# A PRELIMINARY, WORK-BASED STUDY OF HYPERTROPHIC TRAINING AND LANDING MECHANICS OF ADOLESCENT FEMALE ATHLETES IN QUEENSLAND

A Thesis submitted by

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# ABSTRACT

This work-based project employed a quasi-experimental design to investigate the impact of a hypertrophy-based resistance training program aimed at potentially mitigating the well-documented disparity in lower-limb injuries, such as anterior cruciate ligament (ACL) rupture, in adolescent female athletes. Sixteen volunteer adolescent female athletes completed a drop-jump landing task in stepping off a 30cm box landing onto a dual force plate, followed by an immediate jump and re-land protocol. Anthropometric, force, knee flexion, and valgus data were collected. Participants were divided between an intervention and comparison group, with the intervention group completing an eight-week, targeted hypertrophy program. After the intervention period, the drop-jump test was repeated using identical measures. The intervention group showed a statistically significant reduction in lower limb anthropometric mean skinfold data compared with the comparison group. Peak landing force showed a decrease in the intervention group compared with the comparison group and this was most marked in the right limb. Peak propulsive force increased in the intervention group, however, was not statistically significant. No significant differences were observed for knee valgus. Knee flexion angle also showed no statistical significance, although measurements indicated there was a negative correlation between knee valgus right and peak propulsive force. This work-based study suggests that a lower-limb hypertrophy-based intervention program might have a positive effect on adolescent female muscle development over an eight-week period. The resulting reduction in peak landing force at impact may be significant in the mitigation of lower-limb injury in adolescent female athletes participating in court and field-based sports, a topic for future investigation. This conclusion has implications for how practitioner-based training can be implemented in sports exercise environments.

# CERTIFICATION OF THESIS

I Robert Allan Burr declare that the MPSR Thesis entitled 'A preliminary, work-based study of hypertrophic training and landing mechanics of adolescent female athletes in Queensland' is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. The thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signed: [redacted] Date: 6/6/2022

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Student and supervisors' signatures of endorsement are held at the University.

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# DEDICATION

To my wife and children for their love and support throughout the duration of the MPSR and thesis. My parents who, as educators for their entire careers, have always instilled a sound work ethic and a desire for lifelong learning.

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| | |
|---|---|
| 1RM | One Repetition Maximum |
| 6RM | Six Repetition Maximum |
| AFHP | Academy of Fitness & High Performance |
| ACL | Anterior Cruciate Ligament |
| ACSM | American College of Sports Medicine |
| AFL | Australian Football League |
| ANOVA | Analysis of Variance |
| ASCA | Australian Strength and Conditioning Association |
| ASIS | Anterior Superior Iliac Spine |
| BMI | Body Mass Index |
| CG | Comparison Group |
| EPL | English Premier League |
| FFM | Fat Free Mass |
| GRTH | Girth |
| GP | General Practice |
| GRF | Ground Reaction Force |
| IG | Intervention Group |
| IGF-1 | Insulin-like Growth Factor-1 |
| KF-L | Knee Flexion Left |
| KF-R | Knee Flexion Right |
| KV-L | Knee Valgus Left |
| KV-R | Knee Valgus Right |
| LE | Lower Extremity |
| NBA | National Basketball Association |
| NCAA | National Collegiate Athletic Association |
| NFL | National Football Association |
| NMT | Neuromuscular Training |
| NRL | National Rugby League |
| NSCA | National Strength and Conditioning Association |

| | |
|---|---|
| PPF | Peak Drive Off Force |
| PLF | Peak Landing Force |
| PLF-L | Peak Landing Force Left |
| PLF-R | Peak Landing Force Right |
| RM | Repetition Maximum |
| RPE | Rate of Perceived Exertion |
| SKFD | Skinfold |
| SPSS | Statistical Package for the Social Sciences |
| ST | Strength Training |
| USA | United States of America |
| USQ | University of Southern Queensland |
| VMO | Vastus Medialis Oblique |
| WHO | World Health Organisation |

# CHAPTER 1: INTRODUCTION

Research conducted 20 years ago showed that sporting activities involving, jumping, landing, pivoting and deceleration, such as soccer, volleyball, rugby, basketball, netball, and hockey, provide a heightened risk of Anterior Cruciate Ligament (ACL) rupture (Conte, Requa, & Garrick, 2001).

Sex-specific[1] injury disparities in the movements of landing and pivoting show female athletes have a four to six times higher incidence of ACL injury than male athletes (Hewett et al., 2006). In addition, research into injuries classified as 'non-contact', where injury to the limb has occurred in an event with no direct or external force applied, shows that the rate of non-contact injuries to the ACL is two to nine times greater in females than males (Allender, Cowburn, & Foster, 2006; Ireland, 2002).

While non-contact events account for more than two thirds of all ACL injuries in both males and females, running, jumping, landing and cutting manoeuvres appear to place the female adolescent body at more risk of injury to the lower limbs (Ford et al., 2005), but there appears to be a myriad of possible causes for this differentiation in injury rate, including hormonal, biomechanical, structural and/or psychological factors (Clausen et at., 2016).

This is of concern because female participation rates in ball sports are increasing worldwide. For example, 550,000 women play one of four main football codes in Australia, with soccer (football), having the largest participation rate of over 400,000 (Morgan, 2018); world rugby has seen a 60% increase in female participation rates since 2013, with females now making up a quarter of all rugby players in the global game (Ellis, 2018). Moreover, the Australian Football League (Women's) has sustained rapid participation growth of nearly 19%, or 111,642 participants, in Queensland

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[1] Sex-identified is specifically referring to the person's sex assigned at birth, or biological sex, rather than their gender identity.

during 2018 alone, which contributes the greatest number of females playing the game in Australia (AFL Queensland, 2019).

It follows, therefore, that a greater understanding of causes of knee and lower extremity injury to adolescent females, building on the 2005 work of Hewett et. al., can potentially lead to more effective preventions and the avoidance of career-ending surgery.

## 1.1 FOCUS OF THE STUDY

The focus of this research project is to develop a stronger understanding of the mechanisms and risk of lower limb injury to adolescent female athletes and to outline a positive intervention program around reducing such risk. The World Health Organisation defines an 'adolescent' as any person between the ages 10 and 19 (World Health Organisation, n.d.). Sporting injuries in childhood are responsible for 20 to 30% of osteoarthritis cases in adults with some as young as 30 years of age developing the disease (Prieto, Arden, & Hunter, 2014).

Injuries to the foot and ankle in adolescent girls represent 30% of sports medicine treatment, with the sport of basketball contributing 44-45% of all injuries in adolescent athletes (Malanga & Ramirez-Del Toro, 2008). In addition, females are more susceptible to specific lower limb injuries, including the medial tibial (shin) region, than males (Shigenoru et al., 2013).

It is therefore prudent to ask: why are the injury rates of young females and young males so disproportionate? Physical preparation and conditioning of adolescent athletes vary greatly, and perhaps these requirements are poorly understood by coaches, fitness trainers, physical education teachers and parents for this demographic. Such a conclusion has led to organisational position stands being created by national and international Strength and Conditioning regulatory bodies in order to inform and guide any, and all groups involved with the training and coaching of adolescents (Wilson et al., 2017).

It is obvious that physical exercise interventions for injury prevention for adolescent females competing in sport would benefit not only physical education teachers and sports coaches within the secondary school systems and community coaching environments, but the athletes themselves. If female athletes are to excel in their chosen sports or disciplines, advancement to regional and state level and beyond will most likely be the pathway to greater and more competitive environments. However, the rigours of performance at higher competitive levels impose an increased physical demand on all body structures, even though adolescent females have lower injury rates than adolescent males in other parts of the body, females have higher injury rates compared males in ACL rupture (Zech et al., 2021). If early physical intervention models are not understood, practised, and progressed, then it is reasonable to assume that adolescent female athletes will continue unnecessarily to suffer substantially higher injury rates than their male counterparts. This problem is poorly understood by many on the outside of the physical preparation and high-performance spectrum. While many sports personnel employ physical fitness and strength training (ST) for preparation and general injury prevention for adolescent females, the mechanisms of why they may be effective are unclear and little information about physical preparation and training interventions for female adolescent athlete populations tends to be available to those outside high-performance environments.

## 1.2 RESEARCH QUESTIONS

This research focuses on investigating the effect of specific hypertrophic training regimes and the relationship on landing mechanics of the adolescent female athlete in a work-based sports setting, with the aim of developing a benchmark preventative model for reducing the incidence of non-contact ACL injury. As the term 'Q-Angle', used so commonly by Biedert and Warmke (2001) when referencing human biomechanical structures, is an unchangeable dynamic, issues arise as to how best to create a protection or preparation methodology to mitigate sporting demands on the lower limbs. In that context, facilitating an increase in muscle volume and function may have a positive effect on adolescent biomechanics when involved in dynamic sporting activity.

Therefore, this study asks the following three research questions:

> 1 -Might an 8-week strength training intervention program for female adolescent athletes, focusing on muscle hypertrophy, show favourable changes in lower body anthropometrics?
>
> 2 -Might a strength training intervention program focused on lower limb muscle hypertrophy show positive change in landing impact force, and force generation in take off?
>
> 3 -Might muscle hypertrophy, as a result of a training program, impact dynamic knee valgus and knee flexion angle upon landing from a jump, thereby reduce potential lower limb injury risk to female adolescent athletes?

## 1.3 THE RESEARCHER AS A PRACTITIONER

The Professional Studies Program at University of Southern Queensland aims to challenge the researcher-practitioner academically and allows for the continuation of lifelong learning in a matrix of theory and practice-based reflection, demonstrating that learning is a combination of practical and professional applications of knowledge, rather than merely collecting knowledge alone. In this, the Program echoes Bezanson's (2003) assertion that purposeful learning activity undertaken in an ongoing way with the aim of improving knowledge, skills, and competence, can connect career development and employability with lifelong learning in direct and transparent ways.

This researcher expects to derive significant personal and professional advantage from study and research conducted in the field; the more so since previous university study was conducted in a broad curriculum that militated against many of the areas of greatest professional interest and importance to a physical preparation coach. It has been documented (Fergusson, Brömdal, et al., 2020) that application of professional knowledge leads to professional and organisational competence, capability, professional identity, and personal empowerment. This underlines the findings of Fergusson, van der Laan and Baker (2019) in evaluating the Program that, 'intellectual capabilities' made a smaller contribution to professional development in the taxonomies of learning identified by the reflective practice process.

The learning objectives sought as a result of this research will therefore be used to enhance critical judgement, to adopt the use of technology through collaboration and teamwork, to allow the researcher to improve work-based performance, to enhance understanding of the multiple complexities in the physical preparation of adolescent athletes and lastly, to provide innovation through a creative and thoughtful project design.

The researcher has 24 years of field experience in the fitness, well-being and sports industries in multiple countries, including New Zealand, The United Kingdom, India and Australia. While the majority of this field experience has come from the commercial sector, and in tertiary education, significant experience has also been attained through community sporting roles and volunteer-based appointments in sports medicine and coaching. A diverse range of clientele drawn from the general public, youth sport, post-operative rehabilitation, oncology exercise care, regional State, and Olympic level athletes has provided him with a wide and varied range of beneficial experience. The researcher has prescribed and delivered exercise programs, managed teams of fitness professionals, and delivered continuing professional development courses for recognised registering bodies, such as, Sports Medicine Australia (SMA), and the Australian Strength and Conditioning Association (ASCA), including vocational education and training for the Sports, Recreation and Fitness training package in the Australian vocational education and training sector.

As a contributor to the vocational education sector in Australia, the researcher has current contracts with six private secondary schools in Toowoomba and wider Queensland to deliver fitness education to certificate level (AQF Levels III and IV). The school relationship is a vital component of the researcher's professional practice because it facilitates work in the adolescent athlete space and ensures that objectively-sourced and relevant fitness knowledge is passed on to adolescents with the intention of educating and transferring knowledge about athletic preparation, and injury prevention and reduction.

The researcher currently co-owns a commercial strength and conditioning facility in Wandsworth, London, which specialises in coach-led classes for a variety of training ages and stages from beginner level to advanced athletes with a range of sports and interests. International collaboration allows the researcher to remain current with regard to both industry-specific and scholarly knowledge present within the field, including emerging technologies and developing research.

# CHAPTER 2: LITERATURE REVIEW

Sex-identified disparity between adolescent athlete populations is a complex area of research and one informed by multiple considerations. These include the physiology of adolescence, an awareness of existing differences between an individual's chronological and biological ages, and a recognition of what is known of body mass and biomechanical processes.

In exploring the mechanism of muscle hypertrophy and its potential influence on lower limb mechanics for the adolescent female athlete, this review will position the research in the context of relevant literature and will aim to critically explore the data on what it reveals for injuries to that demographic. In the process of developing a method of mitigating injuries it will attempt to highlight opportunities and initiatives for ongoing investigation into effective physical interventions for competitive adolescent female athletes.

## 2.1 INCIDENCE OF INJURY TO ADOLESCENT ATHLETE POPULATIONS AND CURRENT STATISTICS

Although worldwide statistics of injury and sports-related injuries to youth and adolescents are not well defined, it has been identified that injuries, in general, are the leading cause of death, illness and disability among youth in developed countries (Bulger et al., 2021; King, Pickett, & King, 1998). This research showed that in Canada, on average, 36% of youth sustained at least one injury per year equating to more than 600,000 injuries to youth where sports injuries and falls were the leading causes, as well as confirming and supporting the 1995 findings of Bijur and colleagues that sports activities account for a large number and substantial portion of all injuries to children and youth in the USA.

A Swiss study (Michaud, Renaud, & Narring, 2001) highlighted a remarkable correlation with King's figures of 32.1% of youth aged 9-19 years reporting an injury during the preceding 12 months of the survey study with sporting injuries again contributing the highest causation, and with females showing a six-fold difference over other contributors to injury. National data in Argentina showed 31% of students surveyed through the eighth to tenth high school grades (13 to 15 years of age) reported an injury serious enough to miss a full day of school through the year, with 53% of the injuries occurring in a sporting or training environment (Abdi, Abdirahman, & Jacobsen, 2015).

Statistical data was extrapolated over a five-year period in Australia from 2006 to 2011 using a continuous national study of general practice (GP) activity identifying GP encounters with children and adolescents. From this period, there were 65,279 encounters with musculoskeletal visits making up 4.9-5.0% of visits to the GP, but rising to 10% during adolescence (Henschke et al., 2014). The Australian national data did not differentiate between metropolitan, regional or rural areas and this presents an opportunity to perform a potential study into State-based regions, beginning in regional Queensland, to draw specific comparisons to world youth injury data. There was also no representation here for sporting injury statistics to youth and adolescents in Asian or African regions, as no clear studies could be identified.

## 2.2 EXERCISE SCIENCE – PHYSIOLOGICAL ASPECTS OF ADOLESCENT INJURY

The literature of exercise science offers some explanation and statistical analysis regarding injury type in adolescent sporting populations. It is well documented that identified lower limb injury rates are higher in female adolescent populations in direct comparison with their male counterparts (Hanlon et al., 2020; Hewett, Myer & Ford, 2006; Renstrom et al., 2008; Watson et al., 2019). In female athletes, sports-related injuries to the ACL seem to increase during adolescence and peak in occurrence during 13-17 years of age (Sugimoto, Myer, McKeon & Hewett, 2012). A sex related muscle fatigue factor contributes to a higher risk ACL injury, and it is shown that muscle fatigue increases knee abduction moment during a drop jump to a greater extent in young female athletes compared with male athletes (Mclean et al. 2007). Other biomechanical studies have shown that female adolescent athletes land from a jumping maneuver and change direction in a more upright posture than males with their knees and hips close to full extension, which upsets the balance of quadriceps and hamstrings activation (Yoo et al., 2010). This is a significant physiological biological sex difference considering that ground reaction forces can reach three to fourteen times an individual's bodyweight when landing from a jump (Cossin, Ross & Prince, 2021). The angle of knee extension, in particular, on landing and impact with the ground will determine the size of the impact force, and therefore knee load. Increasing the initial knee angle on impact from 135° to 180° (almost vertical) increases the ground impact force by 50% or approximately 1% per degree of initial knee extension (Nigg, 1985).

A French football study also showed that there is statistical significance and variance within sporting codes, highlighting a subsection in the adolescent age group with significant differences in injury rate in under 15-year-old female soccer players compared with the under 19-year-old age group (Le Gall, Carling, & Rielly, 2008). Their findings indicated that the former sub-section ages sustained higher incidences of growth-based overuse injuries. Walden et al. (2012) showed comparative differences in neuromuscular function in the lower limbs, where females were slower to respond to provide stability in the lower limbs in cutting and turning movements in ages 12-17 than males of the same age group. This, they concluded, resulted in significantly higher injury rates in this female age group and led the researchers into investigating a neuromuscular conditioning intervention, which will be outlined in the 'interventions' section of this review (see page 24).

It would be of great interest to see a similar study conducted in Australia, particularly in the rapidly growing code of women's Australian Football league (AFL), which was, until recently, a male-dominated sport. This would be of significance because the dynamics of AFL are similar to that of soccer and involve running, cutting, jumping and landing on a single leg; all of which place females at much higher risk of lower limb injury. (Decker et al., 2003; Hewett et al., 2006; Renstrom et al., 2008; Waldén et al., 2012). An effective intervention strategy would be fundamental in ensuring adolescent and adult females continue to play these traditionally male-dominated sports without existing levels of anxiety over injury.

## 2.3 AGE – BIOLOGICAL VERSUS CHRONOLOGICAL AGE

Children of the same chronological age can vary significantly in biologic maturity. Growth spurts during adolescence are associated with increased risk of injury, particularly in musculotendinous tightness and decreased physeal (growth plate) strength (Bright, Burstein & Elmore, 1974; Flaschsmann et al., 2000; Morsher, 1968). During these growth stages bone mineralisation can lag behind bone growth, leaving the bone weaker and more vulnerable to injury (Bailey et al., 1989).

The Tanner Scale[2] (see Table 2.1 on page 12) shows stages of growth and development during pubescence and an approximate age range to identify where each stage falls. This can be used as a guide only and shows differences in biological age (physical maturity) and chronological age (actual age in years).

[2] Read further in Sexual Maturity Rating (Tanner Staging) https://ncbi.nlm.nih.gov.

The researcher's professional practice has allowed observation of these differences while working with both male rugby league teams (under 15 years age grades) and high school swimming squads (state and national level competitors) where the chronological age range is 12-18 months from youngest to oldest in the squads. However, the age range visually and biologically appears closer to 12 months to 48 months. Injuries in pre-pubescent skeletally immature athletes are varied in nature and include bony coalitions and injury to growth plates; injuries related to overuse (Osteochondrosis diseases - Legg-Calvé-Perthes, Kohler's, Panner's, Freiberg's, Sever's and Osgood-Schlatter's); and acute presentations, such as ligament or tendon injuries and even full fractures (Malanga & Ramirez-del Toro, 2008; Reina et al., 2021). Studies indicate a higher incidence of injury to boys and girls in tanner stages 3 and 4, where faster epiphyseal growth and peak height velocity occurs, than those in less physically mature stages 1 and 2, indicative of difference in biological and chronological age (Soliman et al., 2014).

In summary, then, growth during adolescence produces hormonal changes and changes to overall body size. The anatomy of the adolescent athlete in Tanner's Stages 1-4 with respect to development and growth (including growth plates) show different patterns of injury to those seen in the increased maturity of individuals in Tanner Stage 5, with the main injuries in earlier years coming from overuse and acute trauma (Malanga & Ramirez-Del Toro, 2008). While further consideration of disparities between biological age and chronological age is outside the scope of this investigation, the plethora of studies cited in 2.2 indicate that disparities exist and are worthy of further consideration.

Table 2.1

*Tanner Staging Chart | Child Development 2005*

| TANNER STAGING CHART | | | | | |
|---|---|---|---|---|---|
| **BOYS** | | | | | |
| | STAGE 1 Prepubertal | STAGE 2 8-11.5 years | STAGE 3 11.5-13 years | STAGE 4 12 – 15 years | STAGE 5 > 15 years |
| Growth | 5-6cm/year | 5-6cm/year | 7-8cm/year | 10cm/year | No growth |
| Testes, penis | Testes < 4ml or <2.5cm | Testes 4ml or 2.5-3.5cm, penis usually not yet enlarged | Testes 12ml or 3.6 cm; enlargement, lengthening of penis | Testes 4.1-4.5cm; increased size and breadth of penis | Testes and penis fully matured in shape and size |
| Pubic hair | No pubic hair | Sparse pubic hair at base of penis | Pubic hair over pubis; darker, coarser and more curled | Adult like, but over smaller area | Fully mature |
| **GIRLS** | | | | | |
| | STAGE 1 Prepubertal | STAGE 2 8-11.5 years | STAGE 3 11.5-13 years | STAGE 4 12 – 15 years | STAGE 5 > 15 years |
| Growth | 5-6cm/year | 7-8cm/year | 8cm/year | 7cm/year | No growth |
| Breasts | No breast development | Breast buds | Breast elevation and areolar enlargement | Areolae and papillate form secondary mound | Mature breasts |
| Pubic hair | No pubic hair | Sparse pubic hair on labia; slightly pigmented | On mons pubis; darker, coarser and more curled | Adult like, but over smaller area | Fully mature in type and quantity, extends to thighs |

## 2.4 HORMONES, BODY SIZE, AND BODY MASS INDEX (BMI) INFLUENCE ON INJURY

Dharamsi & LaBella (2013) state that the ACL has estrogen, testosterone and relaxin receptors suggesting that sex hormones may affect the mechanical properties of the ACL and influence the risk of ACL injury. Other studies have found this link to be inconclusive (Bey et al., 2019; Hansen et al., 2013); however there does appear to be a laxity effect by up to one millimetre to the ACL in adolescent females during the midpoint of a menstrual cycle (Hewett, Zazulak, & Myer, 2007). This could lead to a reconsideration of exercise selections, particularly lower impact or landing based movements, for the menstruating athlete by trainers and coaches during training blocks (Constantini, Warren, & Bailliere, 1994).

The risk of sustaining an injury in adolescents with high body mass index (BMI) (see Table 2.2) is greater compared to those with a normal BMI range (Richmond, Kang & Emery, 2013). The BMI scale may not always be considered a scientifically valid reference to weight, overweight, or obesity classification due to changes in the individual's fat-free mass (FFM) or muscle distribution during stages of growth, where Freedman & Sherry (2009) have suggested that it is only a 'relatively good' indicator of excess adiposity for visually overweight youth. Table 2.2 is included as a guide only, then, to changes in general body mass and surface area.

Table 2.2

*BMI chart – Fametrics 2017*

| BODY MASS INDEX (BMI) | |
|---|---|
| **CLASSIFICATION** | BMI SCORE ($kg/m^2$) |
| **Underweight** | <18.5 |
| **Normal** | 18.6 – 24.9 |
| **Overweight** | 25.0 – 29.0 |
| **Obese** | 30.0 – 39.9 |
| **Morbid Obesity** | 40.0 – 49.9 |
| **Super Morbid Obesity** | >50.0 |

A larger, and perhaps more significant consideration for the health of the adolescent ACL are changes to body size and increases in BMI leading to an increase of overall body weight in a short period of time.

During pubertal growth spurts and the associated changes in height and weight, control of the body's dimensions and changes in centre of mass becomes difficult. During puberty, males undergo a large rise in hormone levels, largely growth hormone, and insulin-like growth factor-1 (IGF-1) and testosterone, which contribute to muscle development (Rose et al., 1991). This significant change in muscle mass and strength allows males to accommodate increased BMI and centre of mass changes at a more favourable neuromuscular level than adolescent girls. Whilst females also produce growth hormone and testosterone, the levels are far lower than those of males and hence have a minimal effect, if any, on developing effective muscle mass to counteract increased forces in the knee joint due to changes in body dimensions (Ramos et al., 1998). In addition, females undergo a different fat distribution and redistribution to males during puberty. Males will gain greater amounts of fat free mass with a widening of the shoulder girdle or more android shape, and girls have a greater fat redistribution around the hips and upper legs or gynecoid shape (Loomba-Albrecht et al., 2009).

Higher BMIs in adolescence have also shown a significant relationship to body mass and internal hip rotation angle, leading to incidences of medial tibial stress syndrome (MTSS), often referred to as shin splints (Plisky et al., 2007; Yagi, Muneta, & Sekiya, 2013). Tyler et al., (2006) indicate a relationship between an athlete's weight and the risk of ankle sprain showing that injury to the ankle increases four-fold with athletes with high BMIs or categorised as overweight (BMI > 25). Further, in this study, and more alarmingly, adolescent athletes with high BMI who have sustained a previous ankle injury are 19 times more likely to sustain another non-contact ankle injury than an athlete with a normal BMI with no previous ankle sprain (Tyler et al., 2006).

With such significant changes in dimensions and increased weight to the hip region, and hip angle in females, it is clear that biomechanical impact makes a contribution to increased injury and highlights the value of neuromuscular training for adolescents (Richmond et al., 2013). This is a complex issue. Education for athletes, coaches and parents concerning the maturing and developing body highlights the need for structured and competent physical preparation for sport outside of the sport itself, and is another significant area for future study.

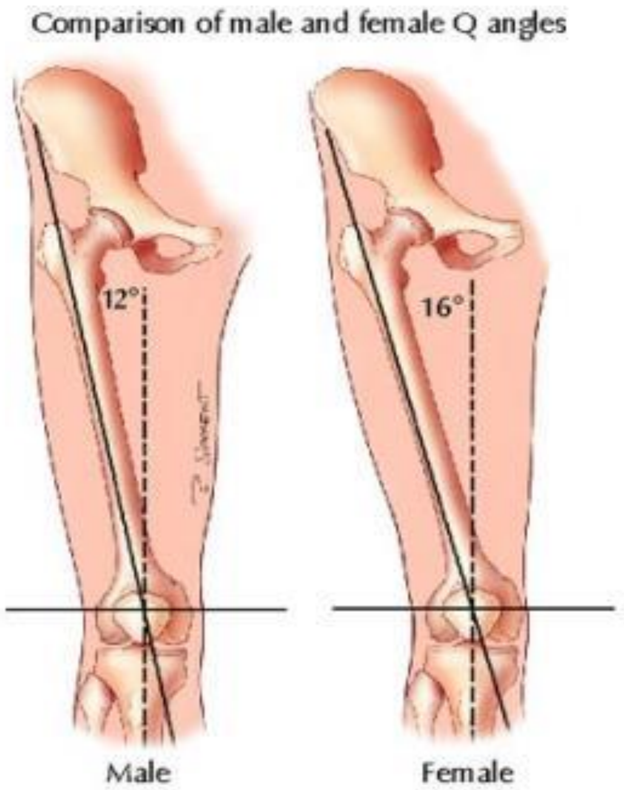


Figure 1 The Q-angle for males and females (source: LGB Medical, 2017).

### 2.4.1 Biomechanical and anatomical considerations

Anatomical variation in hip to knee angle (known as Q-angle[3]), and poor lower extremity alignment has been shown to be a contributor to knee injury in females (Tillman, Bauer, Cavangh & Trimble, 2005). The Q-

[3] The angle formed by the line of traction of the quadriceps tendon on the patella and the line of traction of the patellar tendon on the tibial tubercle. The area is usually larger in women than in men. (Medical Dictionary for the Health Professions and Nursing, 2012).

angle (see Figure 1) is formed by a line from the anterior superior iliac spine (ASIS) through to the centre of the patella and a line from the centre of the patella to the centre of the tibial tubercle. (Medical Dictionary for the Health Professions and Nursing, 2012). Normal Q-angle for males is 12-14 degrees and females are 15-17 degrees due to the naturally wider pelvis in women (Woodland & Francis 1992).

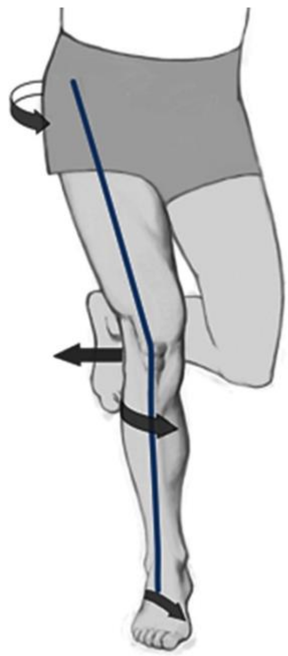

Figure 2 Nature of dynamic knee valgus,
https://www.researchgate.net/figure/Cause-for-functional-or-dynamic-valgus-can-be-internal-rotation-of-the-femur-the-tibia_fig2_258502532

This is observable in professional practice, as is the inability of many adolescent females to align the central angle of the patella with the midline of the foot, the optimal alignment to reduce internal knee forces upon ligamentous tissues when performing a squatting pattern (Ageberg et al., 2010). This angle is exacerbated further in single limb patterns such as lunging, bench stepping, and landing from a jumping action. Ford, Hewett and Myer (2003) performed a significant American-based study with high school-aged female and male basketball players into the mechanics of knee motion during landing, particularly a knee position termed ‘valgus knee’ where central knee alignment falls inwards rather than staying straight in the sagittal plane (see Figure 2).

The purpose of their study was to utilise a three-dimensional motion analysis to determine if biological sex was a factor in the degree of knee valgus when performing a landing position from stepping off a box then to stabilise before performing another vertical jump action. Females showed a landing position with greater knee valgus motion and greater maximum knee angle than male subjects (Ford et al., 2003). Females also showed significant differences between their dominant and non-dominant side in maximum knee angle concluding a significant injury risk to the non-dominant limb and in particular, a non-contact injury event (Ford et at., 2005). Differences in landing kinematics have been identified by sex-identified and occur in multiple joints and planes of motion (Ford et al., 2004). Of particular concern is the action of the hip and knee in the frontal plane, where females display less control in running and ground reaction control force from jump (Ferber, Davis, & Williams, 2003). A study which simulated a jumping sport-specific activity body position of single leg land from a double leg take-off, showed major mechanical and movement differences between males and females. Jenkins, Williams, Hefner, and Welch (2017) show that both sexes display a knee angle formation of knee valgus upon landing, however females landed with far greater valgus, then moved into knee varus (abduction), before quickly moving into knee valgus again at toe-off. Females show approximately a 5-degree greater overall frontal plane movement angle, and with movement from valgus to varus added with the speed in which this occurs, places excessive compressive force on medial structures of the knee and additional force on the lateral side of the knee (Jenkins et al, 2017). This highlights an intervention requirement for awareness of frontal and transverse plane stability intervention strategies for coaches, parents, teachers, and athletes, which will be explored further in this thesis.

Intervention studies have focused on neuromuscular balance to improve knee stability in females (Filipa et al., 2010; Hewett et al., 1999; Petersen et al., 2005;), however very few studies, if any, have focused on specific muscle hypertrophic response[4] in the lower limbs, particularly quadriceps (medial region), hamstrings and gluteal regions, to see whether this serves as a valid intervention to improve knee stability. It could be argued that a certain degree of neuromuscular-based ST may provide sufficient hypertrophic responses, however, it is possible to follow a regular ST program focusing on a purely neuromuscular strength-based outcomes and have no measurable increases in muscle size (Moritani, 1979). No Australian studies on direct muscle hypertrophic responses as interventions for knee injuries have been found to date, suggesting that this is an area of research that may benefit from further investigation.

## 2.5 QUADRICEPS DOMINANCE DEFICIT AND KNEE FLEXION ANGLE

Palmieri-Smith, Mclean, Miller and Wojtys (2009) suggest that females preferentially activate their lateral quadriceps and hamstrings with less medial thigh activation (VMO). This observation, they point out, poses a significant structural problem during a landing and change of direction activity, with most court and field sports involve this action. Indeed, females showed a reduced knee flexion angle at landing of less than 30° (see Figure 3), which strains the ACL with the hamstrings being unable to reduce the strain due to the small size of the tibial angle.

[4] Muscle hypertrophy involves the increase in size of skeletal muscle through a growth in size of its component cells. Two factors contribute to hypertrophy: Sarcoplasmic hypertrophy, which focuses more on increased muscle glycogen storage; and myofibrillar hypertrophy, which focuses more on increased myofibril size (Haff & Triplett, 2015).

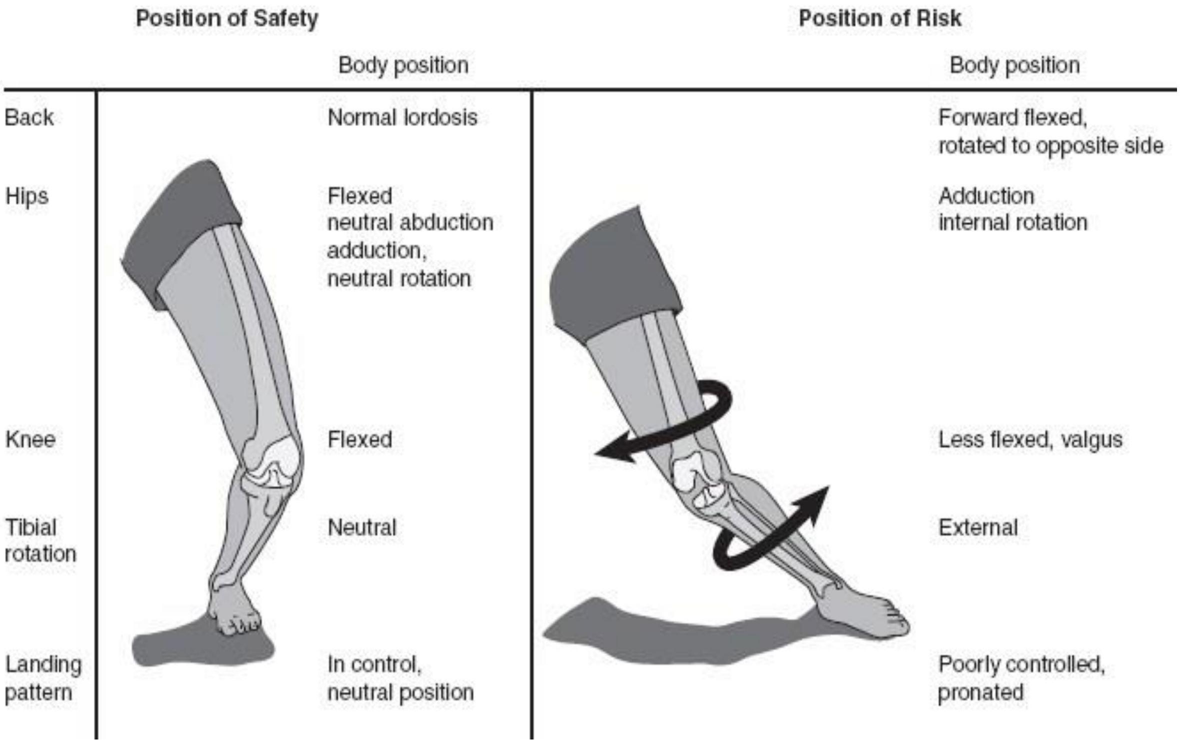


Figure 3 Position of safety and position of risk. Adapted from "Traumatic Knee Injuries," S.A. Makovitch, & C.A. Blauwet, (2016), *Sex Differences in Sports Medicine*.

Landing without contributed VMO activation promotes knee abduction and extension loading with excessive strain on the ACL in a non-contact occurrence.

Letafatkar et al. (2015) found a successful intervention strategy to improve hamstring activity in females, which will be discussed in the interventions section 2.9. Because of the prevalence of non-contact ACL injury, Landry, McKean and Hubley-Kozey, Stanish, and Deluzio (2007) performed one of the first studies to highlight significant combined structural, biomechanical and neuromuscular differences focusing on the activity and function of gastrocnemius muscle of male and female adolescent soccer players. A study method was set up whereby players were tested in an unexpected or unanticipated cutting run and crosscut manoeuvre. The unanticipated method is important as many players who condition in regular expected patterns, such as, pre-formed drills in the training environment, become pre-programmed to stop. Athletes also become programmed to cut or change direction resulting in the neuromuscular system adapting conservatively with less intensity than when in a game or competition scenario (Brown, Palmieri-Smith, & McLean, 2009). Such conservatism can result in less structural 'readiness' and when the joints and structures of the hip, knee and ankle are placed under extreme stress in the dynamic nature of unpredictable gameplay, the body structures are not as conditioned to cope mechanically (Brown et al., 2009). After a three-dimensional kinematic, kinetic and electromyographic analysis was performed, the gastrocnemius study found females in both running and cutting actions had significant mediolateral gastrocnemius imbalance that was not evident in males (Landry et al., 2007). In addition, activity in the quadriceps muscle group was noticeably higher in females for both manoeuvres compared to males.

Myer et al. (2009) suggested that muscle strength, in terms of lower hamstring to quadriceps torque ratio, is a risk factor for ACL injury in female but not in male athletes. Lower limb muscle strength increases less with age among young females compared with young males (Barber-Westin, Noyes, & Galloway, 2006). In addition, muscle activation patterns during side-to-side movements and cutting differ between female and male to the detriment of the former, so not providing adequate joint protection and stability at the knee (Landry et al., 2009).

A further biomechanical and structural difference is that females can also demonstrate ligament dominance, which occurs when an athlete allows the knee ligaments to absorb most of the ground reaction forces over the lower limb musculature (Myer, Ford, & Hewitt, 2004). this effect is visible in increased medial knee motion during general sports manoeuvres, resulting in greater knee valgus moments and increased ground reaction force (Hewett, Stroupe, Nance, & Noyes, 1996). In addition to ligament dominance, knee and quadriceps dominance also result in a reduced hamstring activity, hip flexion angle and increased ankle eversion angle. The combined effect of the structural dominance shown in this study is consistent with the previously noted problems of Q-angle and knee valgus in female adolescents. This results in increased injury rates through reduced hamstring activity and hip and knee flexion angle. As this discourse lacks data through an Australian lens, it is yet another avenue worth delving into further.

It appears that adolescent female athletes are placed at risk from physiological considerations that include age, hormone production, biomechanical-structural issues, and muscle activation disparity compared with males. It remains to consider what social and psychological implications attend this disparity.

## 2.6 SOCIOLOGICAL AND PSYCHOLOGICAL IMPACTS

The sociological and psychological dynamics of injury severity are concerning in showing early depressive symptoms in adolescents with a high athletic identity and sudden lack of positive stress (Manuel et al., 2002). The consequences raise further questions, such as, what are the impacts of sporting injury to mental health in adolescents? What are the long-term psychosomatic concerns? Is there an impact on participation rate in future sport and sporting activities for adolescent females if injury risk is too high?

Calfas and Taylor's 1994 findings on the psychological benefits of sporting activity upon self-esteem and negativity induced by depression, anxiety, stress was supported in a large study with a survey population of 13,857 which used data from the centres for disease control and prevention (CDC) in the USA. Taliaferro et al. (2008) showed that active sporting engagement bestows unique psychological benefits that protect adolescents against not only feelings of hopelessness but also suicide ideation. In this study, adolescent female athletes showed, by a factor of two to one, much higher rates of hopelessness (34%) than males (18%), thus demonstrating a significantly increased suicide risk. With such disproportionally high rates of feelings of hopelessness in females, if a sporting injury were to occur, it would be expected that feelings of hopelessness would only increase. The fallout from sporting injury and rehabilitation is a strong indicator for a recession from activity that fuels dormant lifestyles, potentially leading to bodyweight management concerns, and numerous other health issues (Myer et al., 2014).

Psychological overload, however, can occur when levels of stress become excessive and no longer induce a positive, adaptive response. This is particularly so in sports demanding early specialisation such as, gymnastics and swimming (Malina, 2010), and it seems only sensible to call for further research into the benefits of support personnel working with adolescent athletes to recognise signs of stress and helplessness and promoting ways to intervene or refer within allied health networks.

Fear of re-injury (kinesiophobia) after surgery is a common concern for low-level returns to sport. Flanigan et al. (2013) completed a quantitative study on a return to pre-injury activity levels post ACL knee surgery in Ohio, USA. Of the respondents, 54% reported they did not return to sport or activity and an alarming 52% of the reported group cited kinesiophobia as the reason for non-participation. In a nationwide USA survey, it was found that athletes' experience increased social integration when they become members of a social network that included teammates, coaches and health professionals, family and community (Sabo, Miller, Melnick, Farrell, & Barnes, 2005). In a closely related study, Valovic McLeod et al. (2009) in Arizona, USA, looked at recent injury and health-related quality of life in adolescent athletes, noting that developing an understanding of the effects of injury in this age group is crucial for several reasons. Among them was a worry that sporting injury might lead to a cessation of physical activity, with the multiplicity of negative long-term consequences associated with that, such as obesity, adult-onset diabetes, and cardiovascular disease, as well as the possibility of musculoskeletal injuries poorly managed in adolescence leading to significant disabling conditions such as osteoarthritis later in life. Other factors, they pointed out, could also affect areas of the adolescent's later life outside of the athletic environment, such as education, personal relationships and risk for substance abuse. All this further supports the case, made above, that a support network during the injury cycles for injured adolescents and the delicate stages of acute injury recovery is important, required, and perhaps even essential for adolescent females.

Williams and Anderson (1998) showed life stress was a strong predictor of injury. Youth athletes can be exposed to inappropriate and unrealistic expectations. The frequency of tactical training sessions can vary greatly from sport to sport, with competitive swimming, for example, demanding twice daily exposures. Demands on the adolescent athlete identified by Appleton & Hill, 2012 include an individual expectation to do well while juggling demands of study, home life, and social pressures as well as perfectionistic tendencies prompted by heightened parental and coach-led expectations and criticism.

Social support can change once an athlete is injured and undergoes rehabilitation and 'return to sport' pathways. This has been identified by Yang et al. (2010), who argue that once a young female athlete is injured her social support patterns develop a greater reliance on coaches, trainers, and doctors for social support outside their social circles. Allender et al. (2006) found one of the motivating and primary reasons young girls participated in physical activity sports was a concern for being able to display or maintain a slim body image, and this will be explored in the next section. Also in that context, though, Anderson (1998) has shown that female adolescent athletes can derive positive feelings about body image, improved self-esteem, and experiences of competency that enhance mental health and lead to feelings of success and increased self-confidence.

## 2.7 BODY IMAGE IMPLICATIONS

What are the sociologically and publicly accepted 'norms' and aesthetic shapes for the female adolescent body, and are these accepted 'norms' consistent with females in élite sport? Dr Susan Bordo, a writer from the University of Kentucky known for her contributions to contemporary cultural and 'body studies', states that young adolescent girls can become obsessed with looking like celebrity models such as Kate Moss, or sporting influences such as Maria Sharapova, and want to conform to that image. They are being misguided by powerful, normative media images of the toned, anorexic, aesthetic female body, however enhanced by image-editing software. Bordo states that "rigorous weight training is probably less dangerous and makes you feel better than compulsive dieting, however many girls are capable of combining the two in a double-punishing daily regime" (Bordo, 1997, p. 58).

Would this view be accepted by female athletes involved in sports that naturally shape muscular structures of the body, such as gymnastics and swimming? Bordo (1997) further states that "embodiment" is represented through a set of "ideals" in movement, body shape, expression and behaviour. If these "ideals" of aesthetic feminine body shape are to be believed and passed generationally through parent-child channels or other circles of influence, it would be fair to conclude that there may be a distinct pressure to conform, and consequent anxiety for young female athletes in considering themselves "normal" or "abnormal". These anxieties can result in daily negative calorie deficit, or relative energy deficiency in sport (RED-S) (Mountjoy et al, 2014).

The aforementioned authors also note that weight and body composition are often crucial factors for performance in many sports involving youth (Mountjoy et al, 2014). RED-S can lead to undernourishment thence to delay in recovery and an increased risk of overuse and musculoskeletal injury, so placing the athlete in a catabolic state leading to muscle atrophy (Weiss et al., 2007). Again, self-imposed expectations, demands from peers, or weight restricting regulations in some sports may not suit the adolescent female, with many developing the Female Athlete Triad[5] or (RED-S), which increases the risk of disordered eating. Social comparisons and cultural standards of body image can lead to satisfaction or dissatisfaction with the athlete's own figure relative to the perceived "ideals" to achieve a thin and slender shape. These comparisons may lead females to heightened body-related anxiety, and a negative focus on aspects associated with weight and sexual attractiveness, distorted by body image dissatisfaction (BID), and other related negative psychological states (Franzoi & Klabiber, 2007; Sabiston, Crocker, & Munroe-Chandler, 2005).

This highlights the need for a further and more in-depth understanding of the impacts of body image awareness and the need for a holistic and positive intervention strategy that embraces psychological factors in addition to physiological methods for recovery. Sport trainers, coaches, parents and teachers have a major role in this sector and further education is required in order to find an effective and holistic intervention model.

Finally, although the intervention to be explored and implemented within this research project calls for strength training and the building of muscle volume in the lower limbs, the researcher is confident that the intervention will not add to the accumulation of mass already identified by Papai et al, (2012) in Tanner's fourth and fifth stages, because an adolescent athlete's response to strength training is optimal as muscle

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Female Athlete Triad is a syndrome in which eating disorders or low energy availability) can lead to amenorrhoea/oligomenorrhoea, and decreased bone mineral density (osteoporosis and osteopenia). This condition is seen in females participating in sports that emphasise leanness or low body weight. The Triad is a serious illness with lifelong health consequences and can potentially be fatal. American College of Sports Medicine Position Stand. (Otis, Drinkwater, Johnson, Loucks, &Wilmore, 1997).

hypertrophy occurs with a linear increase in muscle strength (Brown, Patel & Darmawan, 2017; Purcell & Hergenroeder, 1994). The mechanisms of muscle hypertrophy will be explored in the following section.

## 2.8 HYPERTROPHY

It is commonly accepted that resistance exercise (or strength training) elicits a process of muscle hypertrophy or hypertrophic responses to skeletal muscle (Brooke et al., 2015). It is commonly agreed that muscle hypertrophy takes place as a result of graduated and continued exposure to a mechanical load with both high and low-load thresholds (Ozaki et al., 2015). When high and low-load thresholds are applied to skeletal muscle, hypertrophy is related to an increase in muscle volume or mass resulting from a rise in the cross-sectional area of individual muscle fibres (Glass, 2005). The anatomy of skeletal muscle is described below.

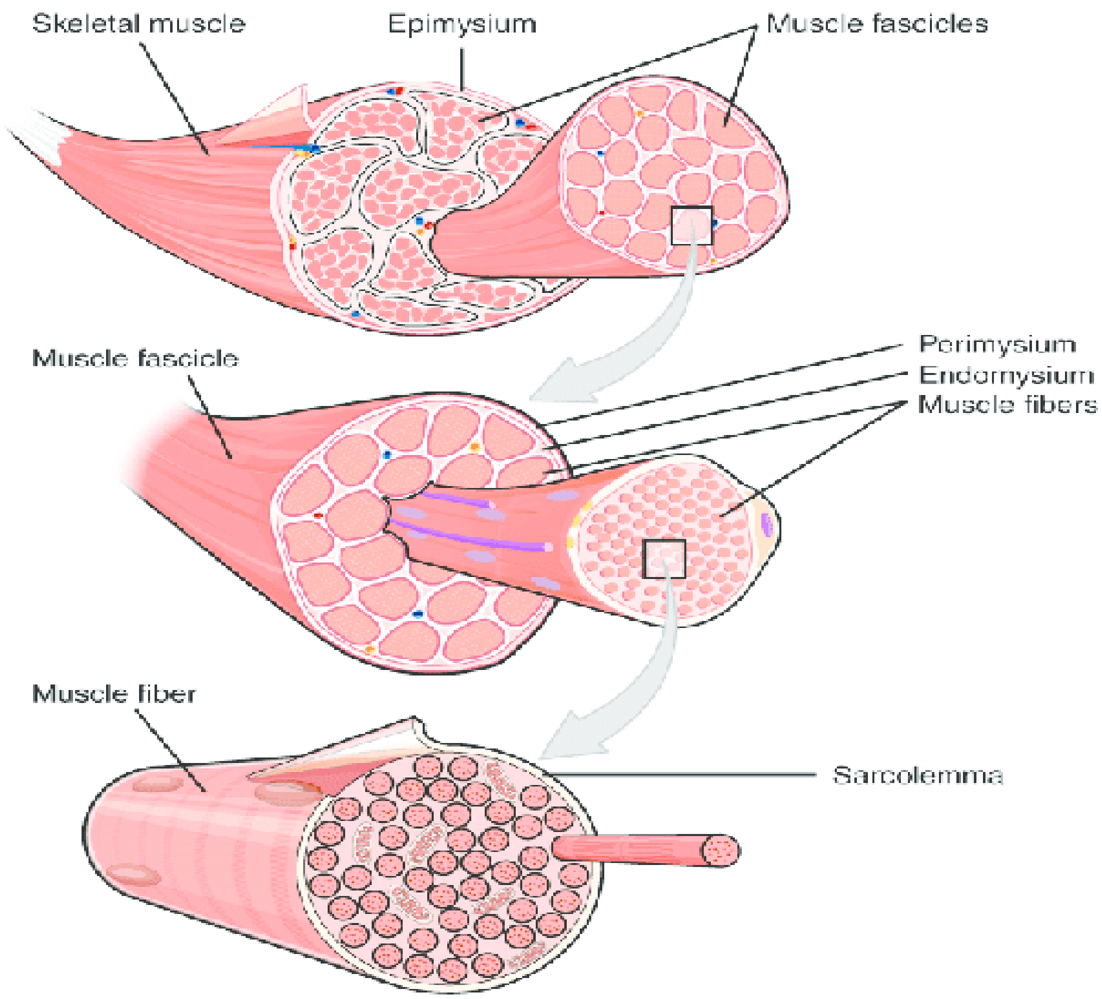


Figure 4 The hierarchical structure of the skeletal muscle. (Cardiac Meets Skeletal: What’s New in Microfluidic Models for Muscle Tissue Engineering - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/The-hierarchical-structure-of-the-skeletal-muscle-Reproduced-from-19-Creative-Commons_fig1_307087879).

### 2.8.1 Basic muscle anatomy

Voluntary muscles in the body contain wrappings of connective tissue made up of fibres. Each fibre is wrapped and separated from neighbouring fibres by a fine layer of connective tissue called the endomysium. The perimysium surrounds a large bundle of fibres, which is a fascicle. Surrounding the entire muscle is a fascia of fibrous tissue known as the epimysium. Fascia, connective tissue outside the epimysium, surrounds and separates the muscles. Portions of the epimysium project inward to divide muscle into compartments (McArdle, Katch, & Katch, 2010).

Muscle fibres are made up of bundles of smaller thread-like structures called myofibrils. Myofibrils are the parts of muscle fibres that contract. They are composed of thick and thin filaments, which are made, respectively, out of the contractile proteins myosin and actin. When muscles contract, the thin actin filaments slide over the thick myosin filaments, generating a force. Myofibrils are surrounded by a matrix known as the sarcoplasm, which contains various fluids, stores of glycogen, non-contractile proteins and organelles (McArdle, Katch, & Katch, 2010). In summary, muscle fibres are composed of myofibrils, which contract, and sarcoplasm, which does not contract. Muscle fibres can increase cross-sectional area in two main ways. It is here that the researcher feels it is important to explain the different organic methods of hypertrophy and why the methodology of exercise prescription is pertinent to the adolescent female cohort participating in this project.

### 2.8.2 Hyperplasia of structures

Research conducted 30 years ago by Nikituk (1990) identified the two main ways in which muscles and muscle structures can increase in size – also known as 'hyperplasia' of structures within the muscle fibre and muscle cell. The first method refers to 'sarcoplasmic hyperplasia', which is an increase in the number of sarcoplasmic organelles, and the second method is 'myofibrillar-mitochondrial hyperplasia', which involves an increase in the number of myofibrils and mitochondria. Myofibrils are the thread-like structures within muscle fibres that are responsible for muscle contraction. They are made of contractile units (called sarcomeres) composed of key contractile proteins: actin and myosin. Increased production or "synthesis" of these contractile proteins adds additional myofibrils and makes them larger (McCracken, 2000).

As myofibrils become larger and more numerous, they are capable of generating greater force while contracting. As such, myofibrillar hypertrophy contributes to the strength gains that follow resistance training. Exercise-induced hypertrophy results from an increase in sarcomeres and myofibrils (Paul & Rosenthal, 2002). Muscle hypertrophy can result from an adaptive response to a process known as 'progressive overload'– a gradual increase in the stress placed upon the musculoskeletal system (Kraemer & Fleck, 2007). For an application in strength training, progressive overload is a process involving a gradual increase in the maximum amount of weight lifted over consecutive training sessions or increases in training volume and tension. The overall effect results in the enlargement of muscles due to the increase in size of individual muscle fibres (Kraemer & Fleck, 2007). It is hypothesised here, that a small increase in individual lower limb muscle fibre size may have a positive impact in dynamic knee kinematics in adolescent female athletes, and this research project seeks to explore this hypothesis.

There are several myogenic signalling pathways that facilitate exercise induced muscle hypertrophy[6], and although they do not have a specific focus in this thesis, it is important to highlight that sarcoplasmic hypertrophy may play a key role in this research project due to the relatively shorter timeframe for muscular adaptations to occur over increased structural myofibrillar hypertrophy. This occurs over a graduated and longer exposure in an athlete's training cycle.

### 2.8.3 Sarcoplasmic hypertrophy

Sarcoplasmic hypertrophy involves an increase in the volume of non-contractile proteins and semifluid plasma between the muscle fibres. While the cross-sectional area of muscle increases, the density of the muscle fibres per unit area decreases and there is no corresponding increase in muscle strength (Verhoshansky & Siff, 2009).

### 2.8.4 Nutrition and hypertrophy

Contemporary research reports that consumption of protein in close proximity to the application of resistance and strength training promotes greater muscular hypertrophy and improves the anabolism and protein synthesis for changes in fat free mass (Phillips, 2011).

Dietary protein interacts positively with resistance exercise providing a trigger for the synthesis of metabolic proteins and enhancing changes in non-muscle tissues, such as tendons and bones. (Phillips, 2012). Muscle protein synthesis has been shown to be optimised in response to exercise through consumption of high biological value protein (approximately 10 grams of essential amino acids upon cessation of a resistance training session). 10 grams of essential amino acids equates to the consumption of 15-25 grams of consumption of a high biological value protein source (Beelen, Burke, Gibala & Van Loon, 2010). Further studies on protein

[6] Such as, Akt/Mammalian Target of Rapamycin (Akt/mTOR), Mitogen-Activated Protein-Kinase (MAPK), and Calcium-Dependent ($Ca_{2+}$).

consumption levels indicate that muscle adaptation to resistance training can be maximised by ingesting 0.3 grams per kilogram of the athlete's bodyweight after resistance exercise sessions and every three to five hours over multiple meals (Phillips, 2014).

High biological-value proteins are rapidly digested, and leucine, high in essential amino acid appears to be more efficient at stimulating muscle protein synthesis (particularly if administered in combination with a carbohydrate source) and consumed within an hour of cessation of resistance exercise (Moore & Soeters, 2015). Increasing awareness of optimal nutrition for muscle development, particularly leucine consumption, for the participants will be an essential component for this study.

While recommendations for daily proteins have been made, sports nutrition guidelines suggest overall nutrient intake of all macronutrients, including fats, carbohydrates and fluid levels throughout a 24-hour period provide vital nutritional support for all performance outcomes (Thomas, Erdman, & Burke, 2016).

### 2.8.5 Exercise variables and hypertrophy

Aside from creating the best anabolic environment through optimal protein levels and nutritional strategies, correct manipulation of training variables is essential for optimal exercise-induced muscle hypertrophy (Liang et al., 2020). Intensity is relative to one repetition maximum (RM), or the most amount of load lifted once by an individual that induces absolute fatigue (Marchese, Tylor, & Fagan, 2019).

Repetition ranges are widely accepted to fall into three categories: low (1-5RM), moderate (6-12RM), and high repetition (15RM or more). Each of the three repetition ranges have been shown to elicit hypertrophic responses, however it is widely accepted, without biological sex comparisons, that a moderate range of 6-12RM optimises hypertrophic response (Zatsiorsky & Kraemer, 2006).

A more recent comparative study on muscle hypertrophy using low load (LL) resistance training versus high load (HL) resistance training for young women, has also favoured the LL model. The LL group performed three sets of three exercises with loads that allowed 30-35 repetitions before eliciting muscular fatigue. The HL group performed the same three exercises for three sets using a load that allowed 8-10 repetitions before inducing a muscle fatigue state. The LL group showed superior muscle hypertrophy response over the HL group. Both groups trained only twice per week for nine weeks. The researchers concluded that this may have been due to two factors; one is that the LL group had a higher overall volume of training, therefore overall time under tension, which has been shown to be favourable for hypertrophy, and two; an additional recruitment of motor units necessary to sustain muscle tension (de Castro Franco et al., 2019).

Informed by the conclusions above, volume of training will have an influence in hypertrophic response. Volume can be divided by the number of total sets, repetitions and loading used in an entire training session. The set is referred to the number of repetitions performed without a rest, and load is the weight used during each set expressed in kilograms. Total volume is a product of [reps x load (kg)] x sets (Schoenfeld, 2010). Higher volume, multiple set per muscle group protocols have proven superior over single set or low volume per muscle group protocols for increased hypertoric response (Krieger, 2010; Wolfe, Lemura, & Cole, 2004). To ensure that optimal conditions for muscle hypertrophy are staged, participants will undergo a graduated increase in volume load over an 8-week period, with moderate repetition ranges of 8-12 per set.

An intervention focused upon localised muscle hypertrophy increase and its relationship to dynamic knee valgus and knee flexion angle is, to the best of the researcher’s knowledge, the first of its kind and an original contribution to knowledge in this field. Other types of intervention for physical preparation and knee injury reduction in adolescent females are explored below.

## 2.9 INTERVENTIONS

There is a plethora of information regarding neuromuscular intervention applications for adolescent female athletes even though no universally accepted ACL injury prevention program currently exists due to the complex nature of the issue (Bien, 2011). Injury prevention programs are diverse with studies focusing on biological sex disparity in structural mechanisms that provide muscle activity around the ACL and lower limb. Varied intervention strategies have been applied involving a mix of pre-activity warm-up drills, during active neuromuscular activation exercises (half time drills), post-activity neuromuscular drills and neuromuscular strength training involving plyometric activities (Herman, Barton, Malliaras, & Morrissey, 2012; Chicorelli, Micheli, Kelly, Zurakowski, & MacDougall, 2016; Soligard et al, 2008). This section will highlight the interventions that have shown significant statistical reduction in non-contact injury rates over the control study groups. As previously mentioned, the non-contact injury data is important, as quantifying a significant result in the reduction of lower limb injury is difficult because unpredictable collision and evasion reactions in the dynamics of sport make accurate predictions of injury problematic.

Multiple studies using neuromuscular pattern and strength programs, collectively show benefit through a frequency of a minimum stimulus of two times per week for a period of six weeks (Hewitt et al., 1999; Mandelbaum et al., 2005; Myer et al., 2013; Yoo et al., 2010). In addition, a combination of pre-season and in-season training is more effective than in-season alone (Yoo et al., 2010). The work of Landry et at. (2007) which linked the coupling of gastrocnemius and quadriceps dominance in females to counter weaker contribution of the hamstrings is of great interest, since moderate hamstrings activation with comparison to quadriceps alone has a relationship to elevated valgus and internal rotation position in the knee which contributes to ACL injury risk (Donnelly et al., 2012; Hewett et al., 2005; Wojtys et al., 2002). Morgan, Donnelly and Reinbolt, (2014) show that males demonstrate the same trait as females by using elevated gastrocnemius-soleus forces. They also noted and confirmed the findings of previous landing force studies in this review, that females produce smaller knee flexor angles on landing which limits the ability to counterbalance the quadriceps and reduces anterior tibial translation, so increasing the likelihood of injury to the ACL. Morgan et al. (2014) show that elevated gastrocnemius activation could substitute for the hamstrings muscles in improving dynamic knee stability to reduce ACL injury. In addition, they note that the gastrocnemius muscle groups play an important role in mitigating ACL injury risk during single leg jump landing which should be applied to female athletic populations as a positive intervention. Work from Petushek et al. (2019) also highlight and support the use of trained implementers to incorportate lower body strength exercises (such as, Nordic hamstrings, lunges and heel-claf raise) with a specific focus on landing stabilization (jump/hop and hold) throughout the sporting season. It can therefore be hypothesised that targeted hamstring and gastrocnemius ST, with emphasis on unilateral exercise priority in conditioning sessions will be instrumental in the prevention of lower extremity injury.

Dharamsi and LaBella (2013) highlight a common thread of three key areas from a plethora of intervention strategies that have been researched, and they merit attention is some detail. The first key area is plyometric based programming, which involves the pairing of eccentric and concentric muscle contraction to increase power output. The most effective plyometric programs have shown a gradual and staged difficulty from two-legged take-offs and landings (squat jumps and box jumps) to one-legged take-offs and landings (hopping, bounding and lateral striding from one leg to another) and from jumping on the spot to travelling jumps (single leg hop and broad jump for distance).

The second key area is a strength-based neuromuscular program utilising a combination of bodyweight resistance, pin-loaded machines and free-weight exercises which builds on progressive strength in key exercises such as squats, lunging patterns, and deadlift variations. These allow a targeting of the hamstrings, gluteal group and hip rotators that aims to counteract the mechanical problems that result in dynamic knee valgus; and also coordinated balance training (standing on single limbs and deliberate unstable surfaces to build proprioceptive feedback).

The third key area is a feedback-driven technique modification (Dharamsi & LaBella 2013). This technique involves supervision by a qualified instructor or strength coach who is specifically trained to recognise dynamic knee valgus in the context of engaging the athlete in recognising unsafe positions for the knees (see Figure 3 – positions of safety and risk on page 14) and how to correct form and technique by not allowing a trainee to progress to advanced exercises until they have demonstrated proper form and technique over time with less difficult exercises. Firm and directed verbal cuing by instructors and coaches is considered essential to the success of this component as many trainees are not aware of their body positions without regular verbal guidance (Dharamsi & LaBella, 2013; Myer et al., 2011; Myer et al., 2013). The combination of progressive strength training for the lower extremities and core included with plyometric activity, and proprioceptive feedback technique training is shown to be a successful intervention model with coach-led programs (Hewett et al., 2006). On the other hand, programs that included only balance and proprioceptive training have been shown not to be effective in reducing ACL injury risk (Hewett et al., 2006; Yoo et al., 2010). (Myer et al., 2013) claim that the inclusion of balance training in combination with strength training to the hamstrings and core muscles, not only improves balance and teaches athletes how to recognise and avoid knee valgus but has demonstrated a 72% reduction in ACL injury rates among adolescent female athletes. Furthermore, work from Griffin et al., 2020 highlight that coaching deceleration techniques coupled with emphasising eccentric leg strength with younger athletes, can reduce potential injury, and improve performance.

At this stage it is important to ask how much actual strength is enough to reduce non-contact injury risk in the adolescent body, and how is this strength measured? As mentioned in the introduction, there exists a stigma about weight training in children and youth. In the researcher's professional experience, many parents and coaches still have major concerns about growing children lifting weights despite information being relatively readily available on the benefits of ST for this demographic. In the interest of allaying those concerns and so removing an impediment to a beneficial process, two methods of bringing about that process will now be examined.

The influence of lower extremity (LE) muscle strength on traumatic knee injury was profiled in a recent Swedish-based study using data from utilising the Swedish Olympic Committee test battery known as Fysprofilen[7] (Augustsson & Ageberg, 2017). The results have the ring of familiarity in showing that weaker LE muscle strength is a risk factor for knee injury, particularly ACL injury in female youth but not in male youth. Further, it is shown that the odds of sustaining traumatic knee injury, including ACL injury in females are nine and a half times higher and seven times more likely, respectively, in females classified 'weak'.

'Weak' and 'strong' females are categorised by a calculation of weight lifted using the barbell squat exercise, versus the athlete's bodyweight. This, the first of five key strength tests in Fysprofilen, involves the athlete performing a squat movement to a parallel depth (lateral mid-line of knee in line with greater trochanter) with as much

[7] Fysprofilen 2017. Retrieved from http//fysprofilen.se/sv/default.aspx?

weight as possible to complete one rep or one repetition maximum (1RM), supervised by well-educated instructors.

A weak athlete is one categorised with a relative value of ≤ 1.05kg, calculated by the formula (1rm weight value divided by the athlete's bodyweight in kilograms); the formula used as the clinical cut-off for high-risk injury (Augustsson & Ageberg, 2017).

Although the abovementioned study is of great value and has vital input into understanding injury to the lower extremity in female adolescents, the researcher feels that the testing itself could cause injury by placing the demands of an extreme high load on a low-training-age adolescent. From the researcher's field experience, it is often the case that females with minimal or no weights room experience are unable to display optimal technique using major compound movements such as the barbell loaded squat, barbell deadlift, and barbell bench press. To prepare the inexperienced adolescent female athlete for the complexities of such lifts, exposure to a regular training stimulus that focuses on a graduated introduction to free weights training over a period of time, and which focuses on building muscle hypertrophy rather than muscular strength seems the ideal method. Fortunately, such a training programme exists in the youth body-weight testing system of the Australian Strength and Conditioning Association (ASCA).

The ASCA has developed a points-based system to assess the readiness of an adolescent for the use of free-weights, mainly barbells, and resistance exercises for ST (see Table 2.3 below). The scoring system is evaluated for each individual by a Strength Coach. If the adolescent is unable to accumulate a minimum score of 18 points in six tests, then they are deemed not ready for barbell orientated strength training methods. For the adolescent with lower scores, the focus for their training sessions becomes centred around the use of bodyweight exercises (mainly those used in the Table 2.3) with appropriate regressions and scaling using varying body angles and positions allowing the adolescent to gradually progress through stages before retesting.

Table 2.3

*Barbell readiness for children and youth | Australian Strength & Conditioning Association*

| EXERCISE | 5 POINTS | 4 POINTS | 3 POINTS | 2 POINTS | 1 POINT | 0 POINTS |
|---|---|---|---|---|---|---|
| **FEMALE YOUTH AGED 13-17** | | | | | | |
| PUSH-UP | $\geq$ 20 | 15-19 | 10-14 | 5-9 | 1-4 | 0 |
| PULL-UP | $\geq$ 6 | 4-5 | 3 | 2 | 1 | 0 |
| 1-LEG SQUAT, stand on box, average of both legs | 5 | 4 | 3 | 2 | 1 | 0 |
| FULL SQUAT in 60 secs, 10%BWT held on chest | $\geq$ 40 | 33-39 | 26-32 | 19-25 | 11-18 | $\leq$ 10 |
| FRONT HOVER HOLD | $\geq$ 120 | 90-120 | 60-90 | 30-60 | 10-30 | $\leq$ 10 |
| TWISTING SIT UPS | $\geq$ 40 | 33-39 | 26-32 | 19-25 | 11-18 | $\leq$ 10 |

The ASCA's endorsed free weight screening point system is important and aligns with the International Olympic Committee's (IOC) view as expressed in its assertion that "pre-pubertal children benefit from resistance training; but the trainability of muscle strength increases with age. There is a minor sex-effect during pre-puberty, which increases with age and maturation" (Bergeron et al., 2015, p.2).

If, then, the benchmark for achieving significant reduction in traumatic knee injuries in adolescent females is achieving a strength ratio of >1.05 in the barbell squat exercise, then a suitable training method to bring the athlete to this point must be established in the interim. In tandem with this, it would be appropriate not only to inform and educate coaches, sport support staff, parents, teachers and athletes themselves about the values and benefits of structured strength training, but to apprise them of the fact that, in the ASCA weight-training system, a safe and trainee-centred mechanism exists to improve FFM in order to better protect the body from the rigours of dynamic forces placed on it in landing, jumping and cutting, rather than using strength training or dieting for an aesthetically pleasing appearance.

Could localised muscle hypertrophy, established via lighter exercise loading principles (less than 1.05 strength ratio to bodyweight) play a vital role in the reduction of female adolescent injury risk? The mechanisms of muscle hypertrophy via optimal nutrition for muscle growth will be taken into account when considering this research project's intervention program. As discussed in the nutrition and hypertrophy section (2.8.4), best practice suggests that regular consumption of protein throughout the day be consumed, and in addition, consumption of 15-25 grams of high biological value protein in combination with a carbohydrate source be administered within a short timeframe from completion of each exercise training session.

## 2.10 CONCLUSION

This literature review has been concerned with the problem of musculoskeletal injury to female adolescent athletes. International statistics quoted show that injury rates in youth athletes are largely consistent across most developed countries. Australian data appears generalised, and opportunities exist for further quantitative and qualitative research. Physiological characteristics between male and female adolescents have been clearly defined and have shown disparities in muscle fatigue levels leading to unfavourable landing mechanics in females.

Knee valgus in adolescent females has been defined, described, and shown to be a leading contributor to injuries to the knees and lower extremities, with Q-angle defined and its contribution to structural injury linked to biomechanical deficiencies. Overuse injuries in the adolescent population were identified and related to the Tanner Staging Chart (see Table 2.1), showing that overuse injuries tend to be more frequent in later stages 3 and 4, at the very stage when adolescent athletes begin to specialise and find themselves more heavily involved in playing, training, or preparing for their sport.

Body mass and injuries related to it show there is a relationship to 'overweightness' and higher BMIs outside of FFM that place the adolescent at risk. This risk was partially explained by noting that, during Tanner's stages 4 and 5, females typically increase fat mass in the lower body regions. However, it was identified that at these stages an adolescent athlete's response to strength training is optimal, as muscle hypertrophy occurs with a linear increase in muscle strength.

Sociological and psychological factors must be considered, with welfare of the adolescent athlete placed in the hands of the "circle of influence" for the individual, for the mental welfare of youth athletes is of utmost importance. Coaches, support staff, teachers, parents, and anyone involved in the athletic development of adolescents have important roles in recognising signs of distress physically, sociologically and psychologically, for Devey et al. (2022) and Taliaferro et al. (2008), have already shown that mental negativity is present to a concerning degree in otherwise healthy adolescent female athletes. Given this and remembering that many are already struggling with the perfectionist ideation of achieving a slim and aesthetically pleasing body image, it is the more important that injury avoidance takes pride of place in endeavours involving adolescent female athletes.

Muscle hypertrophy has been defined and explained with current protocols on eliciting effective hypertrophic responses explored. Nutritional requirements around resistance training and protein consumption have been reviewed with recommendations made. Current successful intervention strategies to reduce lower limb injuries in female adolescents have been considered and show that a combination approach of neuromuscular training (NMT), plyometric exercises and balance training are moderately effective, but that any one of the three methods in isolation does not appear to show a significant reduction in injury occurrence. A recent meta-analyses concluded that an NMT and feedback-driven coaching interventions show how important the role of qualified coaching staff is, in providing real-time education to the athlete in such things as body position, and safe landing technique (Petushek, Sugimoto, Stoolmiller, Smith, & Myer, 2019).

Perhaps one of the most significant, and recent, interventions researched is the Swedish strength training and testing battery methodology of Fysprofilen, which categorised an adolescent as either weak or strong. Weak females show significant differences in lower limb injury rates over females who are classified as strong. These differences were not shown in the adolescent male population. As significant as this appears, a deep concern with Fysprofilen lies in the use of the 1RM protocol[8]. This strength-testing method can contain potential risks for young athletes without a reasonable history of utilising ST. A suggestion would be to use a scaled approach using a safer and controlled lifting protocol with selection of a sub-maximal intensity of 6RM to factor into the 1RM calculation below:

1RM= {[weight lifted x 0.03] x no of repetitions} + weight lifted.

This is perhaps worth testing through further studies, but the use of ASCA appears to add a further dimension to knowledge and practice in this area. Yet another concern using maximum testing is that lifting technique could perhaps be compromised. Knee valgus in the maximum lift could still occur and contribute to a successful measure for record unless a

[8] Repetition Maximum. (n.d.) *Medical Dictionary for the Health Professions and Nursing*. (2012). Retrieved October 27 2017 from https://medical-dictionary.thefreedictionary.com/repetition+maximum

trained and experienced coach were in charge of the testing and evaluation process. The classification rating of weak or strong adolescent females with associated injury risks in Augustsson and Ageberg (2017) research is of great interest, and opportunities exist for an Australian-based study to show the same promising results for this population.

It is known that combination intervention strategies are successful in reducing non-contact injuries. This highlights the need for a multi-faceted approach to successful intervention programmes that should be initiated prior to the onset of puberty in order to prevent maladaptation of biomechanical and neuromuscular patterns from developing in the first instance (Renstrom et al., 2008).

Muscle strength, endurance, neuromuscular control, and overall muscle function differ between the sexes. These factors are important and worth considering for a significant reduction in the likelihood of non-contact knee injury in young female adolescent athletes. Injury screening for modifiable factors such as muscle strength, and injury prevention training including LE strength, is needed in female youth athletes (Augustsson & Ageberg, 2017).

Education appears essential for adolescent athletes in order for them to understand the basic mechanics of body movements in sports (particularly those that involve jumping, landing and cutting). Once understood, then perhaps physical preparation and conditioning programmes will strike adolescent female athletes as not only sensible, but essential for progress in their field of competition.

# CHAPTER 3: METHODOLOGY

## 3.1 INTRODUCTION

This chapter provides detail of the research methodology used to achieve the aims, study focus, and objectives as discussed in research rationale in sections 1.1 and 1.2 of Chapter 1. Section 3.2 outlines the research paradigm, method and research design underpinning the formulation of the research questions and the study design. It then outlines the techniques used in each progressive stage of the study design with the intervention process detailed in section 3.3. The research setting and participant details are provided in sections 3.4 and 3.5 respectively, including the recruitment process, sample size, and allocation of groups. Section 3.6 discusses the specific instruments used in the study and outlines and identifies the specific parameters used to identify anatomical and biomechanical variance, physical performance measures, and significance between groups. Section 3.7 outlines a staged timeline for the study with the specifics of data collection. Section 3.8 contains an outline of analyses, and Section 3.9 discusses ethical considerations.

## 3.2 PARADIGM, METHOD, AND RESEARCH DESIGN

### 3.2.1 Research Paradigm

A critical component when identifying a research topic and formulating research questions in science and social science, is the research design (Abutabenjeh & Jaradat, 2018). In this research, the questions raised marries with the Pragmatist paradigm, which focuses on obtaining the necessary data to answering research questions (Revez & Borges, 2018). A work-based project is uniquely suited to a Pragmatist philosophy, as Pragmatism focuses on the practical outcomes of what we think and do, and can bridge current divides between scientific paradigms, the theory-practice gap, and academic-practitioner interests (Korte & Mercurio, 2017). According to Mackenzie and Knipe (2006), Pragmatism does not oblige the use of one method over another and is therefore a fitting paradigm for this research project because it uses a method dictated by the research questions. Indeed, Tashakkori and Teddlie (2011) state Pragmatists consider the research questions to be more important than the method they use or the worldview they adopt. Thus, the research questions for this study have led to the adoption of a Pragmatist view and a quantitative method.

### 3.2.2 Method

This research adopts a quantitative approach. Creswell and Creswell (2017), describe a quantitative approach as research that focuses on gathering numerical data and generalising it across groups of people to explain a particular phenomenon. In that tradition, this research will focus on collecting primary data rather than depending on secondary data collected from previous research.

As previously stated, the study was framed as a work-based research project investigating the relationship between lower limb muscle hypertrophy and improved dynamic knee mechanics in adolescent female athletes, aiming eventually at potential amendments to strength and conditioning protocols in that demographic. While the study does not specifically measure 'injury' but only extrapolates to it, as shown in Chapter 2, changes in muscle hypertrophy and knee dynamics as described herein may be precursors to reduced levels of injury risk.

### 3.2.3 Research Design

The study sought to investigate a relationship between a physical training stimulus and resulting changes in physiology. With a longitudinal study, the researcher was able to use multiple observations to detect development and change in physical characteristics of the intervention group compared to the comparison group, and individually between groups over a period of time. An overview of the research design is presented in Figure 5.

In order for a physical change to occur within individuals in the defined intervention group (as outlined in section 3.3), the research was ‘time sensitive’, so a longitudinal approach was employed. According to Wang, et al. (2017) longitudinal research uses data that is collected over a meaningful span of time, with “meaningful” defined as “enough passing of time to carry out tasks, observe behaviour and to measure change, that supports the inferences being made and improves research validity.” (p. 3).

The research design involved an observational and cross-sectional application to expand and strengthen the study’s conclusions by way of answering the research questions that contribute to heightened knowledge and validity (Schoonenboom & Johnson, 2017). This method is often used to make inferences about possible relationships or to gather preliminary data to support further research and experimentation (Cherry, 2019).

Within the structure of the observational method, a quasi-experimental comparison cohort study was employed. As a cohort study, it selected a study group with common characteristics, and a comparison group that was similar but without the independent variable of interest. A quasi-experimental design is used when an independent variable is uncommon, or randomisation is not possible. Groups are then followed in order to measure the outcome (Thompson & Panacek, 2006).

The researcher employed a measure of intervention via a physical exercise program that followed two non-randomised groups over an eight-week period divided into stages.

Primarily the research began with a review of literature in the space of female adolescent athlete lower limb injury mechanisms. This was submitted as part of the Post-Graduate Certificate in Professional Studies. A Confirmation of Candidature was then sought for the Master of Professional Studies (Research) program. Upon successful Candidature, the Ethics approval process commenced, which was followed by collaboration with the research setting organisation for potential participant guardian consent and participant assent. A participant study group selection process commenced (*N* = 16), with anthropometric and landing observation data collected. This is referred to as the 'Primary Stage' of the study.

The 'Secondary Stage', which was designed to provide the data necessary to answer research questions one to three, commenced with selection and division into two non-randomised cohorts allocated by the school. These were the Intervention Group (IG) and Comparison Group (CG), with each having eight participants. The IG followed a specific strength training program over an eight-week period aimed at increasing localised muscle tissue to the lower extremities. The CG continued training for and playing their respective sports. The CG training involved only their specific court and field sessions and did not involve any gym-based or resistance training sessions. Upon conclusion of an uninterrupted eight-week training schedule, anthropometric and landing observation data was again collected as above. Data was then extrapolated and formatted for statistical data analysis using the SPSS software package. Analysis and correlational of levels of variance were interpreted. Figure 5 below represents the study design.

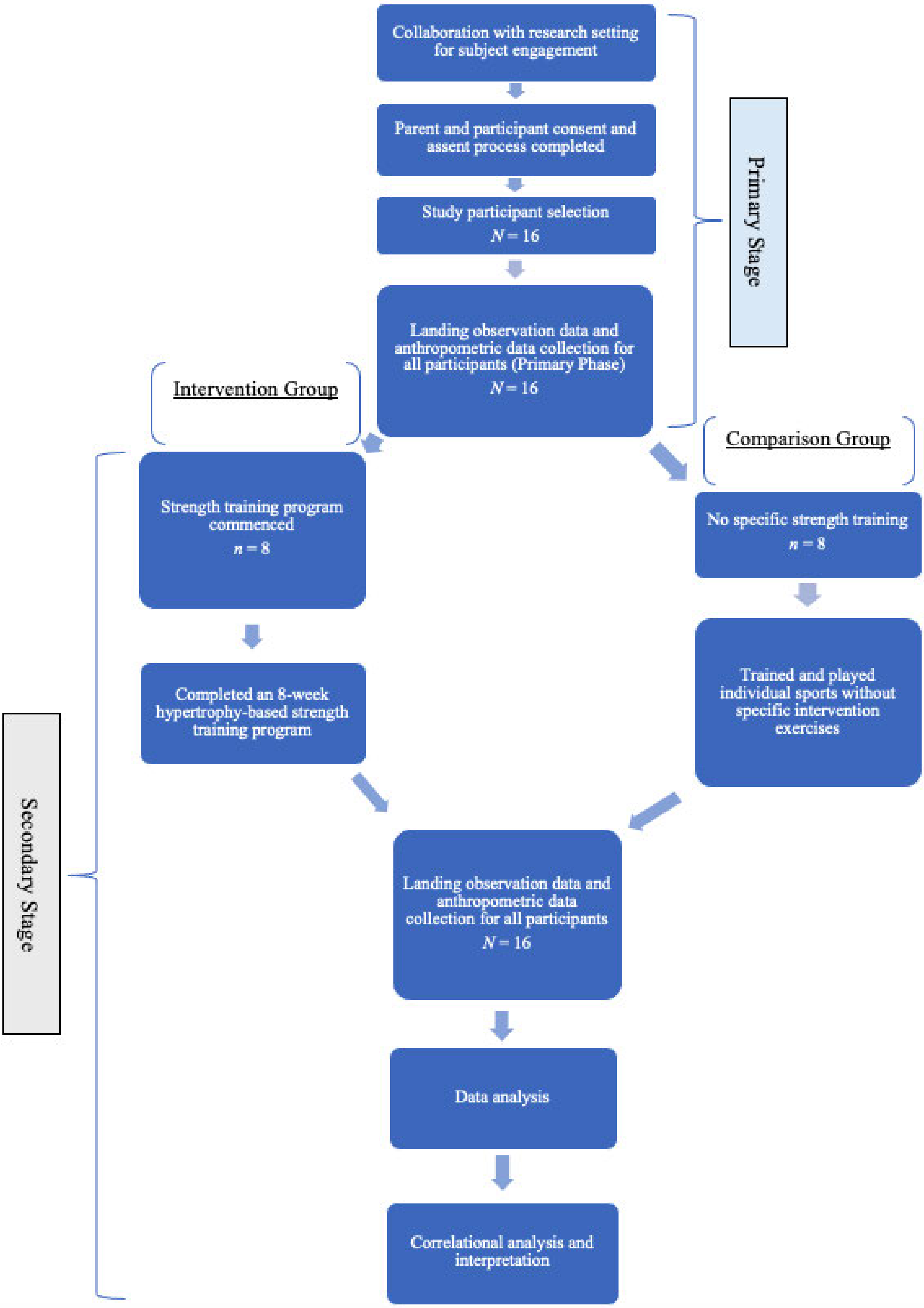



Figure 5 Study design with primary and secondary stages.

## 3.3 INTERVENTION

In the Secondary Stage of the study, participants were divided into two groups. The Intervention Group (IG) followed a specific resistance training program three times per week for a maximum of 40 minutes per session in the research setting (see 3.4). The training program was sectioned into a warm-up phase, resistance phase, and cool-down phase.

The warm-up phase was structured to increase localised blood flow to the lower extremities, increase respiratory rate, and increase stroke volume to prepare for the resistance phase. The warm-up phase consisted of three minutes of stationary cycling and two minutes of dynamic stretching (leg swings – frontal, sagittal, and transverse direction). Muscle activation exercises (gluteal bridge-single-double, VMO modified partial lunges, lateral band walking) concluded the warm-up phase.

The resistance phase was divided into two separate workouts: 'Day 1'; and 'Day 2'. This allowed for enhanced variability, and to mitigate any potential boredom. Day 1 consisted of five strength exercises balanced over hip and knee movements with a bias to hip movement. The exercises were Barbell Romanian Deadlift, Isometric Wall Squat, Ball Leg Curls, Copenhagen Adductors off bench, and loaded Box Step-ups. Day 2 also consisted of five lower body strength exercises with, again, a bias to hip movement. The clustering of 'A' and 'B' exercises allow for a short 10 second transition or brief rest period between exercises to complete the required number of sets. After each cluster a two-minute rest is required before moving to the next exercise cluster. The exercises were Bulgarian Split Squat using a one and one-quarter concentric repetition protocol, Barbell loaded Supine Hip Extension, standing single-leg Calf Raise, banded Lateral Walk, and Nordic Falls (eccentric phase only).

The cool-down phase consisted of two minutes of stationary cycling and three minutes of lower body static stretching, which included the muscle groups of quadriceps, hamstrings, adductors, gluteals, gastrocnemius, and mid- to lower-spine regions.

Workouts were sequenced into 'blocks' over a 14-day cycle to ensure six workouts were completed including three each of Day 1 and Day 2. Both workout days were periodised to accumulate volume load (VL) over the eight weeks. VL is defined as the total number of performed repetitions and weight (expressed in kilograms) lifted, for example [repetitions (no.) x external load (kg)]. VL is accepted as a valuable tool for monitoring and comparing dosages in experimental conditions (Kok et al. 2009; Tran et al. 2006) and for athletic development (Haff et al. 2008). Since VL represents several modifiable variables in strength and resistance training, it is considered advantageous for periodising and manipulating training effect (Peterson et al., 2011). Day 1 VL increased by 34% over the eight weeks, and Day 2 VL increased by 27%. The IG completed four blocks in total over the eight weeks, and overall, 24 workouts were completed by each of the participants in this group. Full program details can be found in Figures 6 and 7 below.

| DAY 1 | | WEEK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1A | Barbell Romanian Deadlift | SETS X REPS | 2 x 15 | 2 x 15 | 3 x 12 | 3 x 12 | 3 x 10 | 3 x 10 | 3 x 8 | 3 x 8 |
| | | SPEED | 201 | 201 | 201 | 201 | 201 | 201 | 201 | 201 |
| | | REST PERIOD | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs |
| | | TOTAL REPS | 30 | 30 | 36 | 36 | 30 | 30 | 24 | 24 |
| 1B | Wall Sit | SETS X REPS | 2 x 60 sec | 2 x 60 sec | 3 x 60 sec | 3 x 60 sec | 3 x 90 sec | 3 x 90 sec | 3 x 90 sec | 3 x 90 sec |
| | | SPEED | hold | hold | hold | hold | hold | hold | hold | hold |
| | | REST PERIOD | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min |
| | | TOTAL REPS | 120 sec | 120 sec | 180 sec | 180 sec | 270 sec | 270 sec | 270 sec | 270 sec |
| 2A | Ball Leg Curls | SETS X REPS | 2 x 60 sec | 2 x 60 sec | 3 x 60 sec | 3 x 60 sec | 3 x 90 sec | 3 x 90 sec | 3 x 90 sec | 3 x 90 sec |
| | | SPEED | hold | hold | hold | hold | hold | hold | hold | hold |
| | | REST PERIOD | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs |
| | | TOTAL REPS | 20 | 20 | 24 | 24 | 30 | 30 | 45 | 45 |
| 2B | Copenhagen Adductors off bench | SETS X REPS | 2 x 8 | 2 x 8 | 2 x 10 | 2 x 10 | 3 x 10 | 3 x 10 | 3 x 12 | 3 x 12 |
| | | SPEED | 311 | 311 | 311 | 311 | 311 | 311 | 311 | 311 |
| | | REST PERIOD | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | TOTAL REPS | 16 | 16 | 20 | 20 | 30 | 30 | 36 | 36 |
| 3 | Box Step Up (loaded) | SETS X REPS | 2 x 12 | 2 x 12 | 3 x 10 | 3 x 10 | 4 x 8 | 4 x 8 | 4 x 8 | 4 x 8 |
| | | TEMPO | 311 | 311 | 311 | 311 | 311 | 311 | 311 | 311 |
| | | REST PERIOD | 10 sec | 10 sec | 10 sec | 10 sec | 10 sec | 10 sec | 10 sec | 10 sec |
| | | TOTAL REPS | 24 | 24 | 30 | 30 | 32 | 32 | 32 | 32 |

Figure 6 Day 1 Hypertrophy Programme of an alternating day training split

| DAY 2 | | WEEK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1A | Bulgarian Split Squat (1 1/4 reps) | SETS X REPS | 2 x 12 | 2 x 12 | 3 x 10 | 3 x 10 | 4 x 8 | 4 x 8 | 4 x 8 | 4 x 8 |
| | | TEMPO | 311 | 311 | 311 | 311 | 311 | 311 | 311 | 311 |
| | | REST PERIOD | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs |
| | | TOTAL REPS | 24 | 24 | 30 | 30 | 32 | 32 | 32 | 32 |
| 1B | Barbell Supine Hip Extension | SETS X REPS | 2 x 12 | 2 x 12 | 3 x 10 | 3 x 10 | 4 x 8 | 4 x 8 | 4 x 8 | 4 x 8 |
| | | TEMPO | 311 | 311 | 311 | 311 | 311 | 311 | 311 | 311 |
| | | REST PERIOD | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min |
| | | TOTAL REPS | 24 | 24 | 30 | 30 | 32 | 32 | 32 | 32 |
| 2A | Standing Single Calf Raise off box | SETS X REPS | 2 x 12 | 2 x 12 | 2 x 12 | 3 x 10 | 3 x 10 | 3 x 10 | 3 x 10 | 3 x 10 |
| | | SPEED | 311 | 311 | 311 | 311 | 311 | 311 | 311 | 311 |
| | | REST PERIOD | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs | 10 secs |
| | | TOTAL REPS | 24 | 24 | 24 | 30 | 30 | 30 | 30 | 30 |
| 2B | Lateral Band Walk | SETS X REPS | 2 x 10 | 2 x 10 | 3 x 10 | 3 x 10 | 3 x 10 | 3 x 10 | 3 x 10 | 3 x 10 |
| | | SPEED | Slow | Slow | Slow | Slow | Slow | Slow | Slow | Slow |
| | | REST PERIOD | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | TOTAL REPS | 20 | 20 | 30 | 30 | 30 | 30 | 30 | 30 |
| 1B | Nordic Curls (eccentric only) | SETS X REPS | 2 x 8 | 2 x 8 | 2 x 8 | 2 x 8 | 3 x 8 | 3 x 8 | 3 x 8 | 3 x 8 |
| | | TEMPO | 50X | 50X | 50X | 50X | 50X | 50X | 50X | 50X |
| | | REST PERIOD | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min | 2 min |
| | | TOTAL REPS | 16 | 16 | 16 | 16 | 24 | 24 | 24 | 24 |

Figure 7 Day 2 Hypertrophy Programme of an alternating day training split

## 3.4 RESEARCH SETTING

The research was undertaken in the Darling Downs region of Queensland at an independent private secondary school for girls, of approximately 510 day-students between middle school and seniors, and 174 boarding students. Preliminary and post-intervention observations were conducted in the school's sports gymnasium, and intervention training programs were conducted in the school’s strength and conditioning weights room. In addition, the researcher’s Toowoomba workplace was utilised (i.e., The Academy of Fitness & High Performance or AFHP) in a commercial training facility on the basis of one day per week.

## 3.5 PARTICIPANTS

Participants were invited to take part in the study through a collaboration between the researcher, the workplace (i.e., AFHP), and the Health and Physical Education department from the school after USQ Human Ethics approval, and formal endorsement from the school's executive board. Sixteen adolescent female court and field sport athletes (age: 14.8 ± 1.1 years; height: 166.2 ± 5.0 cm; body mass: 63.4 ± 8.5; body mass index: 23.0 ± 3.3 kg/m$^2$ voluntarily agreed to participate in this study (see section 3.9 Ethical Considerations).

Table 3.1

*Descriptive data of participants.*

| | **Age (years)** | **Height (m)** | **Body mass (kg)** | **BMI (kg/m$^2$)** |
|---|---|---|---|---|
| **Intervention group** | 14.8 ± 1.4 | 1.65 ± 0.05 | 66.1 ± 7.7 | 24.2 ± 2.4 |
| **Comparison group** | 14.9 ± 0.83 | 1.67 ± 0.05 | 60.6 ± 8.9 | 21.8 ± 3.8 |

### 3.5.1 Selection Criterion

The study participants were selected from the school's representative sporting groups with the assistance for the Head of Sport and High-Performance Coordinator. As the study has a particular reference to 'athlete', the primary qualification process and key criterion for selection hinged on the participants' representative level for their sport.

### 3.5.2 Inclusion Criterion

If the participant represented their school or club sport at regional competitive level, then, the participant qualified for selection at the athlete level. Secondary qualification for selection was dependant on type of sport.

As the study involved jumping and landing, participants from school sports at representative level that involved such movements and change of direction were invited for selection. For the inclusion criterion, sports put forward from the school were Netball, Rugby Union 7s, Touch Rugby, and Athletics (High Jump).

### 3.5.3 Exclusion Criterion

School sport participants in swimming, water polo, equestrian, cycling, triathlon, and distance running were excluded from the research project as these sports do not involve jumping, stopping and change of direction.

### 3.5.4 Interest

Participants were presented with a study document outlining a summary of the literature review, which included statistics on lower limb injury rate disparity in court and field sports for adolescent age groups.

### 3.5.5 COVID-19 Global Pandemic Impact

The global COVID-19 pandemic presented interruptions, and limitations in gathering the data required for this study. The original cohort of participants was selected in February 2020 and stage 1 observational data had been collected and groups selected. The intervention group had commenced the specific strength training program and had progressed to week six of the eight-week program by 26th of March 2020, when the Queensland Government placed major restrictions on businesses, schools and non-essential organisations. As a result, the school as an independent boarding school, was classified as student-free for the remainder of term one and late into term two. The intervention stage of the research project was placed on hold until the Federal and State Governments advised that schools and sporting facilities would be able to operate without restrictions. The research instruments were required to be returned, and the researcher was unable to gain access to the same participants for the remainder of 2020. In February 2021 stage one recommenced with a new cohort of participants from the school, and stage two was completed in June 2021, again with a minor interruption due to boarding school access restrictions and state-wide lockdown in April 2021. Both Intervention and Comparison Groups were assessed at the same time to ensure consistency and accuracy of data collected.

## 3.6 INSTRUMENTATION

Specific instruments were utilised to collect definitive data for this research project.

### 3.6.1 Drop Jump Test – Force Plate Protocol

Set-up: Using 'ForceDecks' (force plates – see 3.6.2), the platforms are zeroed to ensure nothing external is touching the plates. The athlete is then asked to step on the plates to be accurately weighed. The athlete is to remain completely still allowing accurate weight to be recorded symmetrically between left and right limbs. The athlete assumes the start position by standing on a 30-centimetre-high box with feet shoulder-width apart and hands on hips. The athlete is instructed to keep the chest up and look forward then step off the box and land on force measurement plates and jump immediately up again as high as possible. On landing, the athlete keeps completely still on the plates for two to three seconds before returning to the start position for two more repetitions.

The Drop Jump Test was employed to measure ground reaction forces via a fast 'stretch-shortening' moment through an eccentric loading phase. The eccentric loading phase (muscle actively lengthening under tension) is accelerated by means of the added force to the drop action. A key measure from this test is to gather data on how fast an athlete can move from absorption (plate or ground contact) to propulsion (jump).

### 3.6.2 Force Measurement

As the research study involved human movement and specific observation, reliable force measurement technology was investigated to facilitate data collection during the project to answer research questions one, and two. VALD Performance, a Brisbane-based company with worldwide footprint and a focus on Asia, specialises in human measurement technologies and currently supplies data collection products to multiple professional sports clubs including the NRL, NFL, NBA and EPL. In addition, the company provides data technology to over 85 NCAA Universities. The company has an array of athlete testing- and data-capture technologies in its physical testing suite. VALD Performance provided the researcher access to two specific products for this project: 'ForceDecks'; and 'HumanTrak'.

ForceDecks is a dual force plate system (left and right limb independence), which measures ground reaction forces when stepped on or landed upon. The system is widely used in biomechanical research to quantify balance, limb symmetry, gait, and collect data on strength and power profiling. Weighing 9 kg with a loading capacity up to 2,000 kg, each plate is 485 mm in length by 300 mm in width and 55 mm in height. The plates are connected and powered via a three-pin XLR connector cable and linked back to a Windows-based operating system via a USB cable.

ForceDecks Suite software is the main program for testing and analysis and provides real time data, with an export function. Force, measured in KGs in this application, is referred to as ground reaction force (GRF). The ForceDecks plates measure the data in the vertical (v) axis and generate raw left and right limb (vGRF) output, which is summed to generate total vertical force upon which acceleration, velocity and derivatives are calculated. The data captured from the Drop Jump test allowed the researcher to analyse, for each participant, four main data points, which were, ‘peak landing force’, ‘peak landing force left’, and ‘peak landing force right’, and ‘peak propulsive force’.

### 3.6.3 Force Data Point Definitions

The first force variable is ‘peak landing force’ (PLF), which is the highest force generated on landing. The second force variable is ‘peak landing force – left’ (PLF-L) and ‘peak landing force – right’ (PLF-R) measuring lower limb landing asymmetries between left and right side. The final force variable is ‘peak propulsive force’ (PPF), the peak active contraction-based force.

### 3.6.4 Knee Metrics

In order to answer research question three, the collection of knee metrics and angular data was required. For this, VALD Performance’s ‘HumanTrak’ movement analysis system was also supplied to the researcher. The movement analysis system provides a non-marker-based 3D camera and Inertial Measurement Unit (IMU)-combined motion capture and biomechanical analysis. The 3D motion tracking system creates a model of the participant’s body. The reference axes used for the positional 3D system are X-Axis (left to right), Y-Axis (up and down), and Z-Axis (forward and backward). For this study, knee valgus left and right, and knee flexion angle left and right was observed and recorded.

HumanTrak uses an Azure Kinect DK 3D infrared motion RGB camera connected via USB cable to a Windows system laptop. The camera is set in place using a tripod mount with external power cable and laptop USB connection. The system contains four wireless IMU sensors that are placed on the participant’s left and right lateral wrist and ankles.

The following are the variables measured in this study:

Valgus and varus angle**:** For utilising the Drop Jump test to observe a knee valgus position, an angle is measured between the femoral and tibial segments in the frontal plane (see Figure 8). The femoral segment is knee to hip (dashed line), and the tibial segment is knee to ankle (solid line). Varus angle is expressed as a positive angle, with valgus expressed as a negative angle. For reference, a vertical straight leg is 0☐.

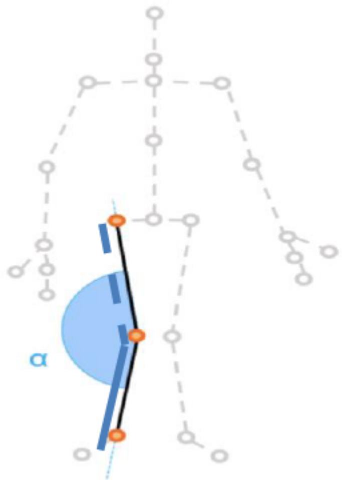



Figure 8. Knee valgus and knee varus angle

Knee flexion angle: For utilising the Drop Jump test to observe knee flexion, an angle is observed between the femur and tibia segments in the sagittal plane (see Figure 9). The femoral segment is knee to hip (dashed line), and the tibial segment is knee to ankle (solid line). Knee flexion is expressed as a positive angle. For reference, a vertical straight leg is 0°.

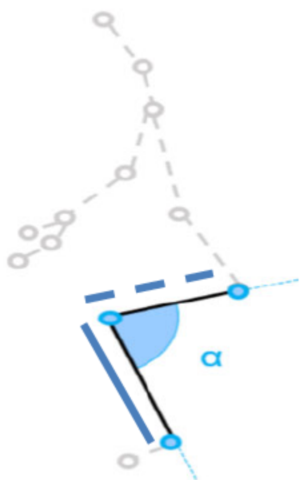



Figure 9. Knee flexion angle

Skinfold (SFFD) testing: In order to observe whether a positive body composition change has occurred (increase in fat-free mass or increase in localised muscle tissue), skinfold measurements were taken using Harpenden Skinfold Callipers at two specific landmarks on the participant's right side on the lower body using the two-hand skinfold calliper technique with calliper aligned to natural cleavage lines of the skin (Eston & Reilly, 2009).

Mid-thigh site: The participant was asked to flex the knee slightly in a standing position with the heel of the right foot resting on the left foot. The distance between the participant's inguinal crease and the anterior proximal border of the patella was halved to establish the mid-point and was marked for the first skinfold site. A vertical fold was used by placing the callipers 1cm distal to the fingers in a proximal to distal direction on the participant's thigh, to collect the mid-thigh sample.

Medial Maximal Calf Site: Skinfolds were taken on the medial aspect of the calf at the level of the maximal circumference with the participant's foot placed upon a chair forming a 90-degree angle to the knee. A vertical fold was used by placing the callipers 1 cm distal to the fingers, again in a proximal to distal direction down the lower limb (Eston & Reilly, 2009).

Lower limb measurements of mid-thigh and calf: Girth circumference for each participant's thigh was taken on the right-hand side using a standardized position, whereby, the participant was asked to stand with most of their weight on the left leg with the right leg forward, knee slightly flexed, and soles of both feet flat on the floor (Wright et al., 2002). The mid-thigh girth measurement was taken from the mark indicated in the process used for the mid-thigh skinfold taken previously. The measuring tape was placed perpendicular to the long axis of the thigh with the zero end of the tape held below the measurement value and recorded in centimetres and to the nearest millimetre. The medial maximal calf circumference was taken on each participant's right-hand side while the participant was in a seated position. The measuring tape was placed around the calf and moved up and down to locate the maximal girth circumference in a plane perpendicular to the long axis of the calf (Wright et al., 2002).

Body Mass Index (BMI): Each participant in each group had their height measured and bodyweight taken. Height was taken using a stadiometer in centimetres and millimetres (converted back to meters for BMI calculation), both pre and post intervention, and pre and post comparison. The participant’s weight was taken using the ForceDecks digital scale. The BMI of each participant was calculated using the ratio between body weight in kilograms and height in meters squared.

### 3.6.5 Reliability and Validity

The specific instruments used during the research were accurate and reliable. Humantrak movement analysis system uses a combination of three real-time data sources, which is able to track and animate data overlays onto real-time video feed, enabling balance lines, joint angles and joint loadings to be calculated. This contextual data provides accurate biofeedback to the researcher.

A validation case by Beshara et al (2020) was performed at Australian Catholic University Biomechanics Laboratory where the HumanTrak system was aligned to match the reference system of the VICON motion capture system (research-grade motion capture) and ATMI force plate systems. The Humantrak system was calibrated to adjust for camera height and tilt to ensure the best field of view. All systems output had final data sampling rate of 100Hz.

Walsh, Ford, Bangen, Myer, & Hewett (2006) performed a study to determine the reliability and validity of portable forces when analysing jumping and landing tasks. Subjects performed three drop jumps and vertical jumps each landing on both a standard strain-gauge laboratory force plate and a portable force plate. Using correlation coefficients for both jump actions, it was determined that accuracy was high and indicated that all force data collected by a resistor-type portable force plate provided similar measure to a standard strain-gauge laboratory force plate. Additionally, the within-session reliability of both landing and jump tests measured by the portable force plates showed high interclass correlation coefficients for maximum landing force, which is one of the major testing variables looked at in the researcher's study.

In conclusion, Walsh et al. (2006) state that:

> The use of portable force plates may facilitate methods of force measurement that can be applied out in the field and therefore a valuable tool for on-site landing and jump force measurements in a variety of settings for large number of subjects (p. 730).

It is possible, then, to be totally confident of the reliability and validity of the measuring instruments used. Similarly, anthropometric criterion-related validity for field-based testing in youth and adolescents indicates the use of BMI, girth measurement, and skinfold thickness are good estimates of body composition (Artero et al, 2011; Ruiz et al, 2011; Castro-Pinero et al., 2010).

## 3.7 DATA COLLECTION

Participants in the study were/are all representative level adolescent female athletes in their respective sports. The study was designed in two stages:

Stage 1: Participant selection of 16 females nominated by the school. This group participated in a landing observation activity, and had primary data collected using the wearable sensor technology (HumanTrak and dual force plates–section 3.6, above), for the landing component. All participants then had their anthropometric data measured by the Researcher, including height, weight (for BMI), mid-thigh circumference, medial maximal calf circumference, mid-thigh skinfold, and medial maximal calf skinfolds to establish a baseline of lower limb anthropometry for both groups. The landing observation study measured knee valgus (adduction or internal frontal plane angle at the knee, measured in degrees), knee flexion angle (in the sagittal plane, measured in degrees), and vertical ground reaction landing forces (peak landing force, force at zero velocity, peak propulsive and dominant/non dominant foot landing force differential measured in KGs).

Stage 2 Intervention and Groups: The intervention group (IG), comprised eight adolescent females as did the comparison group (CG). The CG continued normal sporting activities and training for their respective sports while the IG engaged in the hypertrophy intervention program three times per week in addition to their normal playing and training regime. It is important to note that no participant in the IG group performed any extra resistance training sessions in addition to or outside of the study period. The IG group performed a specific series of exercises on a periodised program over eight weeks, in an aim to improve absolute, relative and structural muscle hypertrophy. Data collection was located within the context of specific hypertrophic training conducted by the AFHP. This included session attendance and tracking of volume and volume loading for each of the IG participants.

Stage 2 Post-intervention: Upon conclusion of the eight-week period, all participants underwent a second data-collecting session using the same protocol from Stage 1, and again measured by the Researcher.

### 3.7.1 Recovery

The researcher was aware that each participant in the study trains for, and plays sport at a representative level, therefore each participant had an individual weekly training load which required adequate recovery. In order to monitor training loads for the participants, regular feedback was requested upon conclusion of the cool-down phase of the session before each participant left the weights room area. A Rate of Perceived Exertion

(RPE) Scale questionnaire was used for feedback to collect values from 1 to 10 for each participant to indicate how hard they felt the overall resistance training session was for that day, with ‘1’ indicating an easy level and ‘10’ indicating the hardest level or maximal effort (Faulkner & Eston, 2008). All 24 sessions were monitored and recorded. If a participant indicated a score of nine or more, advice was given to reduce the volume for the next planned session.

As other research has noted (e.g., Kölling et al., 2019; Romyn et al., 2016; Halson, 2008), varying lifestyles can create limitations and uncertainties for optimal recovery between training sessions. In presenting the findings of the current study, the researcher acknowledges the possible influence upon results of uncontrollable factors such as hours of sleep, hydration, blue light exposure, nutrition, and personal stress levels.

## 3.8 DATA ANALYSIS

The means for dependent variables of three trials for the Drop Jump Tests, and the means for all skinfold and girth measurements for each participant were used for statistical analysis. A correlational analysis for all pre- and post-test data was used to measure the relationship between variables, and SPSS version 27 was the tool used to statically analyse these data for descriptive and inferential information.

The descriptive variables included frequency, means, standard deviations, skewness, and kurtosis for each of the study variables. Pre-intervention and post-intervention *within-group* difference was tested using analysis of variance (ANOVA) for both IG and CG. Analysis of variance was also used to test *between-group* difference to compare IG and CG post-intervention for each of the study’s key variables.

Study variable one was to identify whether the participants in the IG showed a statistically significant change in lower limb body anthropometrics over the CG. Study variable two was to identify positive landing and take-off force changes, and variable three was to identify any improvement in dynamic knee valgus and flexion angle. One-Way ANOVA and two-sample t-tests were used to compare the means for all anthropometric, force-related, and knee-metric data of both groups to determine whether there is statistical evidence that both pre- and post-intervention, are significantly different. Paired t-tests were used to compare landing and take-off forces between limbs. This analytical technique used will provide the data necessary to answer research questions number two and three.

An example of this analytical method was used in a study by Teng, Leong and Kong (2020) which investigated the influence of foot-landing positions at initial contact on knee flexion angles for single-leg drop landings. A similar study using this method by Joseph et al. (2008), compared differences in knee valgus during a drop jump using a medial post.

In addition, SPSS was used to calculate the Pearson product moment correlation coefficients between each of the key study variables. Findings were analysed at the 95% confidence interval and an alpha value less than or equal to 0.05.

## 3.9 ETHICAL CONSIDERATIONS

Any ethical concerns were considered before conducting the research. In addition to USQ's Human Research Ethics Committee approval (number H19REA171), approval was requested from the independent girl's school from the Darling Downs region. Participant information sheets were provided to the school and prospective participants, describing the study, its requirements, and any potential risks. It was emphasised that participation was voluntary. A clear statement was made that participants' personal information would be treated at all times in line with the provisions of the Information Privacy Act 2009.

### 3.9.1 Consent

Participant consent was sought in addition to parental consent. As the study required physical training, a clear outline of what was expected from each participant was presented. For many of the participants, structured and periodised strength training was uncommon, therefore the effect of delayed onset muscle soreness (DOMS) was clearly outlined with prescription of how to manage any discomfort as a result of the physical training.

### 3.9.2 Time

The intervention process required eight weeks of uninterrupted training. It was made clear to the intervention group, that a time requirement of three 30–45-minute training sessions, in addition to their usual sporting commitments, might impact their secondary school workload. However, all participants were able to complete the required training sessions without issue.

### 3.9.3 Data Security

Results of anthropometric measurement, program information, force data and knee metrics were individually shared with participants, parents, and guardians on request. No information was shared with third parties.

# CHAPTER 4: RESULTS

## 4.1 INTRODUCTION

One of the key elements of the study was to explore whether actual physical change could be developed in a study group of female adolescent athletes after an eight-week resistance training protocol focusing primarily on muscle hypertrophy response. A primary aim was to investigate a potential relationship between an increase in lower limb muscle hypertrophy and favourable biomechanical adaptations during a jumping and landing action, similar actions to what occurs in many court and field sports.

This Chapter presents the research results as a basis for further discussion. As outlined in Chapter 3, the study design comprised two key stages, the first, or Primary Stage, consisting of a process for selecting 16 participants willing to take part in the study. Selection for Comparison Group (CG) or Intervention Group (IG) followed the completion by all participants of the initial jump and landing observations, and this marked the conclusion of the Primary Stage. From the 16 participants initially selected, all 16 completed the study and associated testing observations and training sessions. The table below represents the mean, median, standard deviation, skewness and kurtosis for pre intervention data.

Table 4.1

*Summary table – 16 participants at primary stage pre intervention*

| | N | Mean | Median | SD | Skewness | Kurtosis |
|---|---|---|---|---|---|---|
| **SKINFOLDS** | 16 | 49.01 | 46.65 | 17.91 | 0.399 | -1.102 |
| **GIRTH** | 16 | 83.28 | 82.00 | 6.63 | 0.0565 | -0.1606 |
| **BODY MASS INDEX** | 16 | 22.99 | 22.89 | 3.33 | 0.0161 | -0.1291 |
| **PEAK LANDING FORCE** | 16 | 2412.88 | 2372.51 | 469.04 | 0.763 | 2.039 |
| **PEAK LANDING FORCE LEFT** | 16 | 1219.48 | 1203.75 | 279.73 | -0.1466 | -0.0939 |
| **PEAK LANDING FORCE RIGHT** | 16 | 1207.94 | 1201.00 | 275.73 | 1.0159 | 2.2732 |
| **PEAK PROPOLSIVE FORCE** | 16 | 1758.81 | 1599.75 | 544.91 | 2.5574 | 7.919 |
| **KNEE VALGUS LEFT** | 16 | -8.63 | -10.00 | 5.44 | 0.2178 | -1.5593 |
| **KNEE VALGUS RIGHT** | 16 | -13.13 | -12.75 | 7.82 | -0.6505 | -0.1166 |
| **KNEE FLEXION LEFT** | 16 | 69.04 | 66.28 | 24.63 | 0.8061 | 0.9368 |
| **KNEE FLEXION RIGHT** | 16 | 71.21 | 65.68 | 34.11 | 1.9606 | 5.3715 |

## 4.2 ANTHROPOMETRIC RESULTS

The following data provide the results necessary to answer Research Question 1: Might an eight-week strength training intervention program for female adolescent athletes, focusing on muscle hypertrophy, show favourable changes in lower body anthropometrics?

The requirement was to test the difference of anthropometrics within and between groups. The within-group differences between pre- and post-intervention for skinfolds, girth and BMI are provided below and represented in Table 4.2, and between group differences in Table 4.3.

### 4.2.1 Within-group data

Skinfolds (SKFD): For the intervention group, total skinfolds reduced by 47.4mm. This within-group change was not statistically significant ($df$ = 7, F = 0.45, p = 0.52). The comparison group showed a minor increase in total skinfolds of 1.1mm, and this within-group change was also not statistically significant ($df = 7$, $F = 0.02$, $p = 0.89$).

Girth (GRTH): For the intervention group, total lower limb girth reduced by 5.9mm. The within-group change was not statically significant ($df = 7$, $F = 0.10$, $p = 0.75$). The comparison group lower limb grith showed a mean increase of 1.2mm. The within-group change was not statistically significant ($df = 7$, $F = 0.03$, $p = 0.86$).

Body Mass Index (BMI): For the intervention group, BMI reduced by 0.1kg/m$^2$. The within- group change was not statically significant ($df = 7$, $F = 0.02$, $p = 0.90$). The comparison group BMI showed no change.

### 4.2.2 Between-group data

Skinfolds (SKFD): The intervention group mean change in skinfold measurement reduced by 5.9mm. The comparison group mean change was an increase in total skinfolds of 1.2mm. This between-group change was statistically significant (*df* = 1, *F* = 9.22, *p* = 0.002).

Girth (GRTH): The intervention group mean change in girth measurement was a reduction of 1mm. The comparison group mean change was an increase in girth measurement of 0.7mm. This between-group change was not statistically significant (*df* = 1, *F* = 3.74, *p* = 0.08).

Body Mass Index (BMI): The intervention group mean change in BMI was a reduction of 0.2kg/m$^2$. The comparison group BMI showed no change. This between-group change was not statistically significant (*df* = 1, *F* = 0.17, *p* = 0.69).

Skewness and kurtosis analyses indicated data for skinfold, girth and BMI were mostly parametric, with skewness ranges between 0.01 and 0.39 and kurtosis ranges between -0.12 and –1.10, which is important because the analysis of variance tests assume data are normally distributed. The within-group changes for skinfolds, girth measurements, and body mass index are graphically represented in Figure 10, with between-group mean change represented in Figure 11.

Table 4.2

*Within-group differences for SKINFOLDS (SKFD), GIRTH (GRTH) and BODY MASS INDEX (BMI).*

| Variable (unit) | IG Pre-test Mean | IG Post-test Mean | Change (SD) | ANOVA | CG Pre-test Mean | CG Post-test Mean | Change (SD) | ANOVA |
|---|---|---|---|---|---|---|---|---|
| SKFD (mm) | 50.5 | 44.5 | −5.9 (5.7) | $F = 0.45$, $p = 0.52$ | 47.6 | 48.7 | 1.2 (0.7) | $F = 0.02$, $p = 0.89$ |
| GRTH (mm) | 86.6 | 85.8 | −0.8 (0.4) | $F = 0.10$, $p = 0.75$ | 80.0 | 80.7 | 0.7 (1.6) | $F = 0.03$, $p = 0.86$ |
| BMI (kg/m$^2$) | 24.2 | 24.1 | −0.1 (0.16) | $F = 0.02$, $p = 0.90$ | 21.8 | 21.8 | 0 (0.1) | $F = 0.01$, $p = 0.99$ |

Table 4.3

*Between-group differences for SKINFOLDS (SKFD), GIRTH (GRTH) and BODY MASS INDEX (BMI).*

| Variable (unit) | IG Mean Change (SD) | CG Mean Change (SD) | ANOVA |
|---|---|---|---|
| SKFD (mm) | −5.9 (6.4) | 1.2 (1.8) | $F = 9.22$, $p = 0.002$ |
| GRTH (mm) | −1.2 (0.9) | 0.7 (1.9) | $F = 3.74$, $p = 0.08$ |
| BMI (kg/m$^2$) | −0.2 (1.1) | 0 (0.5) | $F = 0.17$, $p = 0.69$ |

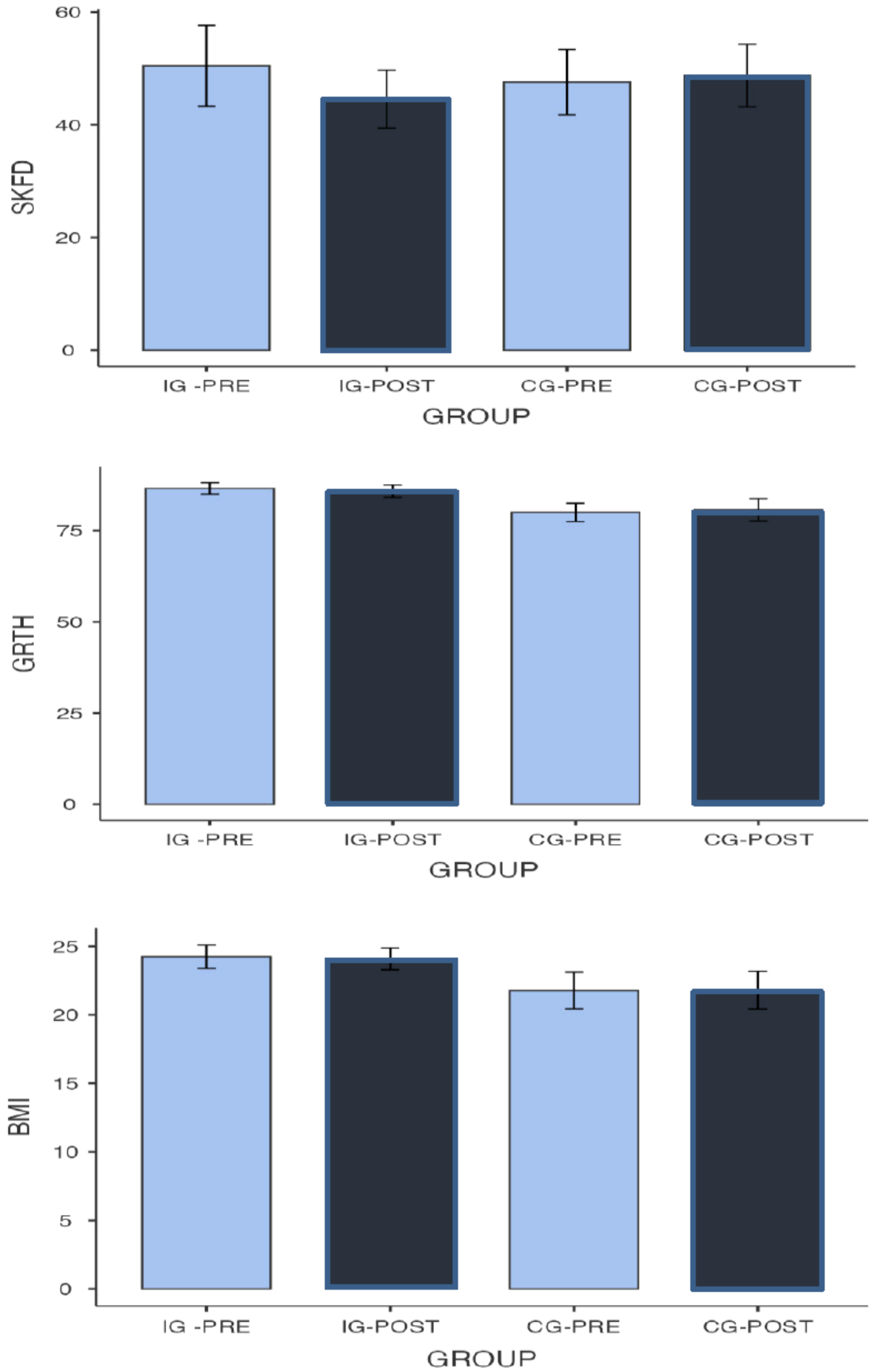



Figure 10 IG-Pre, IG-Post, CG-Pre, CG-Post Anthropometric data of SKFD, GRTH, and BMI

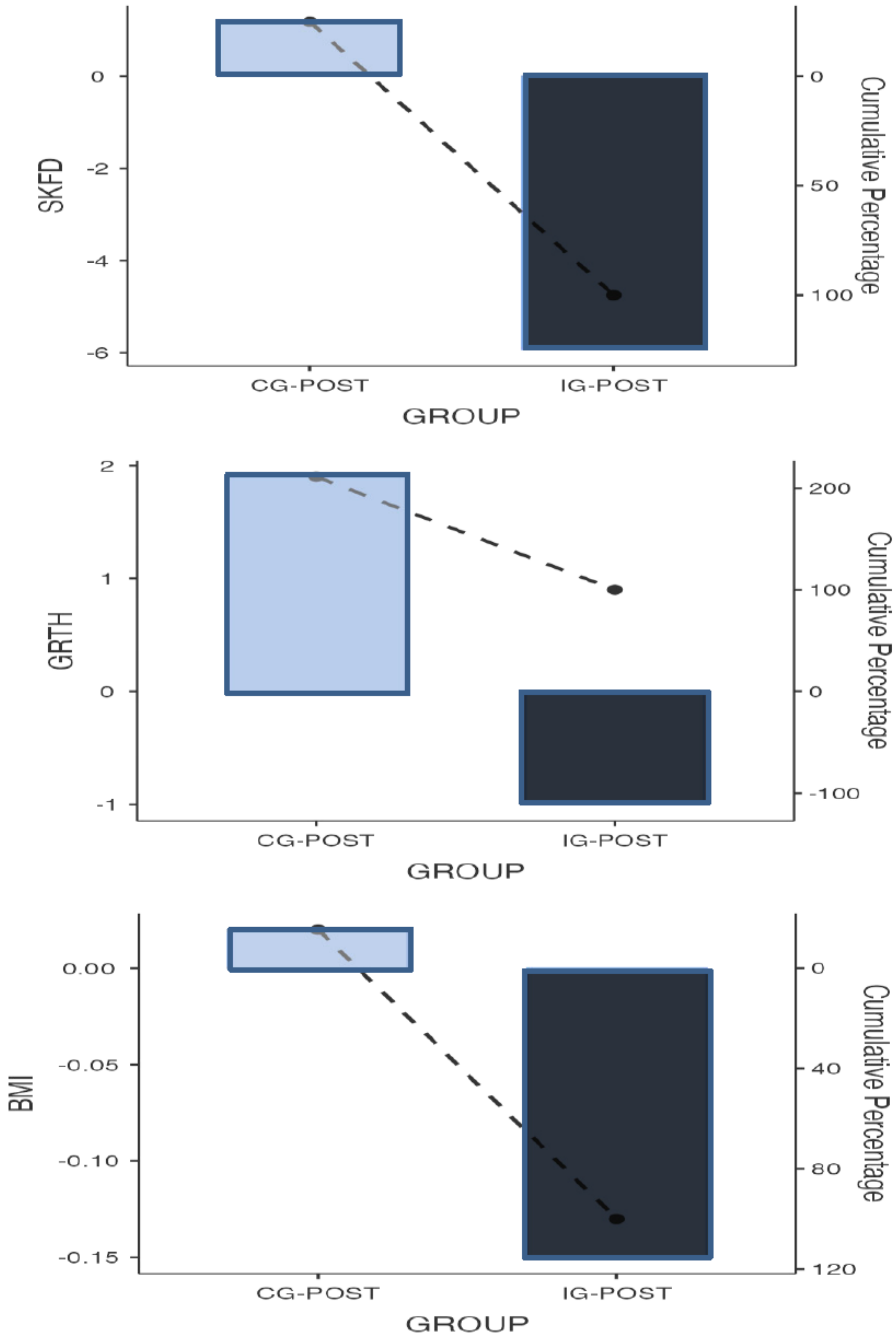



Figure 11 IG-Post, CG-Post mean change between-group data for SKFD, GRTH, and BMI. Dashed lines indicate cumulative change.

## 4.3 FORCE DATA

Research Question 2 - Might a strength-training intervention focused on lower limb hypertrophy show positive change in landing impact force, and force generation in take off? The requirement was to test the difference within and between groups on force variables on landing and take-off movement. The within-group results are outlined below and summarised in Table 4.4.

### 4.3.1 Within-group data

Peak Landing Force (PLF): The total force at landing of the intervention group reduced by 4685 N, with a mean change per participant at -585.88 N. This within-group change was statistically significant (*df* = 7, *F* = 5.48, *p* = 0.035). The total landing force of the comparison group increased by 1031 N with a mean change per participant of 128.67 N. This within-group change was not statistically significant (*df* = 7, *F* = 0.389, *p* = 0.543).

Peak Landing Force Left (PLF-L): The total PLF-L of the intervention group reduced by 1626.83 N, with a mean change per participant of –203.35 N. This within-group change was not statistically significant (*df* = 7, *F* = 2.57, *p* = 0.13). The total PLF-L of the comparison group increased by 79.23 N, with a mean change per participant of 79.23 N. This within-group change mean was not statistically significant (*df* = 7, F = 0.34, p = 0.56).

Peak Landing Force Right (PLF-R): The total PLF-R of the intervention group reduced by 1145.50 N, with a mean change per participant of –143.19 N. This within-group change was not statistically significant (*df* = 7, *F* = 1.17, *p* = 0.29). The total PLF-R of the intervention group increased by 1692.70 N, with a mean change per participant of 211.58

N. This within- group change mean was not statistically significant (*df* = 7, *F* = 3.31, *p* = 0.09).

Peak Propulsive Force (PPF): The total PPF propulsive force of the intervention group increased by 347.33 N, with a mean change per participant of 43.42 N. The within-group change was not statistically significant (*df* = 7, *F* = 0.01, *p* = 0.90). The total PPF propulsive force of the comparison group reduced by 1160.50 KGs, with a mean change per participant of 145.06 KGs. The within-group change was not statistically significant (*df* = 7, F = 1.75, p= 0.20).

The between-group differences between pre- and post-intervention for peak landing force, peak landing force left, peak landing force right, and peak propulsive force are outlined below and summarised in Table 4.5.

### 4.3.2 Between-group data

Peak Landing Force (PLF): The intervention group mean change in PLF was −585.88 N. The comparison group mean change was 128.67 N. This between-group change was statistically significant (*df* = 1, *F* = 6.46, *p* = 0.02).

Peak Landing Force Left (PLF-L): The intervention group mean change in PLF-L was
−233.35 N. The comparison group mean change was 79.23 N. This between-group change was not statistically significant (*df* = 1, *F* = 1.89, *p* = 0.18).

Peak Landing Force Right (PLF-R): The intervention group mean change in PLF-R was 43.42 −143.19 N. The comparison group mean change was

211.58 N. This between-group change was statistically significant ($df$ = 1, $F$ = 4.79, $p$ = 0.04).

Peak Propulsive Force (PPF): The intervention group mean change in PPF was 43.42 N. The comparison group mean change was –145.10 N. This between-group change was not statistically significant ($df$ = 1, $F$ = 3.42, $p$ = 0.08).

Skewness and kurtosis analysis indicated data for peak landing force, peak landing force left, peak landing force right, and peak propulsive force were highly skewed, with skewness ranges between -0.14 and 2.56 which means the dataset has heavier negative tails than normal distribution with kurtosis ranges between –0.09 and 7.92.

The within-group changes for peak landing force, peak landing force-left, and peak landing force-right are graphically represented in Figure 12, and between group mean change represented in Figure 13. Within-group changes for peak propulsive force are graphically represented in Figure 14 and between-group mean change represented in Figure 15.

Table 4.4

*Within-group differences for PEAK LANDING FORCE (PLF), PEAK LANDING FORCE LEFT (PLF-L), PEAK LANDING FORCE RIGHT (PLF-R), and PEAK PROPULSIVE FORCE (PPF)*

| Variable (unit) | IG Pre-test Mean | IG Post-test Mean | Change (SD) | ANOVA | CG Pre-test Mean | CG Post-test Mean | Change (SD) | ANOVA |
|---|---|---|---|---|---|---|---|---|
| PLF (KG) | 2618.00 | 2032.13 | −585.88 (617.09) | $F$ = 5.48, $p$ = 0.03 | 2207.88 | 2206.75 | 128.67 (501.82) | $F$ = 0.389, $p$ = 0.54 |
| PLF-L (KG) | 1331.83 | 1128.48 | −203.35 (134.90) | $F$ = 2.57, $p$ = 0.13 | 1107.08 | 1186.31 | 79.23 (130.11) | $F$ = 0.343., $p$ = 0.56 |
| PLF-R (KG) | 1370 | 1227 | −143.19 (12.37) | $F$ = 1.17, $p$ = 0.29 | 1045.46 | 1257.04 | 211.58 (109.18) | $F$ = 3.31, $p$ = 0.09 |
| PPF (KG) | 1848.00 | 1891.42 | 43.42 (30.90) | $F$ = 0.0142, $p$ = 0.90 | 1669.67 | 1524.60 | −145.10 (51.0) | $F$ = 1.75., $p$ = 0.20 |

Table 4.5

*Between-group differences for PEAK LANDING FORCE (PLF), PEAK LANDING FORCE LEFT (PLF-L), PEAK LANDING FORCE RIGHT (PLF-R), and PEAK PROPULSIVE FORCE (PPF)*

| Variable (unit) | IG Mean Change (SD) | CG Mean Change (SD) | ANOVA |
|---|---|---|---|
| PLF (KG) | −585.88 (617.09) | 128.67 (501.82) | $F$ = 6.46, $p$ = 0.02 |
| PLF-L (KG) | −233.35 (134.90) | 79.23 (130.11) | $F$ = 1.89, $p$ = 0.18 |

| | | | |
|---|---|---|---|
| PLF-R (KG) | −143.19 (12.37) | 211.58 (109.18) | $F = 4.79$, $p = 0.04$ |
| PPF (KG) | 43.42 (30.90) | -145.10 (51.0) | $F = 3.42$, $p = 0.08$ |

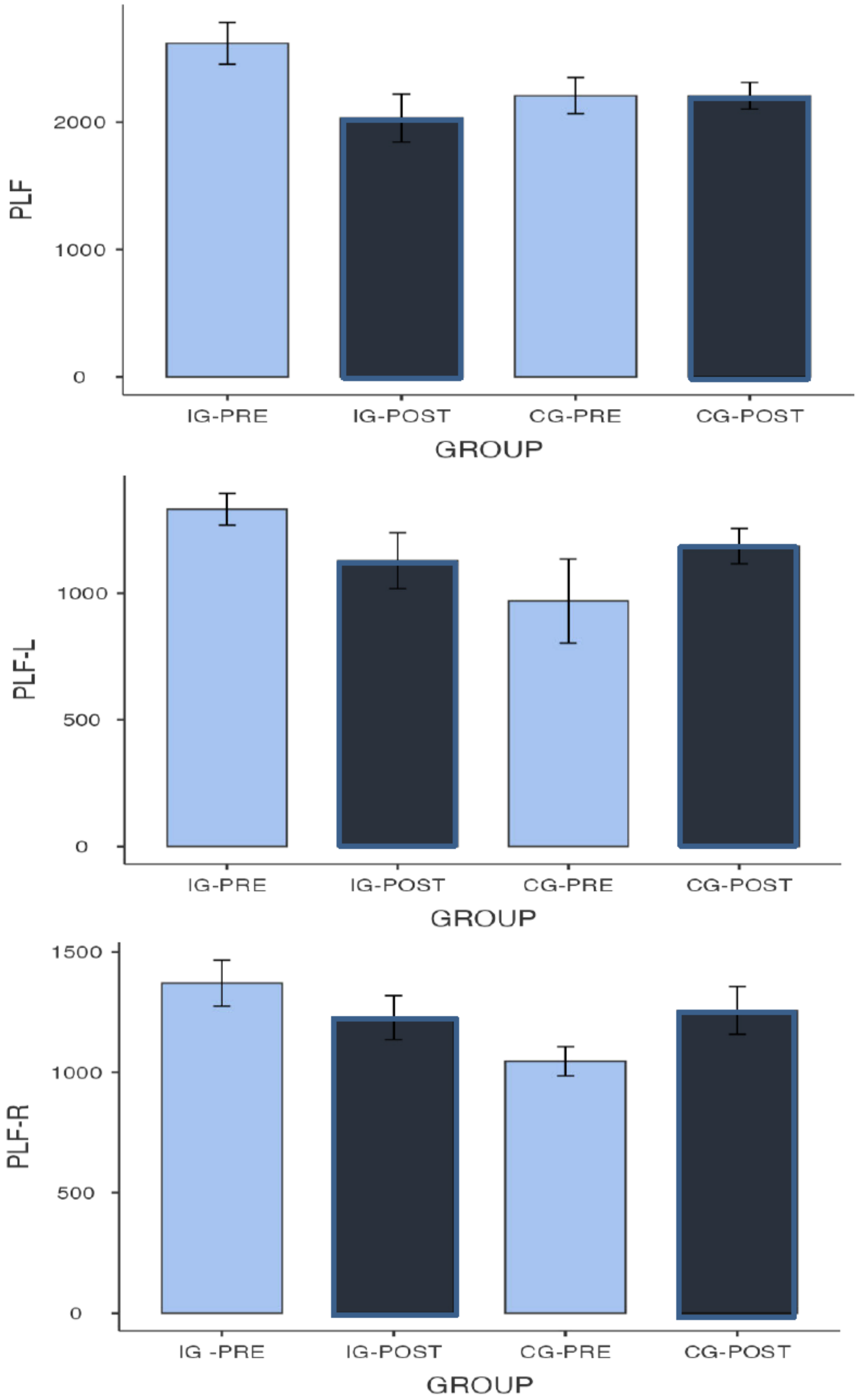



Figure 12 IG-Pre, IG-Post, CG-Pre, CG-Post landing force data for PLF, PLF-L, and PLF-R

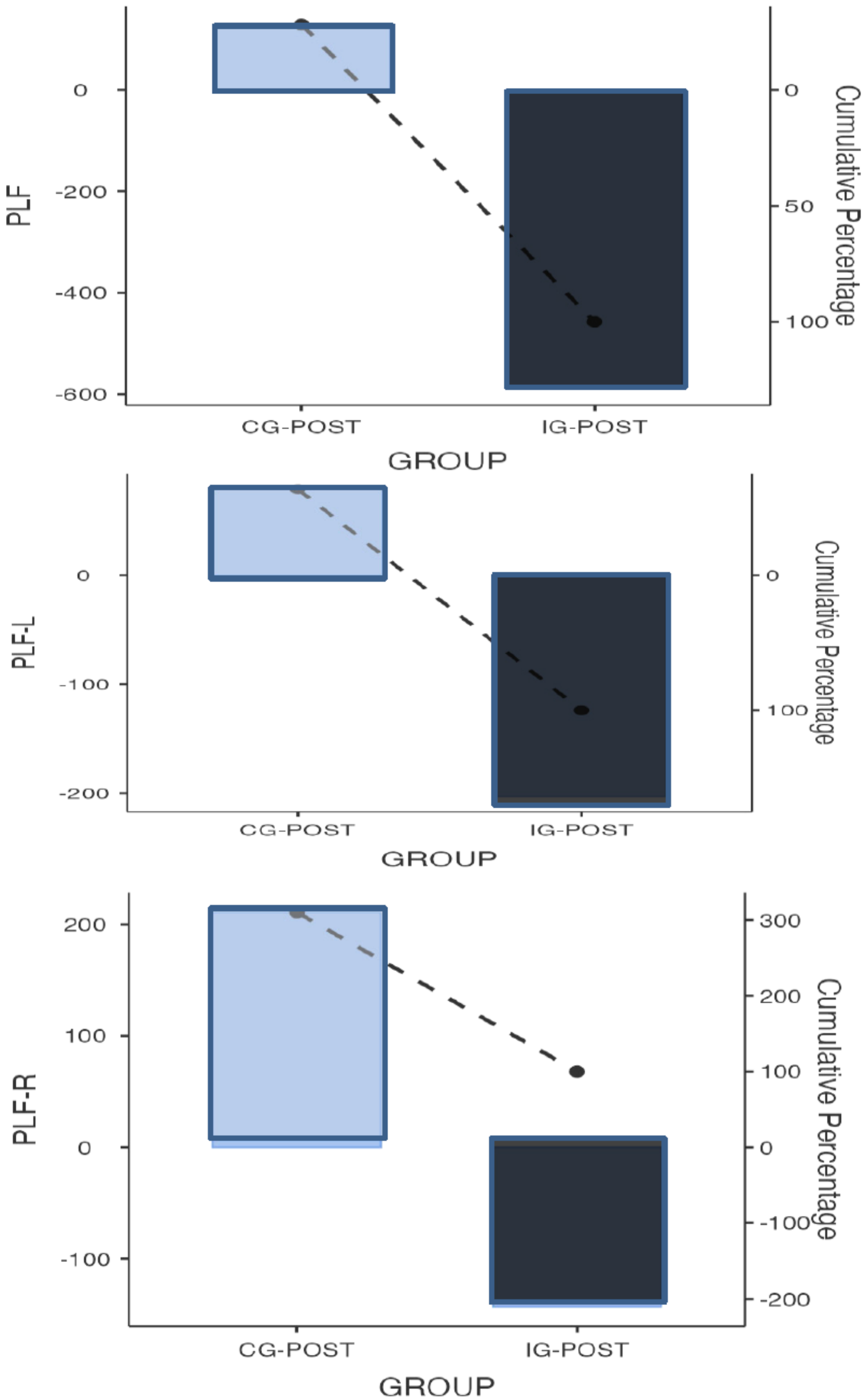



Figure 13 IG-Post, CG-Post mean change between-group landing force data for PLF, PLF-L, PLF-R. Dashed lines indicate cumulative change.

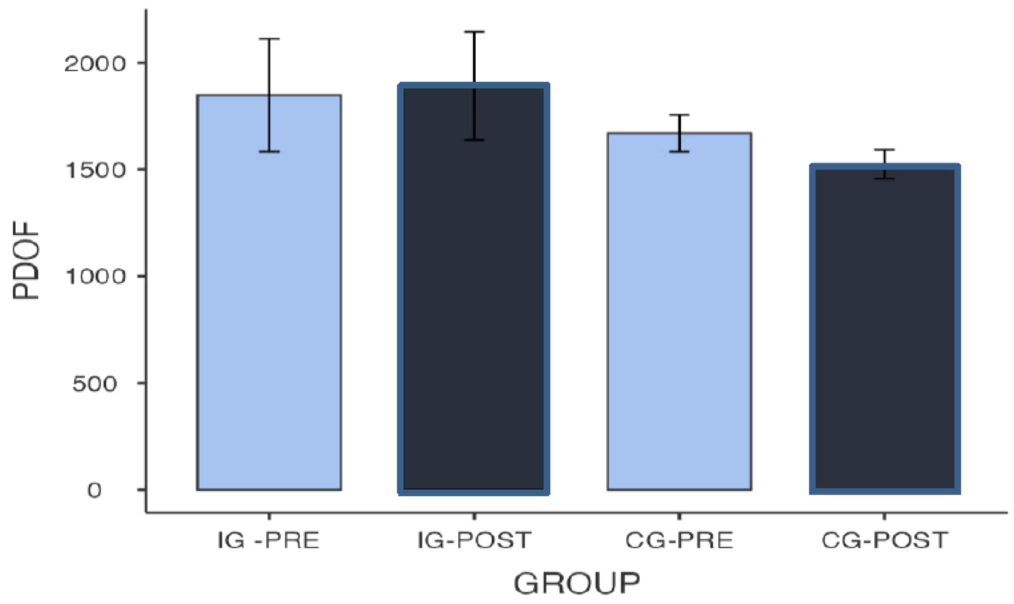



Figure 14 IG-Pre, IG-Post, CG-Pre, CG-Post Peak propulsive force data PPF

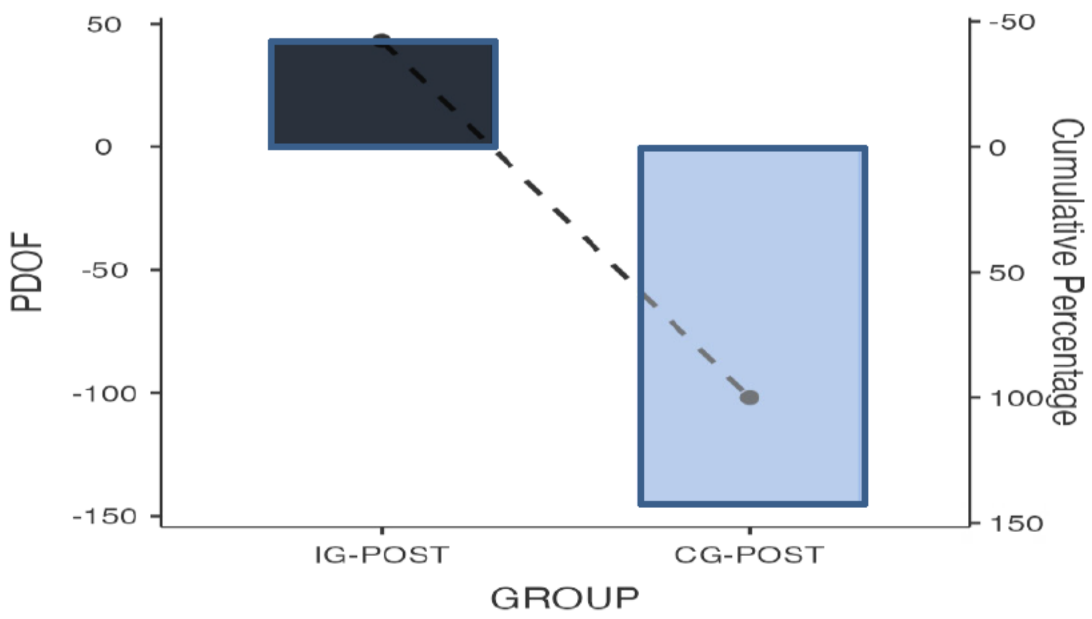



Figure 15 IG-Post, CG-Post PPF force mean-change between group. Dashed lines indicate cumulative change.

## 4.4 KNEE METRICS

Research Question 3 – Might a strength-training intervention show favourable changes in dynamic knee valgus and knee flexion angle upon landing from a jump, thereby reducing potential lower limb injury risk to female adolescent athletes? The requirement was to test the difference within and between groups for dynamic knee valgus and knee flexion angle on a landing task.

The within-group results are outlined below and summarised in Table 4.6.

### 4.4.1 Within-group data

Knee Valgus Left (KVL): The intervention-group change in dynamic KVL was a total decrease of 41.0 degrees with a mean change per participant of a decrease of 0.12 degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.0, *p* = 0.96). The comparison-group dynamic KVL decreased by a total of 32 degrees with a mean change per participant of a decrease of 0.50 degrees. This within-group change was also not statistically significant (*df* = 7, *F* = 0.02, *p* = 0.88).

Knee Valgus (KVR): The intervention-group change in dynamic KVR decreased by a total of 26.0 degrees, with a mean change per participant of −3.25 degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.79, *p* = 0.39). The comparison-group dynamic KVR decreased by a total of 4 degrees. This within-group change was also not statistically significant (*df* = 7, *F* = 0.06, *p* = 0.79).

Knee Flexion Left (KFL): The intervention-group total change for KFL was an increase of 4.55 degrees, with a mean change per participant of 0.57 degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.0, *p* = 0.95). The comparison-group total change in KFL was a reduction of 49.80 degrees, with a mean change per participant of −6.23

degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.25, *p* = 0.625).

Knee Flexion Right (KFR): The intervention-group total change for KFR was an increase of 67.10 degrees, with a mean change per participant of 8.39 degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.42, *p* = 0.52). The comparison-group total change in KFR was a reduction of 58.94 degrees, with a mean change per participant of –7.37 degrees. This within-group change was not statistically significant (*df* = 7, *F* = 0.14, *p* = 0.70).

The between-group differences between pre- and post-intervention for knee valgus left, knee valgus right, knee flexion left, and knee flexion right are outlined below and summarised in Table 4.7.

### 4.4.2 Between-group data

Knee Valgus Left (KVL): The intervention-group mean change in KVL was a decrease of 0.12 degrees. The comparison-group mean change was a decrease of 0.5 degrees. This between-group change was not statistically significant (df =1, F = 0.03, p = 0.84).

Knee Valgus (KVR): The intervention-group mean change in KVR was a decrease of 3.25 degrees. The comparison-group mean change was a decrease of 0.5 degrees. This between- group change was not statistically significant (*df* =1, *F* = 0.59, *p* = 0.46).

Knee Flexion Left (KFL): The intervention-group mean change per participant in KFL was an increase of 0.57 degrees. The comparison-group mean change per participant was a decrease of 6.23 degrees. This between-group change was not statistically significant (*df* = 1, *F* = 0.74, *p* = 0.41).

Knee Flexion Right (KFR): The intervention-group mean change in KFR was an increase of 8.39 degrees. The comparison-group mean change was a decrease of 7.37 degrees. This between-group change was not statistically significant ($df = 1$, $F = 2.52$, $p = 0.13$).

Skewness and kurtosis analysis indicated data for knee valgus left, knee valgus right, knee flexion left, and knee flexion right, were also highly skewed, with ranges between −0.65 and 1.96 in a left-skewed distribution and kurtosis platykurtic distribution ranges between −0.11 and −1.56.

The within-group changes for knee valgus-left and right, are graphically represented in Figure 16, and between group mean change represented in Figure 17. Within-group changes for knee flexion-left and right are graphically represented in Figure 18 and between-group mean change represented in Figure 19.

Table 4.6

*Within-group differences for KNEE VALGUS LEFT (KV-L), KNEE VALGUS RIGHT (KV-R), KNEE FLEXION LEFT (KF-L), and KNEE FLEXION RIGHT (KF-R)*

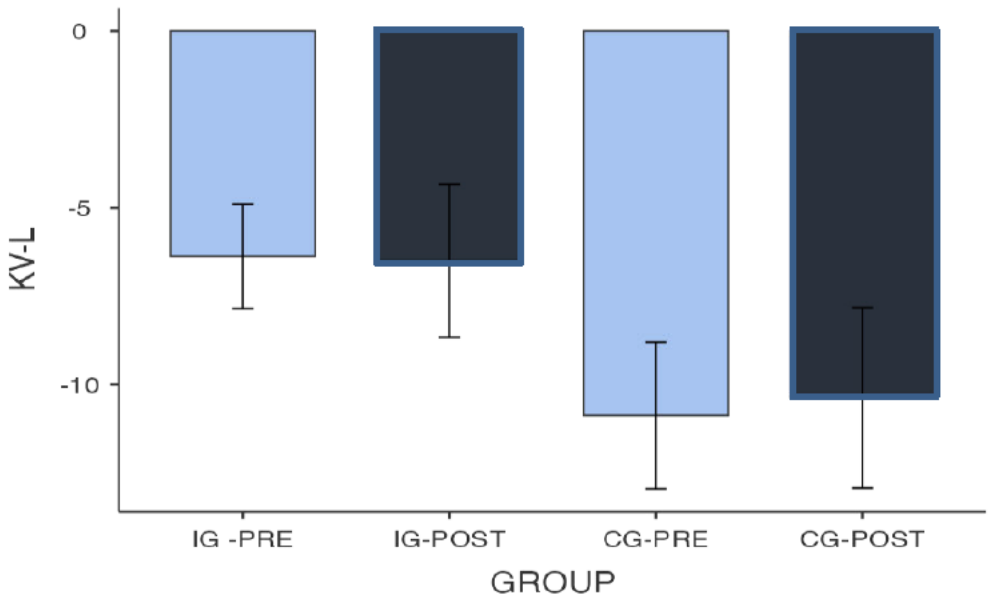
| Variable (unit) | IG Pre-test Mean | IG Post-test Mean | Change (SD) | ANOVA | CG Pre-test Mean | CG Post-test Mean | Change (SD) | ANOVA |
|---|---|---|---|---|---|---|---|---|
| KV-L (Degree) | −6.38 | −6.50 | -0.12 (1.95) | $F = 0.00228$, $p = 0.96$ | −10.88 | −10.38 | −0.50 (1.34) | $F = 0.02$, $p = 0.88$ |
| KV-R (Degree) | −17.13 | −13.88 | −3.25 (2.19) | $F = 0.793$, $p = 0.39$ | −9.13 | −8.63 | -0.50 (2.63) | $F = 0.06$, $p = 0.79$ |
| KF-L (Degree) | 61.39 | 61.96 | 0.57 (2.37) | $F = 0.0$, $p = 0.95$ | 76.69 | 70.47 | −6.23 (4.52) | $F = 0.25$, $p = 0.62$ |
| KF-R (Degree) | 57.95 | 66.34 | 8.39 (11.21) | $F = 0.42$, $p = 0.52$ | 84.42 | 77.05 | -7.37 (5.53) | $F = 0.14$, $p = 0.70$ |

Table 4.7

*Between-group differences for KNEE VALGUS LEFT (KV-L), KNEE VALGUS RIGHT (KV-R), KNEE FLEXION LEFT (KF-L), and KNEE FLEXION RIGHT (KF-R)*

| Variable (unit) | IG Mean Change (SD) | CG Mean Change (SD) | ANOVA |
|---|---|---|---|
| KV-L (Degree) | -0.12 (1.95) | -0.50 (1.34) | $F = 0.0391$, $p = 0.84$ |
| KV-R (Degree) | −3.25 (2.19) | -0.50 (2.63) | $F = 0.599$, $p = 0.46$ |

| | | | |
|---|---|---|---|
| KF-L (Degree) | 0.57 (2.37) | -6.23 (4.52) | $F = 0.748$, $p = 0.41$ |
| KF-R (Degree) | 8.39 (11.21) | -7.37 (5.53) | $F = 2.52$, $p = 0.13$ |



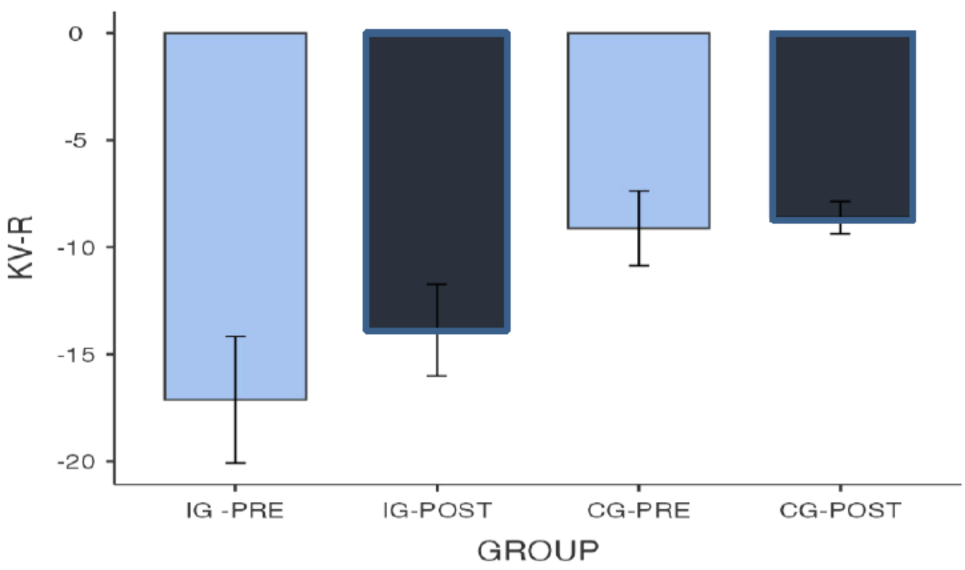




Figure 16 IG-Pre, IG-Post, CG-Pre, and CG-Post for KV-L (top) and KV-R (bottom) data

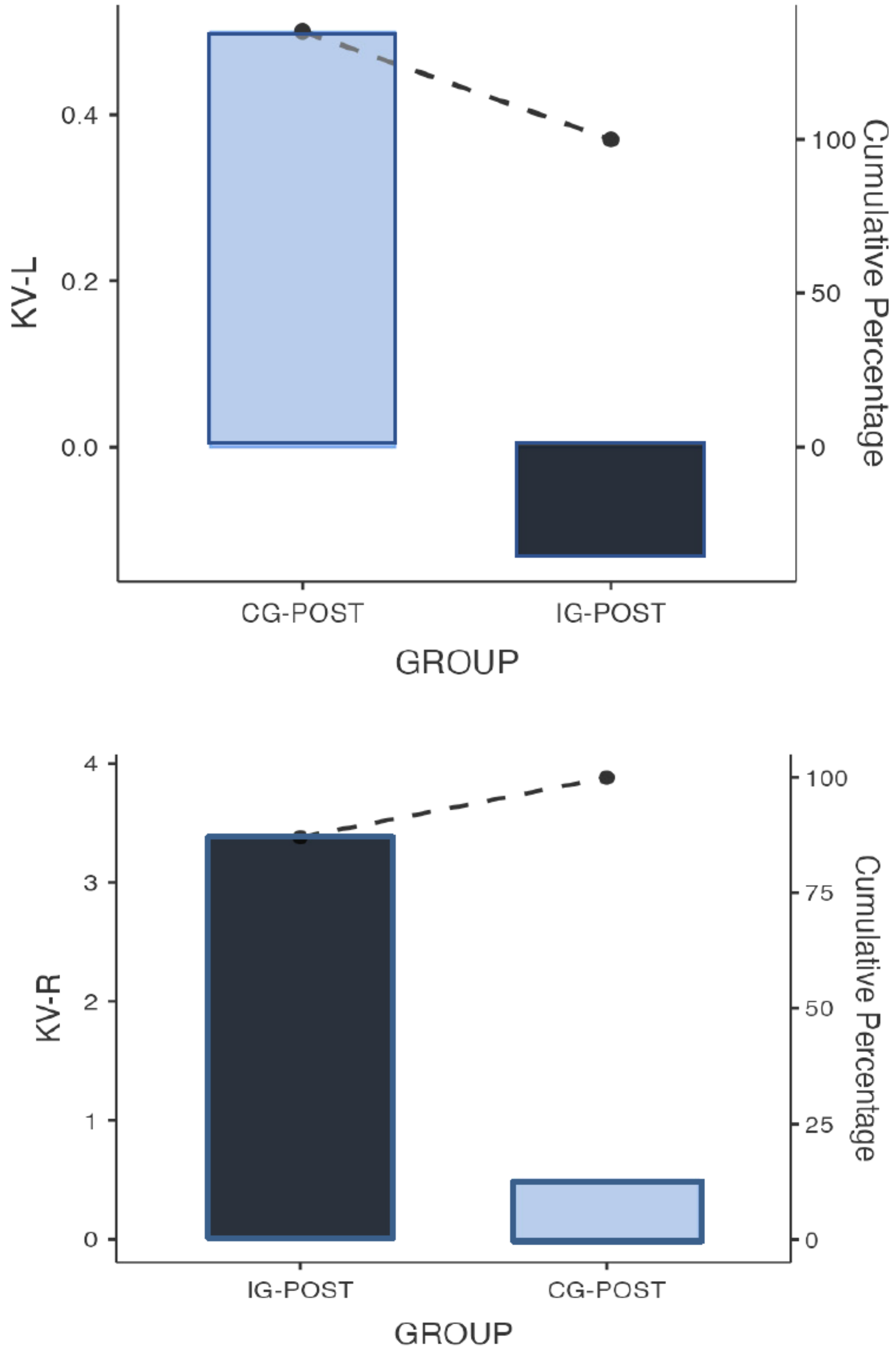



Figure 17 IG-Post, CG-Post KV-L (top) and KV-R (bottom) mean change between-group. Dashed lines indicate cumulative change.

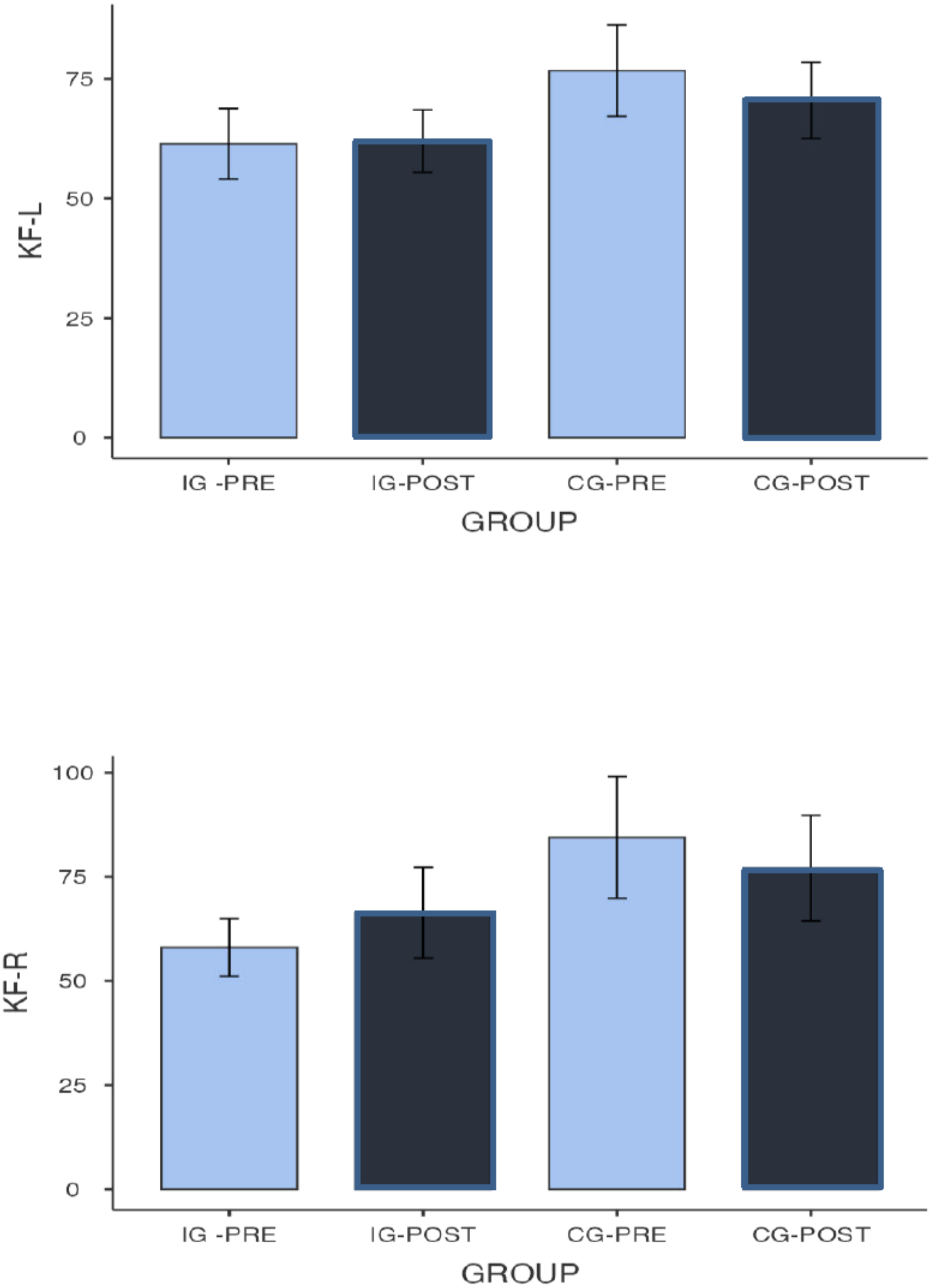



Figure 18 IG-Pre, IG-Post, CG-Pre, CG-Post for KF-L (top) and KVR (bottom) data

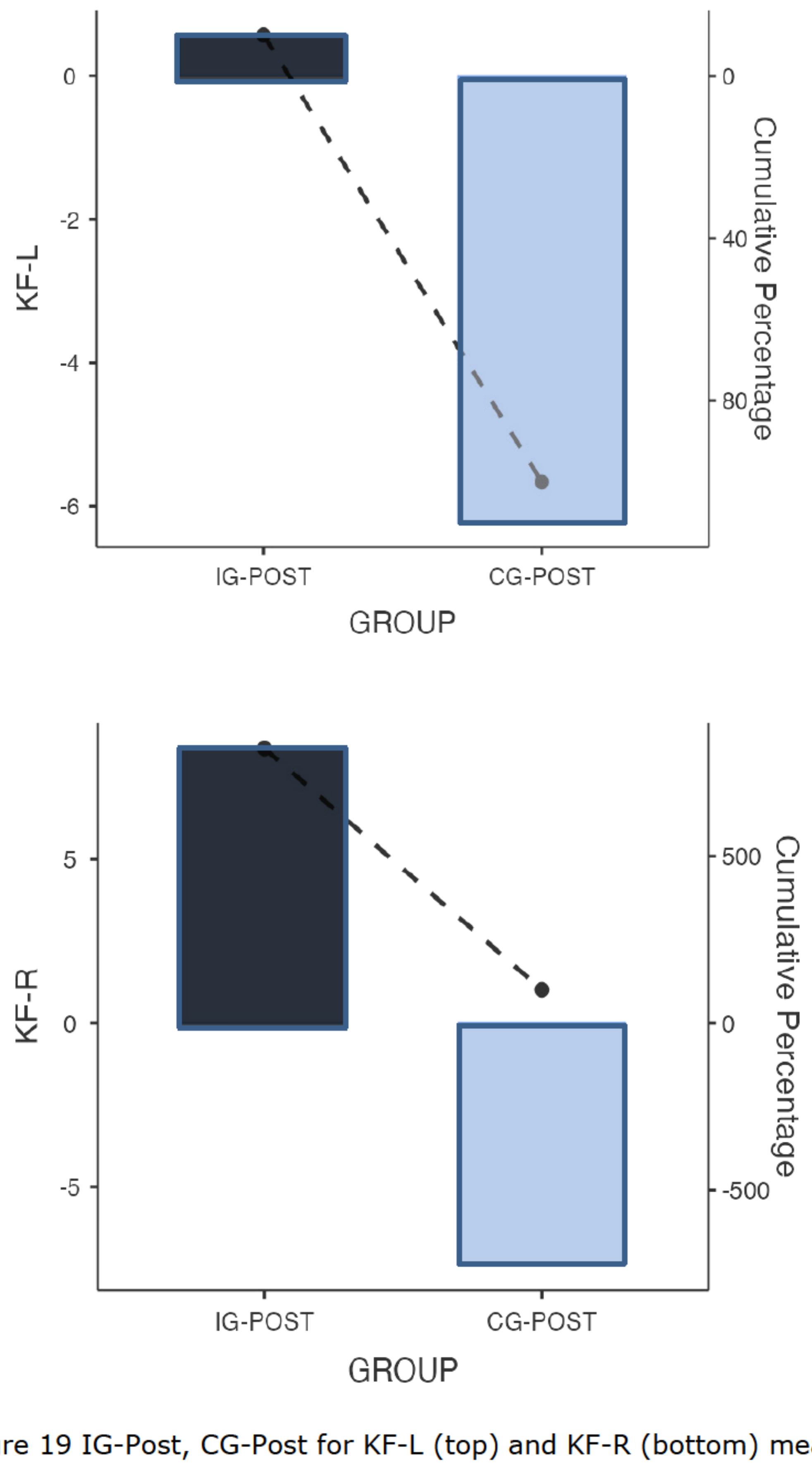



Figure 19 IG-Post, CG-Post for KF-L (top) and KF-R (bottom) mean change between-group. Dashed lines indicate cumulative change.

## 4.5 CORRELATION RESULTS

Further to the task of answering research questions one, two, and three, the following section presents the results from the correlational analysis of all variables for pre and post test data. Table 4.8 presents the Correlation Matrix for each of the variables, followed by Figures 20 - 24 which outline the plots for these correlations with densities for variables using the Pearson's moment coefficient. The researcher recognises the low number of participants that has contributed to these correlation data means the results should be seen as preliminary in nature.

As would be expected in a larger sample size SKFD and GRTH and BMI are all highly correlated to each other. For example, skinfold and girth are related $r$ = 0.60 ($p$ < 0.001), and girth and BMI are related $r$ = 0.92 ($p$ < 0.001). Relevant to research question one, this is a positive correlation. Refer Figure 20.

PLF and PLF-R are related to BMI. For example, bilateral landing force and body mass are related $r$ = 0.35 ($p$ < 0.04), and landing force right are related $r$ = 0.39 ($p$ < 0.02). This is relevant to a part of research question two, exploring change in landing impact forces and force generation in take-off. Refer Figure 21.

As expected, all landing data is highly correlated with PLF and PLF-R, PLF and PLF-L, and PLF-R and PLF-L: $r$ = 0.80 ($p$ < 0.001), $r$ = 0.77 ($p$ < 0.001), and $r$ = 0.57 ($p$ < 0.001). Refer Figure 22

PPF is correlated with KF-L and KF-R: $r$ = 0.55 ($p$ < 0.001) and $r$ = 0.46 ($p$ < 0.001). This is an important and positive correlation related to research question two exploring force generation at take-off. See Figure 23. Interestingly, PPF showed a correlation with KV-R, $r$ = 0.37 ($p$ < 0.03). Relevant to research question three, this is an expected negative correlation. Refer Figure 24. Additionally, as expected, KF-R is highly correlated to KF-L: $r$ = 0.91 ($p$ < 0.001).

Table 4.8

*Correlation Matrix for all variables SKFD, GRTH, BMI, PLF, PLF-L, PLF-R, PPF, KV-L, KV-R, KF-L, KF-R*

Correlation Matrix | Note. * p < .05, ** p < .01, *** p < .001

| | | SKFD | GRTH | PFL | PFL-L | PLF-R | KV-L | KV-R | PPF |
|---|---|---|---|---|---|---|---|---|---|
| SKFD | Pearson's | — | | | | | | | |
| | p-value | — | | | | | | | |
| GRTH | Pearson's | 0.605 *** | — | | | | | | |
| | p-value | < .001 | — | | | | | | |
| PFL | Pearson's | 0.136 | 0.223 | — | | | | | |
| | p-value | 0.459 | 0.221 | — | | | | | |
| PFL-L | Pearson's | 0.181 | 0.248 | 0.744 *** | — | | | | |
| | p-value | 0.322 | 0.170 | < .001 | — | | | | |
| PLF-R | Pearson's | 0.263 | 0.346 | 0.703 *** | 0.570 *** | — | | | |
| | p-value | 0.145 | 0.052 | < .001 | < .001 | — | | | |
| KV-L | Pearson's | -0.138 | 0.126 | -0.161 | 0.015 | -0.084 | — | | |
| | p-value | 0.453 | 0.491 | 0.378 | 0.936 | 0.647 | — | | |
| KV-R | Pearson's | -0.047 | -0.394 * | -0.206 | -0.281 | -0.294 | -0.135 | — | |
| | p-value | 0.800 | 0.026 | 0.257 | 0.120 | 0.103 | 0.462 | — | |
| PPF | Pearson's | -0.106 | 0.163 | 0.208 | 0.316 | 0.240 | -0.058 | -0.372 * | — |
| | p-value | 0.564 | 0.374 | 0.253 | 0.078 | 0.186 | 0.754 | 0.036 | — |

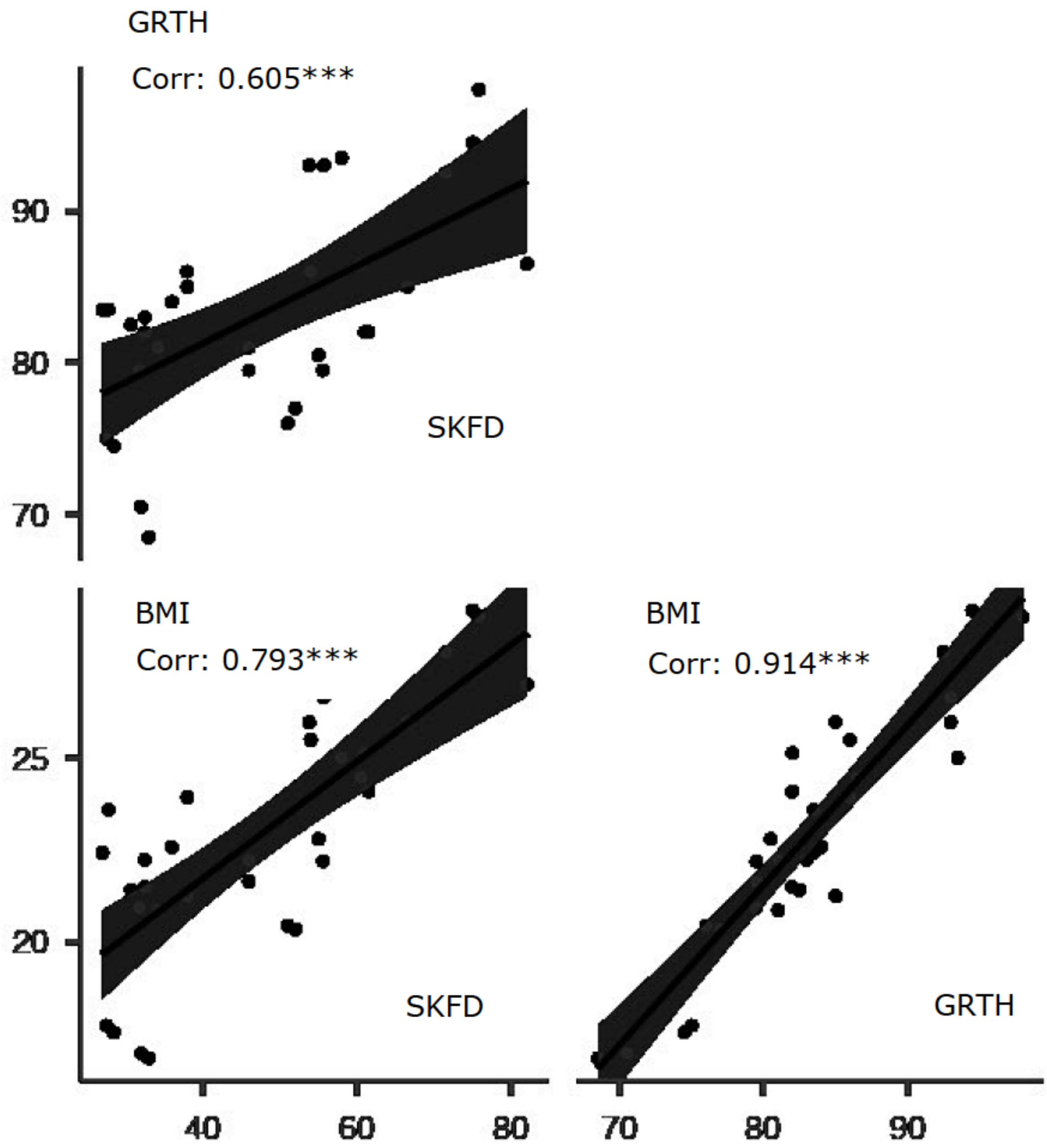



Figure 20 Correlation plot and densities for variables of SKFD, GRTH and BMI

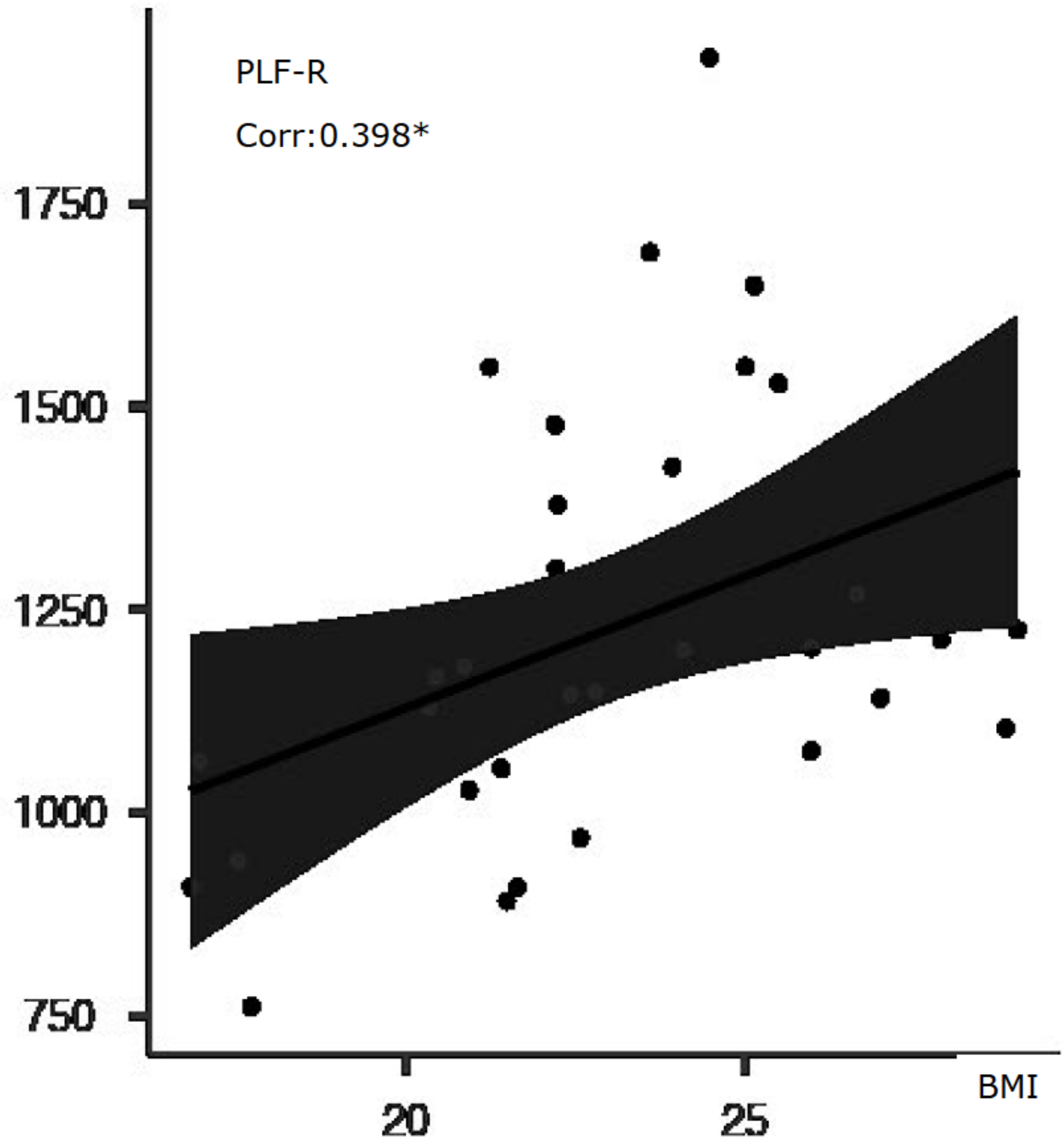



Figure 21 Correlation plot and densities for variables of BMI and PLF-R

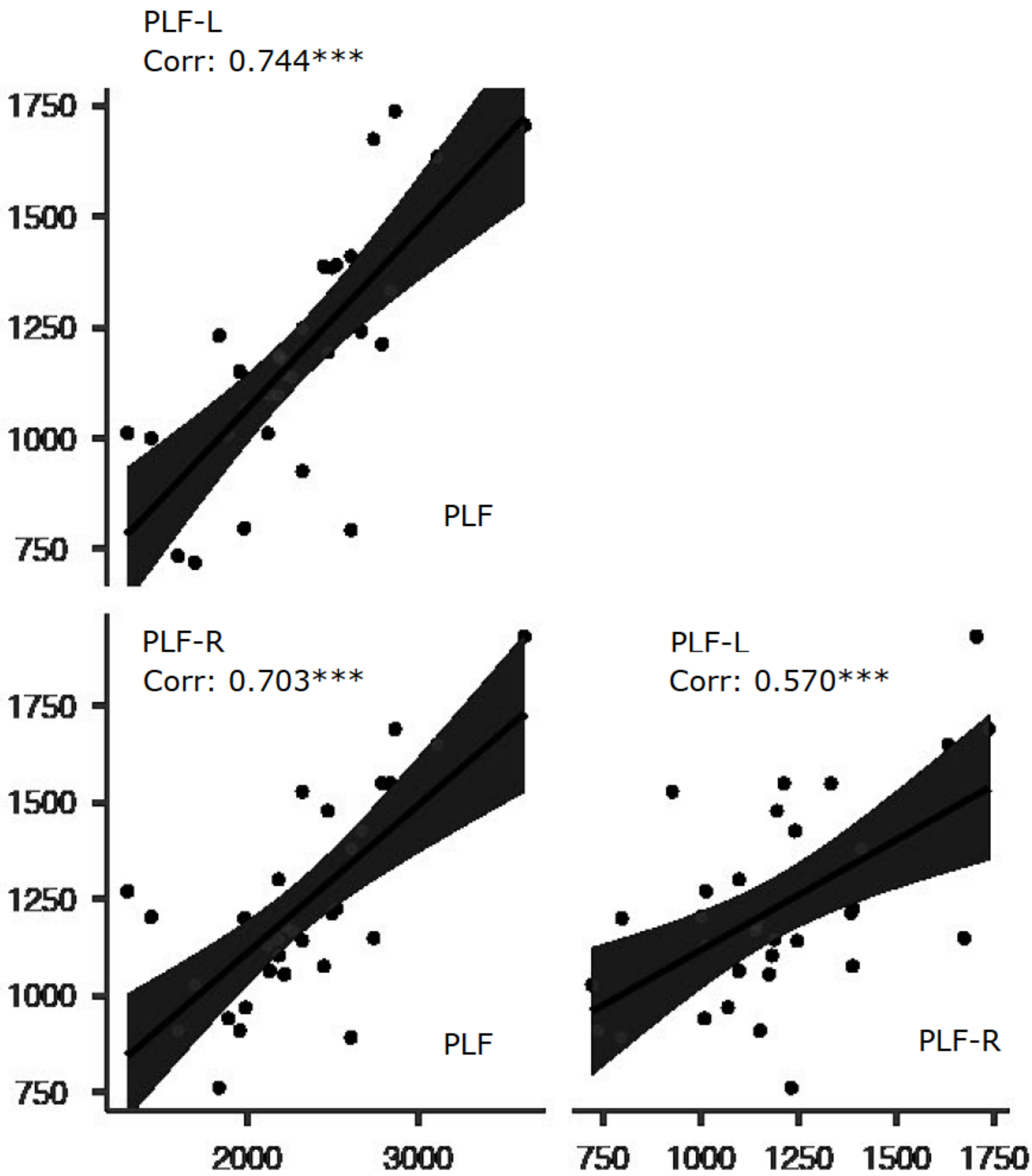



Figure 22 Correlation plot and densities for variables of PLF, PLF-L and PLF-R

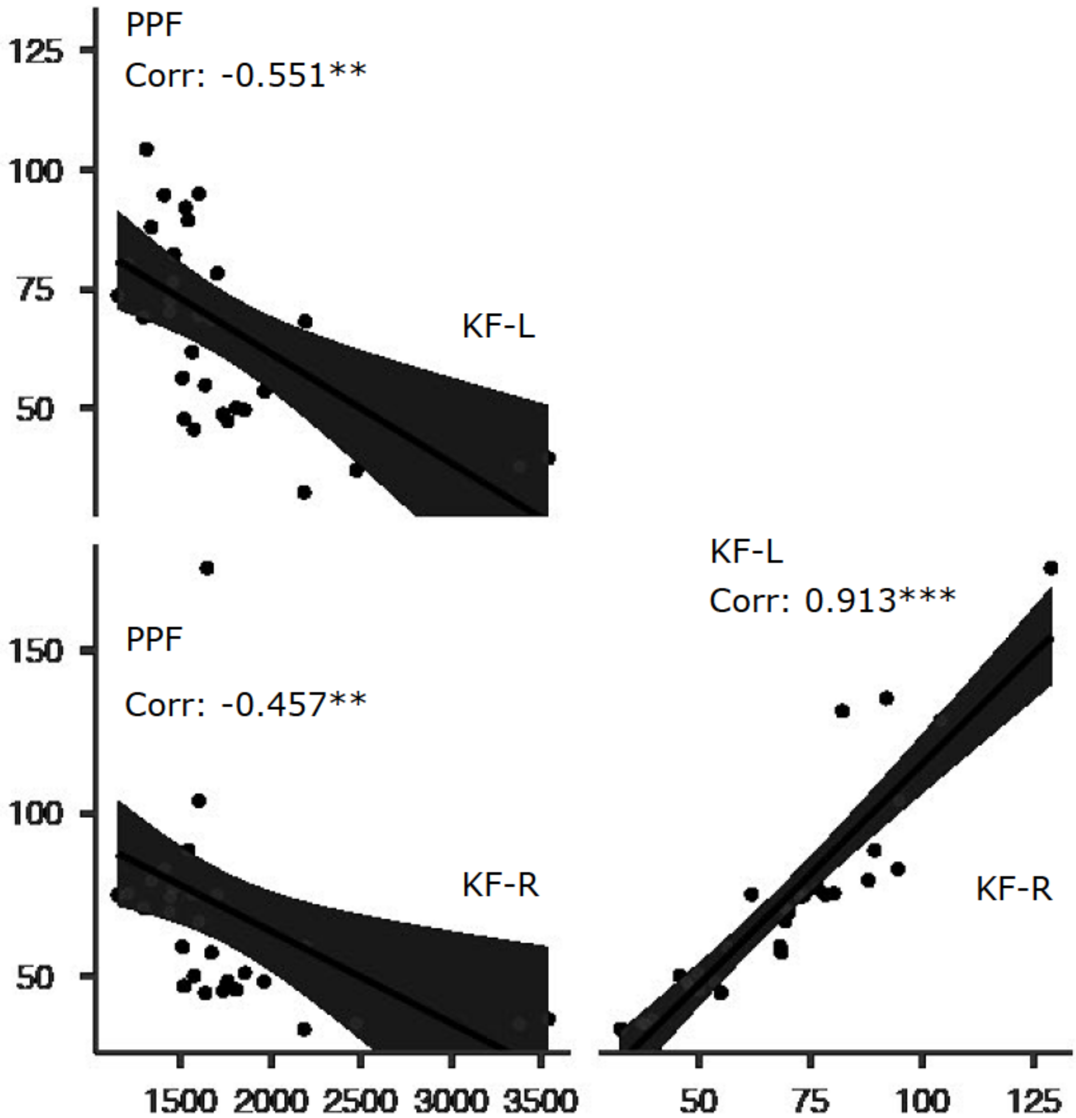



Figure 23 Correlation plot and densities for variables of PPF and KF-L, and KF-R

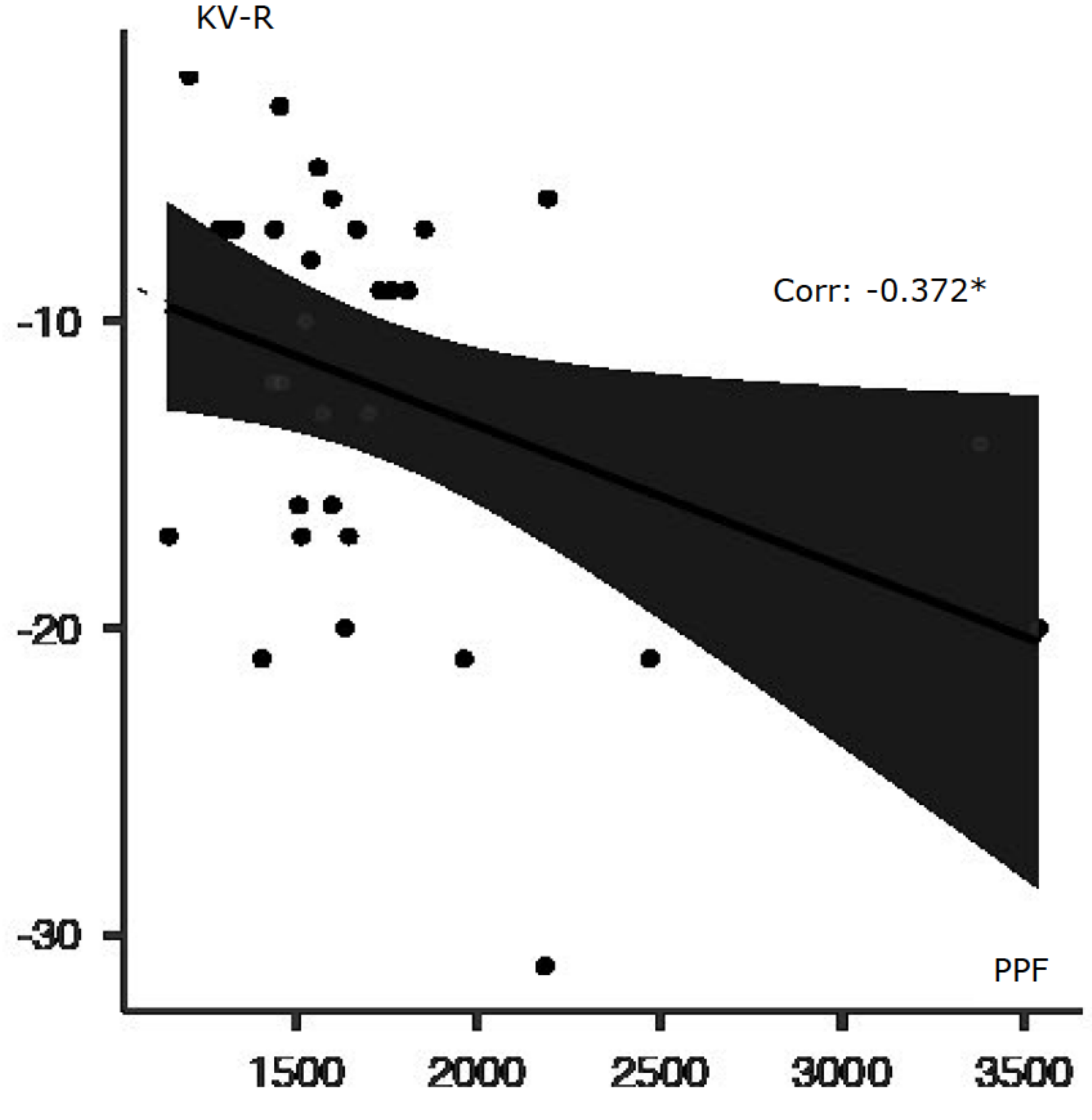



Figure 24 Correlation plot and densities for variables of PPF and KF-R

# CHAPTER 5: DISCUSSION

## 5.1 INTRODUCTION

This study investigated the potential effect of an eight-week hypertrophy-focused training program on adolescent female athletes, considering landing forces, force production, dynamic knee valgus and knee flexion angle in the context of jumping and landing mechanics. It was found that such a training program could indeed provide positive changes in fat free mass in adolescent female athletes, and that the changes so produced had a measurable impact on reducing landing forces and increasing athletic force output. At the same time there were minor insignificant changes in dynamic knee valgus knee kinematics from a jumping-landing task.

In this Chapter the results are interpreted and discussed, building on both knowledge centred in the literature, and observations from the work done. Discussion commences in section 5.2 with reference to the first Research Question around anthropometric change, while section 5.3 discusses force data with reference to Research Question 2 regarding a potential relationship between anthropometric change and force changes. Section 5.4 discusses knee metric data with relation to the third Research Question investigating potential impact of anthropometric change and knee biomechanics in a landing and jumping movement. Section 5.5 discusses correlational data between all variables, and Section 5.6 considers limitations affecting results. The discussion concludes with a summary of outcomes related to the data gathered and research questions.

## 5.2 ANTHROPOMETRIC RESULTS

Total skinfolds reduced within the intervention group, which means there was a positive change to fat free mass overall, due to muscle hypertrophy. The between-group comparison showed a statistical significance in anthropometric results. The intervention group (IG) showed a total reduction in lower limb girth measurements, which correlates with a reduction in lower limb skinfolds. The comparison group (CG) total lower limb girth showed an increase which, coupled with the increase in skinfold measurements, indicates that a potential negative anthropometric change occurred within this group. BMI slightly reduced in the intervention group, which supports the positive anthropometric change.

The significance of the anthropometric changes in the IG indicates the intervention training program was successful in the development of muscle hypertrophy. In terms of Research Question 1, this indicates that an eight-week strength-training intervention program for adolescent female athletes is sufficient to bring about muscle hypertrophy. With statistically significant changes in skinfold measurements, a small reduction in lower limb girth measurements, and a small increase in body mass index, it can tentatively be concluded that the intervention hypertrophy program over this period was successful in exhibiting a change in lower body muscle mass.

## 5.3 FORCE RESULTS

As shown by Figure 12, the total peak landing forces for the IG was slightly larger than the CG in the primary stage of the study. As a result of the IG, however, total peak landing force reduced by a significant margin per participant of 585.88 N over the CG. The CG total peak landing force increased by a mean of 128.67 N for each participant. The within- and between-group total peak landing force as a result of the intervention was statistically significant. Similar findings to these are seen in research by Vescovi, Canavan & Hasson (2008), who showed a mean reduction in landing forces per participant of -222.8 N over the control participants (+54.6 N), after a short six-week plyometric-based intervention program.

Landing forces in left and right limbs also display a reduction that is consistent with the present study's secondary findings regarding total peak landing forces. This is also consistent with findings from Jafarnezhadgero, Madadi-Shad, McCrum & Karamanidis (2019), that conclude that, while peak vertical, anterior, posterior and peak medial ground reaction forces are all reduced as the result of a corrective exercise program within and between IG and CG, the reduction is not statistically significant.

Peak drive off force increased in the intervention group and decreased in the comparison group, again without statistical significance, however research by Derrick (2004) found that increasing knee flexion angle at ground contact can reduce the peak vertical ground reaction impact force, but it can also increase the peak impact acceleration at the leg. This present research finds the same effect. It may therefore be tentatively concluded that the intervention program was able to develop or influence participant athletic abilities.

The overall decrease in peak landing forces bilaterally and unilaterally in the IG coupled with an increase in peak drive off force, indicates a positive change in force displacement and force production for the adolescent female athletes. This is relevant to Research Question 2 on whether or not a lower-limb focused hypertrophy training program might show positive change in landing impact force and force generation in take-off.

## 5.4 KNEE METRICS RESULTS

No statistically significant difference is identified in dynamic knee valgus pre-intervention and post-intervention, either within- or between-groups, despite the IG showing an increase in knee flexion angle (see figure 20 and 21). This finding is consistent with other strength-training intervention research. For example, Herman et al. (2008) concluded strength training alone does not alter knee and hip kinematics in female recreational athletes and suggests further exploration of additional interventions. Lephart et al. (2005), however reported that neuromuscular characteristics of the lower extremity in female athletes can be improved with a basic exercise program in isolation. A recent study by Herman, Pritchard, Cosby and Selkow (2022) highlights how a school-based strength-training program focusing on hip and knee musculature significantly improved jump-landing biomechanics relevant to ACL injury risk, however, and this research also suggests that varied strength-training approaches are warranted in the adolescent age group.

These results are significant to this study. Even though dynamic knee valgus of either leg showed no statistically significant result, the mean increase in knee flexion angle as a result of the intervention highlights the effect of a hypertrophy training program on the participant's ability, first, to absorb landing forces, then produce superior concentric force.

The mean increase in knee flexion angle as a result of the intervention, despite no statistical significance within or between groups, highlights that the hypertrophy training program had an effect on the participant's ability to absorb landing forces then in turn produce superior concentric force than before the intervention. A tentative conclusion can be made that the intervention program was able to have an influence in increasing athletic qualities of the participant via an increase in muscle mass and increased ability to absorb force.

## 5.5 CORRELATION RESULTS

Correlations for all pre-test data were observed. The positive correlations for skinfolds, girth measurements, and body mass index were expected. As skinfolds reduced, so too did total lower body girth measurements due to an increase in localised muscle hypertrophy and tissue density change.

Although BMI in the IG shows only a minor reductive change, this is to be expected, as BMI is an equation of overall weight (mass) divided by the square of height measurement, and statistically significant change is unlikely to be present in such a small sample. This appears to be consistent with other research on interventions on anthropometric status and changes in youth (Collins et al., 2018). However, from the positive anthropometric correlation and observed IG-CG changes in between-group skinfold and girth measurements shown in the present study, an inference can be drawn that the training program is successful in eliciting a favourable body composition, via muscle hypertrophy, change.

The positive correlation between peak landing forces and body mass index is consistent with other research, such as that of Fatahi, Yousefian Molla and Mansouri (2021), who found significant correlation between BMI and maximum landing force. In the same context, the findings of Salles et al. (2011), that increasing or decreasing BMI can affect the kinetic and kinematic variables of the athletes jump and landing, surely hold significance for further research into the mechanics of injury prevention. Further, the positive correlation between peak propulsive force and increased knee flexion angle at impact of the present study support Derrick's (2004) findings that increasing the knee flexion angle at ground contact reduces the peak vertical ground impact force and increase peak impact acceleration (propulsive force). This shows that there is a favourable relationship between strength training focusing on muscle hypertrophy development for an adolescent and effective management of force upon the body.

Interestingly, peak propulsive force also shows a correlation with knee valgus-right. Relevant to research question two, this is an expected negative correlation (see figure 26), as a reduction in dynamic knee valgus angle at impact allows for an increase in force generation. Czasche et al. (2018) show a similar result with reduction in dynamic knee valgus after a strength-training intervention of a similar eight-week duration. Their study did not show statically significant landing force reduction. However, post-intervention, participants showed significant increases in gluteal muscle strength which the researchers attributed to a significant reduction in valgus loading and angle. An interesting observation within the IG group of the present study is that they are all right-limb dominant.

## 5.6 LIMITATIONS

There are particular limitations in this research that should be discussed, and their impacts acknowledged. The first of these concerns was previously addressed in section 3.5.5, where COVID-19 caused a major disruption with the originally selected intervention and comparison group cohorts being prevented from completing the study. New cohorts had to be selected the following year and the study process recommenced, delaying the research project by one year.

The second is the time required to show actual structural and physiologic changes in muscle hypertrophy. The literature suggests that eight weeks is considered the minimum timeframe for this. According to Fleck and Kramer (2014), significant changes in lean muscle mass can be demonstrated in women undergoing strength training programs of between eight and 20 weeks in duration. While a longer intervention timeframe would have been preferable, the study involved high school students, some of whom were boarding, so that fitting the investigation into the Queensland school calendar, particularly with the delay experienced in achieving a commencement date in term two of 2021, presented a challenge.

With only ten weeks allocated per term, and with the inclusion of school extra-curricular activities for some participants, having an uninterrupted period of training was problematic as, if the intervention phase could not be overseen during the term, there was a potential for participants selected in that group to lose access to training facilities during term holidays. In practice, adjustments such as lunch break training sessions and after-school make-up sessions had to be made in order to complete the allocated training sessions required for each IG participant, and these came with some risk of compromising participant recovery.

The second limitation concerned the appropriate dietary intake of protein. As outlined in section 2.8.4, to improve anabolism and protein synthesis, ten grams of essential amino acids via consumption of 15-25 grams of a high biological value protein source is considered ideal for muscle hypertrophy. Intervention Group participants did not always meet this requirement, and in fact, while approximately half of them admitted that they knew the importance of quality value protein requirement during the study, however, they felt their diet could have improved during the research period.

A third limitation lay in accessing a larger number of adolescent female athletes for the selection process. Additionally, the selection process was non-randomised. Working within a school setting sometimes obliged the research to proceed under organisational constraints dictated by the needs of the school and gaining access to some participants as a group was one such constraint. The early stages of recruitment appeared promising as participant numbers initially were ten per group yielding a combined cohort of 20 participants; however, 16 participants completed the requirements of the study.

In summary, then, study aims, processes and outcomes were affected to some extent by the practicalities of the research situation. Enough progress was made towards validating the hypotheses of the study, however, to justify the conclusion that a greater length of time with a greater number and wider range of identically fed participants would surely have produced more significant results.

# CHAPTER 6: CONCLUSIONS

This Chapter will summarise the intent and development of the researcher's investigation into the phenomenon of lower-limb injury in adolescent female athletes. It will then move to a consideration of the learning objectives for the researcher and the 'triple dividend' wherein the benefits of the study to the researcher, the workplace and the profession are established, before ending with conclusions from the project and a discussion of directions for future research.

## 6.1 INTRODUCTION

The focus of this research project was to develop a stronger understanding of the mechanisms and risk of lower limb injury to adolescent female athletes, and to outline an intervention program that may mitigate such risk. The study began with an outline and discussion of biological sex injury disparities in court and field sports that involve jumping, landing, and pivoting.

Chapter 1 raises the spectre of lower-limb injury disparity between males and females in sport, and it is generally accepted that female athletes have two to nine times greater risk of ACL injury in a 'non-contact' occurrence than males. Differences in biomechanical structures of the hips and lower body in males and females is discussed before the issue of an unchangeable dynamic known as 'Q-angle' is introduced in section 1.2 and defined and further explored in section 2.4. This discussion is important because if biomechanical differences are largely unchangeable, then the question arises of what corrective training methodologies should be employed to reduce potential injury risk to adolescent female athletes.

This research has been strongly informed by a detailed review in Chapter 2 of the mechanisms of lower-limb injury risk in the adolescent female athlete population. The Research Design is outlined in section

3.2.3, which details the employment of a landing observation task to replicate the physical demands of ground landing and reaction forces inherent in most court and field sports. Section 3.3 presents a detailed resistance-training intervention program targeted to muscle morphological adaptations in the lower limbs. Section 3.6 describes the instrumentation employed and how the data was collected, and Section 3.7 explains how the data was analysed.

In Chapters 4 and 5 the results are presented, discussed, and interpreted with reference both to the literature review and workplace practice. The results are then discussed in sections with reference to each of the research questions:

Section 5.2 Might an eight-week strength-training intervention program for adolescent female athletes, focusing on muscle hypertrophy, show favourable changes in lower body anthropometrics, and a discussion of anthropometric results?

Section 5.3 Might such a strength training intervention focused on lower limb hypertrophy show positive change in landing impact force, and force generation in take-off, with a discussion of force results?

Section 5.4 Might such a strength training intervention show favourable changes in dynamic knee valgus and knee flexion angle upon landing from a jump, thereby reducing potential lower limb injury risk to female adolescent athletes, with a discussion of knee metrics results? Section 5.5 discusses correlations of all data, with limitations of the study being noted in Section 5.6 before conclusions are drawn in Chapter 6.

Chapter 6 will also outline the learning objectives for the researcher and the triple dividend, whereby the benefits to the researcher, organisation, and profession are established. This chapter will be finalised with conclusions from this this research project and discuss directions for future research.

## 6.2 LEARNING OBJECTIVES – OUTCOMES

Any taxonomy of learning, and particularly one involving human subjects, draws heavily upon the researcher's intellectual, methodological, personal, social, and communication capabilities, and these have certainly been tested in this journey of professional, personal, and organisational development and reflection.

Undertaking this study has been instrumental in developing skills and aptitudes essential to reflective practice in the 21st century, and these include systematic information-gathering, technology adoption, analytical skills, critical judgement, objective judgement, and collaboration and teamwork.

### 6.2.1 Systematic information gathering and technology adoption

A thorough review of current literature was a critical element in this research project, presenting an opportunity to develop systematic processes for collecting, assimilating, and interpreting information fundamental to this research field. The researcher has learned a substantial amount about gathering relevant knowledge in the process of searching then interpreting information. Utilisation of USQ Library databases that allowed access to scholarly literature such as The Directory of Open Access Journals, PubMed, ResearchGate, ScienceDirect, SAGE Journals, Scopus, and Web of Science proved essential components of the research journey. The process of defining and refining search questions proved to be indispensable in meeting this learning objective.

The use of technology is widely discussed in the Exercise Science and Strength and Conditioning industries. While the use of 'wearable gadgets' is not popular with some coaches the researcher has worked with, extending the boundaries of knowledge in the fields mentioned above is, in the researcher's view, justification and rationale for making use of the major advances in velocity-based training technology (VBT), force measurement and kinematic analysis of the last 12-18 months. Indeed, this research was possible only through the provision by VALD Performance of advanced, precise, and industry-validated technology to capture, record, and analyse the key metrics collected for each participant in the study. The researcher was required to undergo specific systems training in order to ensure each instrument was used accurately and effectively for valid and useable data collection and analysis, and he considers it not only time well spent, but a step forward in his personal development as both instructor and ongoing learner.

### 6.2.2 Analytical skills, critical judgement, objective judgement, and collaboration and teamwork

During the planning stages of the research project, careful consideration was given to the methodologies employed for the research design. This included a justification of the choice of research methods for the gathering of evidence throughout the body of work, and for interpretation of results that would lead to recommendations made. Review of current literature was something of an organic process, as the research project spanned three years with some delays and cohort reassignment (see section 3.5.5); therefore, up-to-date knowledge and data currency in the adolescent female athlete training-space was a continually evolving requirement.

As the research involved a physical observation with human subjects, and a further physical intervention process on a group within those subjects, the task of collating and interpreting different pieces of information to identify correlations and how they contributed required both analytical and objective judgement skills.

Social and communication capabilities were enhanced through a collaborative agreement between the workplace at AFHP, the research setting at Fairholme College, a private secondary school, and by the adoption of technical instruments provided by an external organisation, VALD Performance.  Regular collaboration between the school, the school's representatives, and the researcher for access to participants and time schedules was an essential requirement for the overall success of the project.

### 6.2.3 Benefits to the Researcher

This study has made a significant contribution to the researcher's ability to apply real-world knowledge to his field of practice. He has learned that reflective practice, critical thinking, and judgement are key components of self-directed learning.  The transference of professional knowledge acquired throughout the research project is a critical step forward for ongoing professional practice and collaboration opportunities with industry peers.

As with any research having humans at its core, our knowledge in the area of this study continues to expand and evolve, and that process not only places a premium on collaboration with other researchers but provides exciting opportunities for involvement and growth in the physical preparation of young athletes.

### 6.2.4 Benefits to the Organisation

This project has made a measurable contribution to the researcher's workplace environment through thorough review of literature and analysis of data with relation to the mechanisms of structural injury by biological sex and age.  In this it has provided an extremely important learning opportunity that allowed the researcher and organisation to experience a theory-into-practice model which provides the organisation with currency, validity and standing in its industry.  As the organisation works closely with numerous secondary schools in regional Queensland, professional image and standing are improved by the acquisition of current knowledge in the field of injury prevention and the enhanced academic contribution now possible towards the national vocational education curriculum in the subject matter of Sport Coaching, Certificate III, and Certificate IV in Fitness.

### 6.2.5 Benefits to the Profession

The benefits of this project to the profession are threefold. First, it adds to the existing pool of knowledge for mitigating injury risk to female adolescent athletes. In addition, this research provides comparative analysis of current strength-training interventions. Third, it allows further options for all professionals working with adolescent cohorts in the sporting sector, an informed choice of strength-training modality appropriate to the age and the sex of the athlete.

## 6.3 CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Musculoskeletal differences between male and female adolescents have been examined, clearly defined and linked with unfavourable landing mechanics in adolescent females. Knee valgus in female adolescents has been defined and described with regard to causation of injuries to the knee and lower extremities, Q-Angle has been similarly defined, together with its contribution to the biomechanical propensity for structural injury. Furthermore, body mass and injury discussions show that there is a relationship to 'overweightness' and higher BMIs outside of FFM that places the adolescent at risk.

Current successful intervention strategies to reduce lower limb injuries in female adolescents indicate that an approach combining neuromuscular strength training, plyometric exercises and balance training are moderately effective. However, any one of the three methods in isolation has not shown a significant reduction in injury occurrence. Conducted in the spirit of that line of enquiry, this work-based study contributes to, and informs physical preparation staff, sport coaches, volunteers and Health and Physical Education teachers, of the value of a structured strength-training intervention aimed at a muscle development outcome, for at least a strengthening of the lower limbs and a notional reduction in non-contact injury risk. A conjoint benefit of this research is that successful development of muscle tissue in adolescent females might well assist in a development of self-confidence and a positive self-body image that can then be transferred to an improved confidence in sporting ability, as well as being of holistic benefit at a stage in an adolescent's life where such a consideration is important.

This practitioner-based research aimed to explore a potential relationship between lower limb anthropometric change with a resistance training adaptation to analyse knee kinematics in a landing movement. Based on quantitative analysis, an adaptation occurred in the intervention group as the result of an eight-week hypertrophy training program that was statically significant. This was a pleasing outcome for, as noted in the limitations section, dietary protein intake was not consistent for some of the participants in the study. There was a correlation between dynamic right knee valgus and peak propulsive force. This correlation may imply a favourable change in the dominant limb as all participants in the intervention group were right-footed. This suggests a potential improvement in force management and production for the athlete has occurred. There was also a statically significant reduction observed in total peak landing forces for participants in the intervention group. This further highlights an improvement in athletic qualities of the participant as a result of a hypertrophy-based training program.

Future work-based studies might build upon these results by involving a larger participant cohort over a longer and less-interrupted intervention period. Opportunity also exists in a future intervention for the inclusion of a dominant and non-dominant limb aspect, as this would further explore the correlation between anthropometrics and knee kinematics.

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