test leg was slightly flexed with the foot hovering above the ground and no additional swinging was allowed for that leg during the unilateral CMJ.

- *Bilateral and unilateral DJ.* Participants stood on a 20-cm box with their hands on their hips. Their hands were required to remain in the same position throughout the test. They stepped down onto the force plate with both feet simultaneously (bilateral assessment) or on the designated testing leg (unilateral assessment) and rebounded vertically off the ground as rapidly as possible. Participants were instructed to "react quickly off the ground and jump as high as possible". Throughout the flight phase the test leg (or both legs for the bilateral variation) remained fully extended before landing back onto the force plate, returning to the starting position. For the unilateral DJ the non-test leg was slightly flexed with the foot hovering above the ground and was not allowed to perform any additional swinging.
- *Bilateral and unilateral ISQ.* A custom-built squat rack was used for this test. Participants were instructed to step onto the centre of the force plates with their feet pointing forward in a partial squat position with the bar across the back of their shoulders. A goniometer was used to measure the hip and knee joint angles and the height of the bar adjusted so that both joints were flexed to approximately 140° in the squat position. Each trial was initiated with a countdown and participants were instructed to drive up against the bar as "fast and hard as possible" for three seconds. For the unilateral squat, the non-test leg was required to hover next to the test leg to aid in keeping the hips level, and for balance and stability.

B. Field-based netball-specific drills (Day 2 and 4):

The test sessions consisted of drills that formed part of the participants' normal warm-up routine before training or matches during the netball season. Tibial acceleration was measured using a 9-axis inertial measurement unit (IMU) (iMeasureU Blue Trident, Vicon Motion Systems Limited, Oxford, UK). Two IMUs were assigned to each participant while performing the netball-specific drills. The sensors were affixed with a Velcro strap to each leg on the medial aspect of the tibia, just above the medial malleolus. Data was recorded using the CaptureU mobile application (Vicon Motion Systems Limited, Oxford, UK) as participants performed the drills. After the standardised dynamic warm-up, the drills were performed in the following order.

- *Diagonal bound and stick (DB).* Participants were instructed to perform diagonal bounds for eight repetitions on each leg. The instruction was to leap as far and high as they could from the left to the right leg, and right to left leg, every time sticking the landing.
- *Continuous straight-line bounding (CB).* Participants were instructed to perform continuous straight-line bounding for eight repetitions on each leg. The instruction was to

leap as far and high as they could.

- *Loose-ball drill (LBD).* Participants paired up (A and B) and stood facing each other, ~5 m apart, with a netball ball. Participant A was the worker performing the drill. Participant B facilitated the drill by dropping the ball on the left or right side of her own body. As soon as the ball dropped, participant A ran forward to catch the ball before it bounced twice. She returned the ball to participant B and had to restart the drill as fast as possible by getting back to the starting position. Participant B repeated the drill on the other side. After ten drops, five on the left and five on the right, participant A was finished, and the drill was then administered for participant B.
- *Deflection drill (DD)*. Participants set up the same way as for the loose-ball drill. Participant A sprinted towards participant B. Participant B threw the ball in the air on either her left or right side. Participant A had to jump and deflect the ball back to participant B. Participant A then ran back to the starting position to reset the drill and repeat again. After ten deflections, five on the left and five on the right, participant A was finished and the same was done for participant B.
- *Repeated sprints (RS).* Participants performed ten repeated sprints over 10 m. The instruction was to sprint 10 m, stop and turn on their preferred leg, and sprint back to the start. The participants performed five repetitions without rest, self-selecting which leg to turn on for every turn.
- *Small-sided half-court game (2 v 2).* The small-sided half-court game included four participants. Participants were instructed to play a 2-minute game in a 3 x 3 m area. Two participants were attacking and two were defending. All netball rules applied. The aim was to play the ball between the two attacking players to score a goal by placing the ball on the floor in the “goal area”. If the defenders intercepted the ball, or the attacking players lost the ball, the opposite team was able to play the ball to their goal area.

3.2.3 Data processing

Data from all the netball-specific drills was analysed using the IMeasureU Step analysis software (Vicon Motion Systems Limited, Oxford, UK). The software provides total step counts, step count per intensity bin (total number of steps executed in 1 g intensity bands ranging from 1 g to >200 g), and impact loads (measured as an arbitrary unit that is calculated by multiplying the number of steps by the acceleration experienced at each contact) for each individual leg.

All force-time and impact load data were exported to Microsoft Excel™ to calculate inter-limb asymmetries and express the data as means and standard deviations (SD). For the strength assessments net force (ground reaction force – body weight) inter-limb asymmetries were quantified using the following variables: peak vertical force of the ISQ (FISQ), peak force during the CMJ take-off phase (FCMJ) and peak force during the DJ rebound take-off (FDJ). For the netball-specific drills inter-limb asymmetries were quantified for impact load in the DB, CB, LBD, DD, RS and 2 v 2.

The following equations were used to quantify inter-limb asymmetries:[11]

Bilateral asymmetry equation: (right leg – left leg) / (right leg + left leg) x 100

Unilateral asymmetry equation: 100 / (maximum value) x (min minimum value) x (-1) + 100

The bilateral asymmetry equation was used to calculate the inter-limb asymmetry for every trial of the bilateral strength assessments, as well as impact load during the netball-specific drills. The unilateral asymmetry equation was used to quantify inter-limb asymmetries for each of the trials of the unilateral strength assessments. All asymmetry metrics were expressed as vector quantities (with magnitude and direction) where asymmetry to the right was indicated by a positive value, and asymmetry to the left by a negative value. Thus, the asymmetry was calculated for each trial and then averaged for further analysis.

3.2.4 Statistical analysis

For additional analyses the data was transferred into IBM SPSS Statistics 27. Within- and between-day reliability was quantified for each participant for all performance and asymmetry metrics. For the court-based assessments only between-day reliability was calculated because there was only one repetition done for each drill on the two testing days. Absolute reliability, the degree to which repeated measurements vary for individuals, was assessed using the mean within-individual coefficient of variation ((CV).[46] The CV was calculated to describe within-day ([SD of 3 trials] / [mean of 3 trials] x 100) and between-day ([SD of D1 and D2 / mean of D1 and D2] x 100) absolute reliability, where D1 and D2 represent the average of the three trials on each day. CV values of ≤10% were deemed acceptable.[16,47] Relative reliability describes the degree to which participants maintain their position in a sample with repeated measures.[46] The intraclass correlation coefficient (ICC) was determined to describe relative reliability using a two-way mixed-effects model with absolute agreement and 95% confidence intervals. ICC values <0.5 were considered poor, from 0.5 to 0.75 moderate, from 0.76 to 0.90 good, and greater than 0.90 were considered excellent reliability.[12,48]

3.3 Results

Descriptive statistics for the test outcome measures are shown in Table 1 (strength assessments) and Table 2 (netball-specific drills). Three participants were not able to attend both days for the strength assessments and netball-specific drills and were excluded from the study. Thus, only 22 participants had complete data sets that were included in this study.

Within-day reliability results for the strength assessments are shown in Table 1. Force metrics for all three unilateral strength assessments had good to excellent within-day reliability (CV: 3.5 – 8.0%; ICC: 0.84 – 0.98). Reliability of most force metrics during the bilateral strength assessments was good to excellent (CV: 3.4 – 10.5%; ICC: 0.89 – 0.96).

Scalar asymmetry values and within-day asymmetry reliability for force variables attained during the bilateral and unilateral strength tests are reported in Table 3. The scalar asymmetry values were calculated to describe the group mean asymmetry instead of vector asymmetry values, to accurately described the magnitude of asymmetry seen across the group. Vector asymmetry values would've artificially lowered the magnitude of the group's mean asymmetry result because of the different negative and positive values indicating the direction of the asymmetry. Group mean asymmetry values during the bilateral strength assessments ranged from 3.5 ± 2.7% (FCMJ asymmetry) to 8.3 ± 5.7% (FDJ asymmetry). During the unilateral strength assessments asymmetry values ranged from 5.3 ± 3.0% (FCMJ asymmetry) to 11.2 ± 6.3% (FDJ asymmetry).

Although not visually represented in a table, vector asymmetry values were considered when determining the within-day reliability of the asymmetry variables of the unilateral and bilateral strength assessments (i.e., both magnitude and direction of asymmetry was accounted for). With the exception of bilateral FCMJ asymmetry on day 2 (CV: 8.3%), all force asymmetry values in all of the strength assessments across both days demonstrated unacceptable CVs, ranging from 26.4 - 6455%. Table 3 highlights the average within-individual CV. ICC values for the bilateral assessments on both days were good to excellent (0.89 – 0.94). However, for unilateral strength assessments only FCMJ on day 1 showed a moderate ICC (0.72), while the ICC for all other unilateral asymmetry variables were poor to moderate, ranging from 0.16 to 0.67. The ICC was calculated from the whole group data.

Between-day reliability for all force metrics from all the strength assessments was good to excellent (CV: 4.0 – 13.5%; ICC: 0.70 – 0.96) (Table 4). CV values for the asymmetry variables was poor, with a range of 28.2 – 2760.9%. ICC values for bilateral FDJ and FISQ was good, ICC: 0.90 and 0.82 respectively. The ICC for FCMJ was excellent (0.98). The unilateral assessments had good ICC values for FDJ and FISQ (0.79 and 0.78 respectively). Unilateral FCMJ had a poor ICC (0.25). The only force asymmetry variable that had good reliability was unilateral FDJ asymmetry (CV: 7.6%; ICC: 0.79).

Table 5 displays impact load and between-day reliability for the left and right leg during netball-specific training drills. Impact load metrics for the netball-specific drills that had specific repetitions prescribed for each side (DB, CB, LBD and DD) had moderate between-day reliability (CV: 11.1 – 19.0; ICC: 0.72 – 0.86). The drills that were open and allowed for self-selected turning legs or random gameplay (RS and 2 vs 2), had poor between-day reliability (CV: 14.8 – 23.4;

ICC: 0.44 – 0.57). When looking at the entire session, combining all netball-specific drills, the between-day reliability for left and right leg impact load showed moderate reliability (CV: 11.1% and 11.3% and ICC: 0.73 and 0.75).

Impact load asymmetry and between-day impact load asymmetry reliability during netball-specific training drills are shown in Table 6. For the individual netball-specific drills asymmetry values ranged from 5.8 ± 5.3% (LB) to 11.7 ± 8.1% (CB). Overall asymmetry for the session combining all the netball-specific drills was 5.0 ± 3.9% on day 1 and 5.1 ± 3.1% on day 2. Between-day reliability for impact load asymmetry for all the netball-specific drills was poor (CV: 44.3 – 422.6%; ICC: -0.01 – 0.26).

3.4 Discussion

This study aimed to investigate the within- and between-day reliability of inter-limb asymmetry in force production during unilateral and bilateral lower body strength assessments as well as between-day reliability of impact load and impact load asymmetry using shin-mounted IMUs during netball-specific training drills.

Force metrics for both variations of all the lower body strength assessments had good to excellent within- and between-day reliability. Force asymmetry variables for all strength assessments demonstrated unacceptable within-day absolute reliability (CV: 26.4 – 645.5%). Relative within-day reliability for the force asymmetries in the bilateral strength tests were good to excellent (ICC: 0.89 – 0.94) and poor to moderate for the unilateral strength assessments (ICC: 016 – 0.67). Absolute between-day reliability for all force asymmetry variables were poor. Relative between-day reliability for force asymmetry variables obtained through bilateral assessments ranged from good to excellent. The unilateral variations demonstrated moderate to poor relative between-day reliability. Absolute and relative asymmetry reliability scores represent different elements of reliability. As discussed previously, individual variation in absolute asymmetry scores (CV) may be unacceptably high, and relative position of asymmetry scores within a group may be acceptably agreeable on repeated observations (ICC). Absolute reliability speaks to how reliably we could identify the actual scores of the individuals, whereas relative reliability speaks to how reliably we could differentiate between the scores of different individuals.

Impact load during most sport-specific drills had moderate relative between-day reliability, but the repeated sprints and small-sided half-court game had poor relative between-day reliability. All CVs exceeded 10% and thus absolute reliability for all impact load metrics was not acceptable. Impact load asymmetry demonstrated very poor between-day reliability.

In a study with recreational soccer players Burland et al.[14] reported generally high between-day reliability for cumulative impact load during acceleration-deceleration, plant and cut, and COD tasks (ICC: 0.75 – 0.89). In the current study slightly lower reliability (ICC: 0.52 – 0.75) was found for impact load during the netball specific drills that involved a prescribed number of repetitions per side (DB, CB, LBD, DD). Lower impact load reliability (ICC: 0.28 – 0.40) was demonstrated for the drills that were less constrained and allowed for self-selected turning legs (RS) and simulated match play (2 v 2). When considering the entire session (all the drills collectively) the cumulative impact load showed moderate reliability (ICC: 0.58 and 0.60 for left and right respectively) and lower CVs (11%) than the individual drills (13 – 23%). Despite generally high relative reliability for impact load metrics of most drills, the high between-session CVs indicate that only large changes may be interpreted as meaningful fluctuations in unilateral impact load between days or as differences between drills or session types.[16]

In the current study, impact load asymmetry was calculated as the inter-limb difference divided by the sum of the limbs, expressed as a percentage. Both the absolute and relative reliability of impact load asymmetry was very poor for all drills. Very few studies have quantified between-session relative reliability of asymmetry data, making it difficult to make any comparisons with the current results. Bailey et al.[16] showed excellent relative reliability (ICC: 0.88) for peak force asymmetry during a CMJ but also found very poor absolute reliability (CV: 1 497%). Pérez-Castilla et al.[18] also found that none of the asymmetry variables met the criterion for acceptable relative reliability during the unilateral or bilateral standing broad jump (ICC: -0.40 – 0.58). In a different study by Pérez-Castilla et al.[15] none of the asymmetry variables during a unilateral CMJ met the criterion for acceptable reliability (ICC: 0.15 – 0.64), however acceptable reliability was reached for most of the asymmetry variables during the bilateral CMJ (ICC: 074 – 0.77). In the current study vector asymmetry values were considered when determining the within-day reliability of the asymmetry variables of the strength assessments and similar results were found. Poor absolute reliability (CV: 26.4 – 645.5%) was seen for all force asymmetry values, except for peak take-off force asymmetry during the bilateral CMJ. In the current study slightly higher within-day relative reliability was seen for the bilateral assessments (ICC: 0.89 – 0.94) compared to previous studies. Similar to Pérez-Castilla et al.[15] between-day relative reliability for the force asymmetry metric during the bilateral CMJ was excellent (ICC: 0.98). Force asymmetry metrics for the unilateral strength assessments had good ICC values for the DJ and ISQ but was poor for the unilateral CMJ.

The impact load asymmetry results seen in the current study are most likely due to the variable nature in the direction of asymmetry between sessions. The implication for practitioners is that a single measure of inter-limb asymmetry should not be used to infer consistent preference or dominance of a limb during sport-specific drills, and that multiple sessions may need to be monitored and data assessed on an individual basis. Poor reliability of asymmetry metrics also poses a problem for research that aims to understand its relevance for performance and injury risk, where high variability limits its potential use for predicting or tracking an outcome of interest.

Although the current study provides relevant information on the within- and between-session reliability of impact load and impact load asymmetry, it is not without limitations. Even though each drill in the sport-specific assessments included multiple repetitions or actions, only one trial of each drill on each day and only one retest day were possible based on the allowed time with competitive athletes without disturbing the regular training schedule. Multiple retest days would permit a more detailed assessment of day-to-day variation in asymmetry during field drills. Participants all volunteered from the same convenience sample of university netball players, and the high between-subject variation may have contributed to poor group reliability statistics. Finally, although participants were familiar with the drills as they formed part of their regular warm-up routine, practice trials before the measured trial may yield higher reliability.

3.5 Conclusion

In conclusion, single limb impact load in standardized warm-up drills shows moderate relative reliability between sessions in trained, experienced netball players, but drills including small-sided games show less consistency. Furthermore, individual impact load variation is high (>10%) between sessions and should be used cautiously when monitoring player training load using wearable sensors. Based on current findings, clinical interpretations and interventions based on inter-limb comparisons should not rely on asymmetry percentage from field-based drills using single trials. Despite their apparent higher ecological validity, the relative reliability and individual consistency of impact load asymmetry is unacceptably poor for identifying real and meaningful changes. There is a need for more measurement studies on IMU-derived asymmetry metrics and their calculation to identify reliable ways to inform practitioners in sport and exercise science research and practice.

The between-session reliability of force variables obtained through unilateral and bilateral variations of isometric, ballistic and plyometric strength assessments was good. On the other hand, the asymmetry variables presented poor reliability, possibly due to the variable nature of the direction of asymmetry. Before making any decisions regarding an athlete’s injury risk or asymmetry profile, practitioners should examine the reliability over repeated sessions to ensure that the magnitude and direction is consistent.

Table 1: Absolute and relative force and within-day reliability for bilateral and unilateral strength tests on two days (mean ± SD)

			DAY 1				DAY 2			
			Bilateral Test							
			Absolute (N)	**Relative ($N \cdot kg^{-1}$)**	**CV**	**ICC (95% CI)**	**Absolute (N)**	**Relative ($N \cdot kg^{-1}$)**	**CV**	**ICC (95% CI)**
CMJ	**Peak take-off force**	**Left**	790.5 ± 108.6	11.5 ± 1.5	3.6	0.96 (0.90-0.98)	785.2 ± 106.0	11.4 ± 1.3	3.4	0.96 (0.92-0.98)
		Right	797.8 ± 102.2	11.6 ± 1.6	4.1	0.95 (0.87-0.98)	792.7 ± 94.1	11.5 ± 1.3	4.8	0.92 (0.81-0.97)
		Total	1547.0 ± 191.7	22.5 ± 2.8			1550.4 ± 180.2	22.6 ± 2.1		
DJ	**Peak drive-off force**	**Left**	1354.5 ± 315.5	19.8 ± 4.5	8.4	0.94 (0.88-097)	1440.5 ± 256.9	21.0 ± 3.4	8.7	0.89 (0.76-0.95)
		Right	1506.8 ± 340.3	22.0 ± 5.0	10.5	0.89 (0.78-0.95)	1633.1 ± 368.3	23.8 ± 5.5	8.9	0.93 (0.86-0.97)
		Total	2769.9 ± 571.9	40.4 ± 8.0			2997.9 ± 559.9	43.7 ± 7.8		
ISQ	**Peak vertical force**	**Left**	1057.7 ± 190.1	15.4 ± 2.6	5.7	0.96 (0.92-0.98)	1066.3 ± 200.4	15.5 ± 2.5	5.6	0.96 (0.92-0.98)
		Right	1081.4 ± 189.3	15.7 ± 2.8	5.9	0.95 (0.89-0.98)	1085.5 ± 207.4	15.8 ± 3.0	7.1	0.92 (0.84-0.96)
		Total	2118.0 ± 352.0	30.8 ± 5.0			2127.4 ± 364.0	30.9 ± 4.8		
			Unilateral Test							
			Absolute (N)	**Relative ($N \cdot kg^{-1}$)**	**CV**	**ICC (95% CI)**	**Absolute (N)**	**Relative ($N \cdot kg^{-1}$)**	**CV**	**ICC (95% CI)**
CMJ	**Peak take-off force**	**Left**	1286.0 ± 169.4	18.7 ± 2.1	4.2	0.96 (0.91-0.98)	1307.0 ± 206.8	18.9 ± 2.0	4.1	0.96 (0.92-0.98)
		Right	1277.1 ± 195.0	18.5 ± 2.1	3.5	0.98 (0.96-0.99)	1311.0 ± 214.0	19.0 ± 2.0	3.6	0.97 (0.95-0.99)
DJ	**Peak drive-off force**	**Left**	1905.1 ± 283.1	26.4 ± 7.0	5.7	0.91 (0.82-0.96)	2036.9 ± 327.4	29.6 ± 4.6	5.1	0.94 (0.88-0.97)
		Right	1953.8 ± 345.4	26.9 ± 7.0	8.0	0.91 (0.81-0.96)	2060.8 ± 291.5	30.0 ± 3.8	7.8	0.84 (0.68-0.93)
ISQ	**Peak vertical force**	**Left**	1761.9 ± 371.6	25.5 ± 4.2	4.1	0.98 (0.97-0.99)	1834.5 ± 376.3	26.5 ± 4.3	4.8	0.98 (0.96-0.99)
		Right	1788.3 ± 358.6	25.8 ± 3.7	4.8	0.98 (0.95-0.99)	1875.9 ± 356.3	27.1 ± 3.9	4.4	0.98 (0.96-0.99)

CMJ: Countermovement jump; DJ: Drop jump; ISQ: Isometric squat

Table 2: Total steps, average step intensity and duration of netball-specific drills on two days

		DAY 1			DAY 2		
		Total steps (n)	**Average intensity (g)**	**Duration (min:s)**	**Total steps (n)**	**Average intensity (g)**	**Duration (min:s)**
DB	**Left**	19.6 ± 4.2	13.0 ± 4.6	00:26	19.7 ± 5.6	12.9 ± 4.3	00:24
	Right	20.2 ± 4.2	12.4 ± 4.2		20.1 ± 5.0	12.2 ± 3.7	
CB	**Left**	12.0 ± 3.1	21.2 ± 7.6	00:15	12.1 ± 3.7	24.3 ± 8.5	00:15
	Right	12.3 ± 4.3	25.7 ± 13.8		12.3 ± 4.1	23.8 ± 10.3	
LBD	**Left**	34.6 ± 6.2	21.8 ± 5.2	00:41	31.1 ± 4.5	27.7 ± 7.4	00:35
	Right	34.9 ± 6.2	22.8 ± 7.2		32.1 ± 3.8	26.8 ± 7.0	
DD	**Left**	40.9 ± 7.7	20.1 ± 5.0	00:43	38.2 ± 6.9	24.3 ± 6.8	00:40
	Right	40.2 ± 7.0	21.0 ± 4.7		37.2 ± 6.6	24.8 ± 6.9	
RS	**Left**	26.9 ± 4.2	31.5 ± 8.5	00:29	26.7 ± 3.5	37.1 ± 10.2	00:28
	Right	26.3 ± 4.2	34.1 ± 11.1		26.6 ± 4.0	34.3 ± 8.7	
2 v 2	**Left**	99.3 ± 24.4	13.8 ± 2.5	02:27	111.7 ± 12.3	16.3 ± 3.5	02:36
	Right	98.5 ± 20.7	14.9 ± 4.1		110.8 ± 13.1	17.2 ± 4.4	
ES	**Left**	538.9 ± 65.2	13.0 ± 1.6	26:00	544.1 ± 49.8	14.8 ± 2.3	25:10
	Right	536.0 ± 65.8	13.8 ± 2.5		541.4 ± 46.9	14.9 ± 2.6	

DB: Diagonal bound and stick; CB: Continuous straight-line bounding; LBD: Loose-ball drill; DD: Deflection drill; RS: Repeated sprints; 2 vs 2: Small-sided game; ES: Entire session

Table 3: Asymmetry (%) and within-day asymmetry reliability for bilateral and unilateral strength tests on two days (mean ± SD)

			DAY 1			DAY 2		
			Asymmetry	**CV**	**ICC (95% CI)**	**Asymmetry**	**CV**	**ICC (95% CI)**
CMJ	**Peak take-off force**	Bilateral	3.5 ± 2.7	53.2	0.91 (0.82-0.96)	3.8 ± 3.2	8.3	0.94 (0.87-0.97)
		Unilateral	5.5 ± 2.9	156.0	0.72 (0.43-0.87)	5.3 ± 3.0	140.2	0.16 (-0.65-0.62)
DJ	**Peak drive-off force**	Bilateral	7.7 ± 4.9	75.2	0.89 (0.78-0.95)	8.3 ± 5.7	179.3	0.90 (0.79-0.95)
		Unilateral	11.2 ± 6.3	215.8	0.67 (0.32-0.85)	9.1 ± 5.1	26.4	0.53 (0.08-0.79)
ISQ	**Peak vertical force**	Bilateral	5.6 ± 3.0	41.6	0.89 (0.78-0.95)	6.6 ± 4.5	89.0	0.92 (0.84-0.97)
		Unilateral	7.0 ± 3.1	59.9	0.67 (0.33-0.85)	6.5 ± 2.7	102.0	0.62 (0.24-0.83)

CMJ: Countermovement jump; DJ: Drop jump; ISQ: Isometric squat; CI: confidence interval

Table 4: Between-day reliability for force and force asymmetry in bilateral and unilateral tests

			BILATERAL TEST		**UNILATERAL TEST**	
			CV	**ICC (95% CI)**	**CV**	**ICC (95% CI)**
CMJ	**Peak take-off force**	**Left**	4.1	0.92 (0.81-0.97)	4.9	0.88 (0.72-0.95)
		Right	4.0	0.90 (0.77-0.96)	4.7	0.92 (0.81-0.97)
		Asymmetry	1334.6	0.98 (0.95-0.99)	130.8	0.25 (-0.83-0.69)
DJ	**Peak drive-off force**	**Left**	8.6	0.84 (0.62-0.94)	7.2	0.82 (0.51-0.93)
		Right	9.6	0.74 (0.40-0.89)	5.3	0.89 (0.69-0.96)
		Asymmetry	125.4	0.90 (0.76-0.96)	7.6	0.79 (0.47-0.92)
ISQ	**Peak vertical force**	**Left**	4.4	0.94 (0.87-098)	4.8	0.96 (0.87-0.98)
		Right	6.9	0.85 (0.63-0.94)	5.5	0.93 (0.81-0.97)
		Asymmetry	30	0.82 (0.57-0.93)	184.9	0.78 (0.47-0.91)

CMJ: Countermovement jump; DJ: Drop jump; ISQ: Isometric squat; CI: confidence interval

Table 5: Impact load (mean ± SD) and between-day reliability for the left and right limbs during netball-specific training drills

		DAY 1	DAY 2		
		Impact load (AU)		CV	ICC (95% CI)
DB	**Left**	249.4 ± 94.4	246.6 ± 85.5	13.5	0.75 (0.48-0.89)
	Right	248.7 ± 95.0	246.0 ± 110.7	19.0	0.52 (0.13-0.77)
CB	**Left**	246.7 ± 84.4	277.7 ± 91.0	17.2	0.56 (0.21-0.79)
	Right	283.0 ± 109.4	269.9 ± 98.0	15.9	0.68 (0.37-0.85)
LBD	**Left**	755.3 ± 221.9	867.1 ± 286.3	16.4	0.58 (0.22-0.80)
	Right	782.6 ± 214.1	856.7 ± 224.5	13.4	0.67 (0.35-0.85)
DD	**Left**	808.3 ± 209.9	912.2 ± 254.0	12.8	0.57 (0.20-0.80)
	Right	837.1 ± 212.3	915.5 ± 275.1	13.6	0.58 (0.23-0.80)
RS	**Left**	828.4 ± 195.1	982.6 ± 257.7	15.3	0.40 (0.00-0.69)
	Right	872.3 ± 256.7	894.2 ± 196.6	14.8	0.34 (-0.09-0.67)
2 v 2	**Left**	1364.9 ± 415.4	1826.8 ± 444.0	23.4	0.33 (-0.10-0.66)
	Right	1451.1 ± 431.7	1913.4 ± 595.3	21.3	0.28 (-0.08-0.60)
ES	**Left**	7073.6 ± 1438.4	8109.7 ± 1725.3	11.3	0.58 (0.08-0.82)
	Right	7430.9 ± 1764.7	8130.0 ± 1769.3	11.1	0.60 (0.24-0.81)

DB: Diagonal bound and stick; CB: Continuous straight-line bounding; LBD: Loose-ball drill; DD: Deflection drill; RS: Repeated sprints; 2 vs 2: Small-sided game; ES: Entire session; CI: confidence interval

Table 6: Impact load asymmetry (%) and between-day reliability during netball-specific training drills

	DAY 1	DAY 2	CV	ICC (95% CI)
DB	10.5 ± 9.9	11.7 ± 8.1	341.1	-0.21 (-0.61-0.24)
CB	11.6 ± 8.2	8.3 ± 5.8	306.0	0.02 (-0.35-0.41)
LBD	7.0 ± 5.0	9.5 ± 5.7	199.8	0.11 (-0.33-0.51)
DD	5.8 ± 5.3	7.4 ± 5.6	422.6	-0.14 (-0.54-0.30)
RS	8.4 ± 6.2	6.1 ± 5.0	311.0	-0.003 (-0.33-0.37)
2 v 2	9.2 ± 7.9	7.0 ± 4.9	122.9	0.15 (-0.30-0.54)
ES	5.0 ± 3.9	5.1 ± 3.1	44.3	-0.07 (-0.47-0.35)

DB: Diagonal bound and stick; CB: Continuous straight-line bounding; LBD: Loose-ball drill; DD: Deflection drill; RS: Repeated sprints; 2 v 2: Small-sided game; ES: Entire session; CI: confidence interval

Chapter 4: Conclusion

4.1 Summary

Inter-limb asymmetries are prevalent in sport and have a possible effect on athletic performance and injury risk. Current research often reports on the reliability of the performance variables achieved during specific tasks used to quantify asymmetries, but rarely report on the reliability of the asymmetry measure itself.[15-16] Results from recent studies support that the reliability of constituent variables is good, but ratios calculated from them has been shown to be unacceptable.[15,18] For an asymmetry to be considered "real" the asymmetry scores should be more than the variability of the test, usually indicated by the CV.[1,11] Any variability in the asymmetry measure will be missed if the reliability of the single-leg performance variables is the only reliability reported on in asymmetry studies.[16]

Therefore, one of the aims of the current study was to determine the within- and between-day reliability of PF and inter-limb PF asymmetry variables in commonly used unilateral and bilateral isometric, ballistic and plyometric lower body assessments to determine how consistent asymmetry magnitude and direction are within- and between sessions. In agreement with existing literature, all force metrics for both variations of all the lower body strength assessments had good to excellent within- and between-session absolute and relative reliability. On the other hand, force asymmetry variables for all strength assessments demonstrated unacceptable within-day absolute reliability (CV: 26.4 – 645.5%), good to excellent relative within-day reliability for the force asymmetries in the bilateral strength tests (ICC: 0.89 – 0.94) and poor to moderate for the unilateral strength assessments (ICC: 016 – 0.67). Absolute between-day reliability for all force asymmetry variables were poor. Relative between-day reliability for force asymmetry variables obtained through bilateral assessments ranged from good to excellent but the unilateral variations demonstrated moderate to poor relative between-day reliability. Based on these results practitioners should use caution when considering the results of strength asymmetry assessments, as they may not be as reliable as they often seem to be, which may reflect the very task- and metric-specific nature and the inconsistency in the magnitude and direction of strength asymmetry between sessions.[1,16]

Quantifying inter-limb asymmetries during sport-specific movements will be valuable to the practitioner and might provide more ecologically objective data for performance and return-to-play decisions. IMUs attached to the tibia make it possible to measure the frequency and intensity of ground contacts while athletes are participating in their sport.[35,43-44] Good reliability has been demonstrated for step count and tibial acceleration metrics acquired from IMUs during running-based tasks,[14,37] but the reliability of asymmetry ratios calculated from these metrics has yet to be studied. Therefore, the second aim of this study was to quantify the between-day reliability for impact load and impact load asymmetry during sport-specific drills in court-based athletes. The results show that single limb impact load during the sport-specific drills that was controlled by a prescribed number of repetitions per limb had moderate relative between-day reliability and the drills that were less constrained had poor relative between-day reliability. Furthermore, variation is high (>10%) between sessions for individual impact load and should be used cautiously when monitoring player training load using wearable sensors. Impact load asymmetry variables demonstrated very poor between-day reliability, which indicates that clinical interpretations and interventions based on inter-limb comparisons should not rely on asymmetry percentage from field-based drills using single trials. Based on the findings of the current study, the relative reliability of impact load asymmetry is unacceptably poor for identifying real and meaningful changes in asymmetry.

4.2 Limitations

Even though participants in this study were all from the same convenience sample of university netball players, the high between-subject variation may have contributed to poor group reliability statistics. To quantify absolute reliability, the CV or standard error of measurement (SEM) can be calculated. Both these measures of absolute reliability have assumptions associated with them. SEM assumes the lack of proportional bias and CV assumes the opposite.[16] A possible limitation to the current study could be that we didn't perform an evaluation of proportional bias, or the lack thereof, to justify the selection of CV to describe absolute reliability. For the strength assessments, multiple trials were included and a familiarisation session was included, but perhaps better test familiarity could yield higher reliability. Potential variability in fatigue across testing days because of netball training sessions that took place after testing could have also affected the test-retest reliability. For the sport-specific assessments, only two testing days were possible and even though each drill included multiple repetitions, players only performed one trial of each drill. Multiple trials and retest days would permit a more detailed assessment of day-to-day variation in asymmetry during field drills. Finally, although participants were familiar with the drills as they formed part of their regular warm-up routine, practice trials before the measured trials may yield higher reliability.

4.3 Practical implications and future research

As with previous literature, within-and between-session reliability for single leg performance variables for both unilateral and bilateral variations of the strength assessments are excellent, but the force asymmetry measures show high within- and between-session variability. The relative between-session reliability for the asymmetry ratio quantified during bilateral assessments are good, however, practitioners should be sure that for the asymmetry to be meaningful and real, the asymmetry value should be higher than the variability of the test.

Caution should be used when quantifying asymmetries with unilateral tasks, as these have been found to show poor between-session reliability. This has practical implications to the practitioner who has the need to quantify unilateral lower-limb asymmetry in capacity, which can't be done through bilateral assessments because they highlight the between-limb differences in compensatory strategies. The unilateral drop jump showed good reliability in the current study and practitioners may consider using that specific assessment with their athletes after evaluating its reliability with that specific cohort. Practitioners should therefore not only look at the ecological validity of a specific test to create an asymmetry profile of an athlete, but also consider the reliability and variability of the test, test metrics and asymmetry measures before basing any decision or programming on the results.

Findings from the second part of this study show that single limb impact load in standardized warm-up drills had moderate relative reliability between sessions in netball players, but small-sided games and repeated sprints showed less consistency and high individual impact load variation between sessions. Practitioners should be cautious when monitoring asymmetry in player training load using wearable sensors, and clinical interpretations and interventions based on inter-limb comparisons should not rely on impact load asymmetry percentage from field-based drills using single trials. Even though wearable sensors have apparent higher ecological validity, the relative reliability and individual consistency of impact load asymmetry is unacceptably poor for identifying real and meaningful changes. In order to identify reliable ways to inform practitioners in sport and exercise science research and practice, there is a need for more measurement studies on IMU-derived asymmetry metrics and their calculation. The current study supports existing evidence that where there is a need for a lower limb asymmetry profile in an athlete or team, practitioners are advised to quantify both inter-limb differences and the reliability of asymmetry scores. Before decisions on performance or sports participation are based on asymmetry results, practitioners are advised to interpret scores on an individual basis, with inter-limb asymmetries measured and monitored longitudinally as a vector value, across various tasks and drills.

References

1. Parkinson AO, Apps CL, Morris JG, Barnett CT, Lewis MGC. The calculation, thresholds and reposrting of inter-limb strength asymmetry: A systematic review. J Sports Sci Med. 2021; 20:594-617.

2. Bishop C, Turner A, Read P. Effects of inter-limb asymmetries on physical and sports performance: A systematic review. J Sports Sci. 2018; 36(10):1135-44.

3. Fort-Vanmeerhaege A, Gual G, Romero-Rodriguez D, Unnitha V. Lower limb neuromuscular asymmetries in volleyball and basketball players. J Hum Kinet. 2016; 50(1):135-43. doi:10.1515/hukin-2015-0150

4. Bishop C, Turner A, Jarvis P, Chavada S, Read P. Considerations for selecting field-based strength and power fitness tests to measure asymmetries. J Strength Cond Res. 2017; 31(9):2635-44.

5. Madruga-Parera M, Dos'Santos T, Bishop C, Turner A, Blanco D, Beltran-Garrido V, Moreno-Perez V, Romero-Rodriguez D. Assesing inter-limb asymmetries in soccer players: Magnitude, direction and association with performance. J Hum Kinet. 2021; 79:41-53.

6. Helme M, Tee J, Emmonds S, Low C. Does lower-limb asymmetry increase injury risk in sport? A systematic review. Phys Ther Sport. 2021; 49:204-13.

7. Weakley, J, Black G, McLaren Shaun, Scantlebury Sean, Suchomel Timothy J., McMahon Eric, et al. Testing and profiling athletes: Recommendations for test selection, implementation, and maximizing information. Strength & Conditioning Journal. 2023; doi:10.1519/ssc.0000000000000784

8. Bishop C, Turner A, Maloney S, Lake J, Loturco I, Bromley T, Read P. Drop jump asymmetry is associated with reduced sprint and change-of-direction speed performance in adult female soccer players. Sports (Basel). 2019; 7(29):1 - 10.

9. Bishop C, Pereira LA, Reis VP, Read P, Turner AN, Loturco I. Comparing the magnitude and direction of asymmetry during the squat, countermovement and drop jump tests in elite youth female soccer players. J Sports Sci. 2020; 38(11-12):1296-303.

10. Bishop C, Lake J, Loturco I, Papadopoulus K, Turner A, Read P. Inter-limb asymmetries: The need for an individual approach to data analysis. J Strength Cond Res. 2021; 35(1):695-701. doi:https://doi.org/10.1519/jsc.0000000000002729

11. Bishop C, Read P, Chavad S, Jarvis P, Turner A. Inter-limb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. Strength Cond J. 2018; 40(4):1-6.

12. Bishop C, Read P, Chavad S, Jarvis P, Turner A. Using unilateral strength, power and reactive strength tests to detect the magnitude and direction of asymmetry: A test-retest design. Sports (Basel). 2019; 7(3):1-14. doi:http://dx.doi:10.3390/sports7030058

13. Wylde MJ, Callaway AJ, Williams JM, Yap J, Leow S, Yong LC. Limb specific training magnitude and asymmetry measurement to discriminate between athletes with and without unilateral or bilateral lower limb injury history. Phys Ther Sport. 2022; 56:76-83.

14. Burland JP, Outerleys JB, Lattermann C, Davis IS. Reliability of wearable sensors to assess impact metrics during sport-specific tasks. J Sports Sci. 2021; 39:406-11. doi:https://doi.org/10.1080/02640414.2020.1823131

15. Peréz-Castilla A, García-Ramos A, Janicijevic D, Delgado-García G, De la Cruz JC, Rojas F.J, Cepero M. Between-session reliability of performance and asymmetry varaiables obtained during unilateral and bilateral countermovement jumps in basketball players. PLoS ONE. 2021; 16(7) doi:https://doi.org/10.1371/journal.pone.0255458

16. Bailey CA, Sato K, McInnis TC. A technical report on reliability measurement in asymmetry studies. J Strength Cond Res. 2021; 35:1779-83.

17. Bishop C, Read P, Lake J, Loturco I, Dawes J, Madruga M, Romero-Rodrigues D, Chavda S, Turner A. Unilateral isometric squat: Test reliability, interlimb asymmetries, and relationships with limb dominance. J Strength Cond Res. 2021; 35:S144-S51.

18. Pérez-Castilla A, García-Ramos A, Janicijevic D, Miras-Moreno S, De la Cruz J.C, Rojas F.J, Cepero M. Unilateral or bilateral standing broad jumps: Which jump type provides inter-limb asymmetries with a higher reliability? J Sports Sci Med. 2021; 20(2):317-27. doi:https://doi.org/10.52082/jssm.2021.317

19. Bailey CA, Sato K, Alexander R, Chiang C, Stone MH. Isometric force production symmetry and jumping performance in collegiate athletes. J. trainology. 2013; 2:1-5.

20. Benjanuvatra N, Lay BS, Alderson JA, Blanksby BA. Comparison of ground reaction force asymmetry in one- and two-legged countermovement jumps. J Strength Cond Res. 2013; 27(10)

21. Maloney, SJ. The relationship between asymmetry and athletic performance: A critical review. J Strength Cond Res. 2019; 33(9):2579-93.

22. Jaric, S. Muscle strength testing: Use of normalisation for body size. Sports Med. 2002; 32:615-31.

23. Comyns TM, Flanagan EP, Fleming S, Fitzgerald E, Harper DJ. Inter-day reliability and usefulness of a reactive strength index derived from 2 maximal rebound jump tests. Int J Sports Physiol Perform. 2019; 29:1200-4. doi:https://doi.Org/10.1123/ijspp.2018-0829

24. Brady CJ, Harrison AJ, Comyns TM. A review of the reliability of biomechanical variables produced during the isometric mid-thigh pull and isometric squat and the reporting of normative data. Sports Biomech. 2020; 19(1):1-25. doi:https://doi.org/10.1080/14763141.2018.1452968

25. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 2 - training considerations for improving maximal power production. Sports Med. 2011; 41(2):125-46.

26. Brady CJ, Harrison AJ, Flanagan EP, Haff GG, Comyns TM. A comparison of the isometric midthigh pull and isometric squat: Intra-day reliability, usefulness and the magnitude of difference between tests. Int J Sports Physiol Peform. 2018; 13:844-52.

27. Hart N, Nimphius S, Wilkie J, Newton R. Reliability and validity of unilateral and bilateral isometric strength measures using a customised, portable apparatus. JASC. 2012; 20:61-7.

28. Dos'Santos T, Thomas C, Jones PA, Comfort P. Assessing muscle-strength asymmetry via a unilateral-stance isometric midthigh pull. Int J Sports Physiol Peform. 2017; 12(4):505-11. doi:http://dx.doi.org/10.1123/ijspp.2016-0179

29. Hart N, Nimphius S, Spiteri T, Newton RU. Leg strength and lean mass symmetry influences kicking performance in australian football. J Sports Sci Med. 2014; 13:157-65.

30. Heishman A, Daub B, Miller R, Brown B, Freitas E, Bemben M. Countermovement jump inter-limb asymmetries in collegiate basketball players. Sports. 2019; 7(5):103. doi:10.3390/sports7050103

31. Lockie RG, Callaghan SJ, Berry SP, Cooke ER, Jordan CA, Luczo TM, Jeffriess MD. Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. J Strength Cond Res. 2014; 28(12):3557-66.

32. Bishop C, Read P, McCubbine J, Turner A. Vertical and horizontal asymmetries are related to slower sprinting and jump performance in elite youth female soccer players. J Strength Cond Res. 2021; 31:56-63.

33. Bailey CA, Sato K, Burnett A, Stone MH. Carry-over of force production symmetry in athletes of differing strength levels. J Strength Cond Res. 2015; 29(11):3188-96.

34. Bishop C, Read P, Brazier J, Jarvis P, Chavada S, Bromley T, Turner A. Effects of inter-limb asymmetries on acceleration and chage of direction speed: A between-sport comparison of professional soccer and cricket athletes. J Strength Cond Res. 2021; 35:2095-101.

35. Armitage M, Beato M, McErlain-Naylor SA. Inter-unit reliability of imu step metrics using imeasureu blue trident inertial measurement units for running-based team sport tasks. J Sports Sci. 2021; 39:1512-8.

36. Parrington L, Phillips E, Wong A, Finch M, Wain E, MacMahon C. Validation of inertial measurement units for tracking 100 m sprint data. 34rd International conference on biomechanics in sport. Tsukuba, Japan: Juiy; 2016. p. 18-22.

37. Sheerin KR, Besier TF, Reid D, Hume PA. The one-week and six-month reliability and variability of three-dimensional tibial acceleration in runners. Sports Biomech. 2018; 17:531-40. doi:https://doi.org/10.1080/14763141.2017.1371214

38. Thomas C, Comfort P, Jones PA, Dos'Santos T. Strength and conditioning for netball: A needs analysis and training recommendations. Strength Cond J. 2017; 39(4):10-21.

39. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training load monitoring in team sports: A novel framework separating physiological and biomechanical load-adaptation pathways. Sports Med. 2017; 47(11):2135-42. doi:10.1007/s40279-017-0714-2

40. Clark NC, Mullally EM. Prevalence and magnitude of preseason clinically-significant single-leg balance and hop test asymmetries in an english adult netball club. Phys Ther Sport. 2019; 40:44-52. doi:https://doi.org/10.1016/j.ptsp.2019.08.008

41. Van Gogh MJ, Wallace LK, Coutts AJ. Positional demands and physical activity profiles of netball. J Strength Cond Res. 2020; 34(5):1422-30.

42. Whitehead S, Weakley J, Cormack S, Alfano H, Kerss J, Mooney M, Jones B. The applied sport science and medicine of netball: A systematic scoping review. Sports Med. 2021; 51:1715-31.

43. Weiss KJ, Whatman C, McGuigan MR, Besier TF. Measuring lower limb cumulative load for injury prevention in sport. JASC. 2019; 27(1):45-50.

44. Bolam SM, Batinica B, Yeung TC, Weaver S, Cantamessa A, Vanderboor TC, Yeung S, Munro JT, Fernandez JW, Besier TF, Monk AP. Remote patient monitoring with wearable sensors following knee arthroplasty. Sensors (Basel). 2021; 21(15) doi:https://doi.org/10.3390/s21155143

45. Hopkins WG. Measures of reliability in sports medicine and science. Sports Med. 2000; 30(1):1-15.

46. Liaw LL, Hsieh C, Lo S, Chen H, Lee S, Lin J. The relative and absolute reliability of two balance performance measures in chronic stroke patients. Disability and Rehabilitation. 2008; 30:656-61. doi:https://doi.org/10.1080/09638280701400698

47. Cormack S, Newton R, McGuigan M, Doyle T. Reliability measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Peform. 2008; 3:131-44.

48. Koo TK, Li MY. A guideline of selecting and reporting intra-class correlation coefficients for reliability research. J. Chiropr. Med. 2016; 15:155-63.

ANNEXURES

Annexure A: Research ethics committee approval certificate (2020)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- ORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

13 August 2020

Approval Certificate
New Application

Ethics Reference No.: 503/2020
Title: Asymmetry in lower limb strength and mechanical loading during sport-specific drills in netball players

Dear Mrs CB Britz

The **New Application** as supported by documents received between 2020-07-29 and 2020-08-12 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2020-08-12 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Ethics Approval is valid for 1 year and needs to be renewed annually by 2021-08-13.
- Please remember to use your protocol number (503/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers
MBChB MMed (Int) MPharmMed PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure B: Research ethics committee approval certificate (2021)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

Faculty of Health Sciences **Research Ethics Committee**

30 July 2021

Approval Certificate
Annual Renewal

Dear Mrs CB Britz

Ethics Reference No.: 503/2020
Title: Asymmetry in lower limb strength and mechanical loading during sport-specific drills in netball players

The **Annual Renewal** as supported by documents received between 2021-06-29 and 2021-07-28 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2021-07-28 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2022-07-30.
- Please remember to use your protocol number (503/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Dr R Sommers
MBChB, MMed (Int), MPharmMed, PhD
Deputy Chairperson *of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure C: Research ethics committee title amendment approval certificate (2021)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

13 October 2021

Approval Certificate
Amendment

Dear Mrs CB Britz

Ethics Reference No.: 503/2020
Title: Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players.

The **Amendment** as supported by documents received between 2021-09-29 and 2021-10-13 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2021-10-13 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Please remember to use your protocol number (503/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers
MBChB MMed (Int) MPharmMed PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

1)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure D: Research ethics committee approval certificate (2022)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 18 March 2022 and Expires 18 March 2027.
- IORG #: IORG0001762 OMB No. 0990-0278 Approved for use through August 31, 2023

Faculty of Health Sciences **Research Ethics Committee**

14 July 2022

Approval Certificate
Annual Renewal

Dear Mrs CB Britz,

Ethics Reference No.: 503/2020 – Line 3
Title: Asymmetry in lower limb strength and mechanical loading during sport-specific drills in netball players

The **Annual Renewal** as supported by documents received between 2022-06-14 and 2022-07-13 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2022-07-13 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2023-07-14.
- Please remember to use your protocol number (503/2020) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Dr R Sommers
MBChB, MMed (Int), MPharmMed, PhD
***Deputy Chairperson** of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure E: Research ethics committee approval certificate (2023)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 18 March 2022 and Expires 18 March 2027.
- IORG #: IORG0001762 OMB No. 0990-0278 Approved for use through August 31, 2023.

Faculty of Health Sciences **Research Ethics Committee**

20 June 2023

Approval Certificate
Annual Renewal

Dear Mrs CB Britz

Ethics Reference No.: 503/2020 – Line 4
Title: Between-session reliability of performance and asymmetry variables during lower limb strength tests and sport-specific tasks in netball players

The Annual Renewal as supported by documents received between 2023-05-23 and 2023-06-14 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2023-06-14 as resolved by its quorate meeting.

Please note the following about your ethics approval:
- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2024-06-20.
- Please remember to use your protocol number (503/2020) on any documents or correspondence with the Reseasrch Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your researc, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amenement for approval by the committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Dr R Sommers
MBChB, MMed (Int), MPharmMed, PhD
Deputy Chairperson *of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure F: Permission letter from SEMLI

SEMLI
Sport, Exercise Medicine and Lifestyle Institute

27 May 2020

To whom it may concern:

<u>Permission to use SEMLI's facilities, equipment and associated data</u>

I hereby grant the following student permission to use SEMLI facilities and equipment and associated data for research purposes for their degree.

Student name:	Charné Britz
Student number:	14017327
Degree programme:	MSc Sports Science (Biomechanics)
Working title:	Asymmetry in lower limb strength and sport-specific mechanical loading in netball players

The project falls under the umbrella protocol (431/2015) entitled "Student athlete health, well-being and sports performance: A prospective study over 5 years", for which I am the principal investigator.

Prof. M Schwellnus
Director: SEMLI
Faculty of Health Sciences
University of Pretoria

SEMLI, Top Floor, Corner Burnett & Richard Street, Hillcrest Sports Campus, Hatfield, Pretoria

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

Annexure G: Permission letter from TuksSport

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TuksSport

3rd June 2020

To Whom It May Concern:

RE: Permission for Study within TuksSport

This letter serves as confirmation that TuksSport, through my office, has been approached by the researcher requesting permission to approach our various TuksSport specific clubs for the purpose of the research stated below.

Degree: MSc Sport Science (Biomechanics)

Student: Ms. C. Britz (14017327)

Faculty and Department: Faculty of Health Sciences, Department of Physiology

We hereby grant permission for the researchers to approach the TuksSport Club, as agreed upon with myself. We suggest that this drive is done through my office, so as to encourage the coaches participation and endorsement of the research. The request is that the findings of the research be provided to TuksSport and club after assessment and on completion of the research.

At TuksSport, we are encouraging the practical research application into our club systems, which aligns with the University of Pretoria's 2025 strategic vision and plan and ultimately aid and enhance our sporting performances on the field of play.

Please feel free to contact me if you have any questions.

Yours Sincerely

Mr S. Ball

DEPUTY DIRECTOR: Coaching & Performance Management

Building and Room no: TuksSport Complex
University of Pretoria
PRETORIA 0002
Republic of South Africa

Tel: (012) 420 2828

Fax: 086 636 4014

Email address: steven.ball@up.ac.za

www.up.ac.za

Annexure H: Participant informed consent

Student athlete health, well-being and sports performance: A prospective study over 5 years

ADULT PARTICIPANT INFORMATION AND INFORMED CONSENT DOCUMENT

Introduction

You are invited to volunteer to participate in a research study. This leaflet is to help you to decide if you would like to participate. Before you agree to take part in this study you should fully understand what is involved. If you have any questions that are not fully explained in this leaflet, do not hesitate to contact the investigators.

The nature and purpose of this study

Researchers from the Institute for Sport, Exercise Medicine and Lifestyle Research at the University of Pretoria will conduct a study entitled "Student athlete health, well-being and sports performance: A prospective study over 5 years". The study aims to identify factors that affect student athlete health (Illness, injury), well-being (psychological status), academic performance and sports performance.

Explanation of procedures to be followed

Your participation in this research study is entirely voluntary. A number of the components described below are part of the routine assessment and monitoring procedures for your sport. Should you agree to participate, you would be asked to give consent to participate in the following components of the study:

- Functional movement and musculoskeletal screening assessment. This is a series of tests to assess your movement quality, mobility and strength. The assessment will be completed 1 – 2 times per year by a sport scientist.
- Sport-specific physiological testing. Sport scientists conduct a series of tests to assess physiological components that are relevant to your sport, which may include body composition, flexibility, explosive power, muscular strength, muscular endurance, speed, agility, aerobic or anaerobic capacity, or sports-specific performance related tests. You will receive the results of all tests, which may be used by your coaches to inform your training program. The testing will take place 1 – 4 times per year.
- Biomechanical analysis: Motion capture techniques, are used to analyse athletic movement qualities and sport specific technique. These assessments take place 1 – 4 times per year.
- Complete an annual online medical history questionnaire. You will be provided with a unique user account to an online athlete management system where the form will be completed, and this will take less than 1 hour in total.
- Undergo a standard physical examination, based on recommended procedures for athletes by international bodies such as IOC and FIFA. The examination will be completed annually by a sports physician at the University of Pretoria sports campus.
- Donate a blood sample (15ml or 3 teaspoons). This sample will be used for the extraction and analysis of genetic material (DNA). The DNA will only be used for scientific research purposes relating to determination of the risk of injuries and illness. Samples will be destroyed on completion of the study.

- Complete an illness/injury monitoring questionnaire. Once a week, you will complete a short online questionnaire where you will be asked a few questions about any injuries or illnesses that have occurred. The questionnaire will take no more than 15 minutes to complete.
- Physical load and training response monitoring through a daily questionnaire that will take no more than 5 minutes to complete.
- Complete the Nutritional and Dietary Supplement Assessment monitoring questionnaire once a year
- Provide the research team with access to your academic records.
- Provide the research team access to your medical records, if you were treated by a medical or allied health professional. This includes medical records that are captured by medical staff on the electronic online athlete management system that is used at the Sport, Exercise Medicine and Lifestyle Institute (SEMLI).

All questionnaires may be completed on your personal computer, a computer at the university, a tablet, or a smart phone. If using a tablet or smart phone, it can be completed off-line and uploaded when wi-fi connection is available.

Potential risks of this study

- The completion of questionnaires or a physical examination is not associated with any risk. Questionnaires and other clinical data (paper and electronic) will be kept confidential and secure, and will not be made available to any party other than the research team without the consent of the individual participant.
- Musculoskeletal, physiological and biomechanical assessment requires physical tasks that involve some risk of musculoskeletal injury. However, all tasks will involve similar loads and movements that you engage in during regular training and competition. These types of tests are standard procedure in elite sport. You will be allowed to complete a full warm-up routine of your choice before beginning the testing. All reasonable precautions to reduce the risk of injury will be taken, and all testing will be conducted by appropriately qualified staff.
- All medical conditions will be treated as usual by your doctor or physiotherapist, and training will continue as usual under your strength and conditioning trainer. Medical records will be captured and stored on a fully secure electronic online athlete management system that is used at the Sport, Exercise Medicine and Lifestyle Institute (SEMLI).
- The potential risks during the 5 ml (1 teaspoon) blood collection include: infection, delayed healing, haematoma, physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of trained phlebotomists, use of sterile techniques and the use of disposable, single-use materials.
- Genetic information: To make sure that your specific genetic information is kept secure and confidential, the following procedures will be adopted: 1) all the blood samples will be labelled on collection using a numerical coding system that is linked to player details on a master list that will be placed in a sealed envelope, 2) this sealed master list will then be kept in a secure facility and in a separate location, 3) only the principle investigator and senior co-investigators will have access to this master list, 4) the master list will only be opened if a sample needs to be destroyed, should a participant request this. All data will be analysed anonymously and DNA samples will be destroyed on completion of the study. Your personal genetic information will not be made known to you, your teammates, team medical staff, coaches, or management. The information will be kept secure, anonymous and will only be used for research purposes. Because this area of research is still in the exploratory phase, we will not be able to provide individual feedback with regards to the results and implications of genetic testing.

- You may withdraw from this study at any time without question.

Potential benefits of this study

You will be provided with the results of your musculoskeletal, physiological and biomechanical assessments, which you may share with your coach or strength and conditioning trainer. The research questions that will be addressed by this study have been identified to have a direct impact on improving health, well-being and performance in student athletes. The anticipated benefits of this study are that the results will further our understanding of the possible cause/s of medical conditions and injuries in athletes.

Ethical Approval

This Protocol was submitted to the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (telephone number 012 356 3084) and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki (last update: October 2013), which deals with the recommendations guiding doctors in biomedical research involving human/subjects. A copy of the Declaration may be obtained from the investigator should you wish to review it.

Confidentiality

All records obtained whilst in this study will be regarded as confidential. Once we have analysed the information no one will be able to identify you. Results will be published or presented in such a fashion that participants remain unidentifiable.

Contact

Please feel free to contact a member of the research team or the University of Pretoria Health Sciences Research Office should you have any questions related to the study. You can contact the principal investigator on the following number: (012) 420 1804.

Faculty of Health Sciences - Research Ethics Committee
Tswelopele Building, Level 4, Rooms 4-59 and 4-Faculty of Health Sciences, Dr Savage Road, Gezina, Pretoria
Tel: (012) 356 3084 or (012) 356 3085
Fax: (086) 651 6047
Email: manda.smith@up.ac.za / deepeka.behari@up.ac.za / fhsethics@up.ac.za
University of Pretoria Research Ethics approval number: 83/2016

Consent to participate in this study

I confirm that I have received, read (or had read to me) and understood the above written information regarding the nature, process, risks, discomforts and benefits of the study. I have been given opportunity to submit questions and am satisfied that they have been answered satisfactorily. I agree that research data provided by me or with my permission during the study may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used. I understand that if I do not participate it will not alter my management in any way. I understand that I may withdraw from this study at any time without further question.

I hereby consent to participate in the following components of the study as described in the participant information that I received

Please initial under either "yes" or "no" for each component:

	Yes	**No**
Functional movement and musculoskeletal screening		
Sport-specific testing		
Biomechanical assessment		
Annual Online Medical History Questionnaire		
Annual Medical Screening Examination		
Weekly illness/injury monitoring questionnaire		
Access to my medical records		
Physical load and daily training response monitoring		
Nutritional and Dietary Supplement Assessment		
Genetic component of this study		
Access to my academic records		

Please complete the participant and witness columns:

	Participant (Athlete)	**Witness**	**Investigator**
Name Please Print			To be completed by research team
Signature			To be completed by research team
Date			To be completed by research team