A WORK-BASED STUDY OF LEG STRENGTH AND AGILITY PERFORMANCE IN ADOLESCENT FEMALE ATHLETES PARTICIPATING IN COMPETITIVE QUEENSLAND AUSTRALIAN FOOTBALL: IMPLICATIONS FOR FUTURE PRACTICE

A Thesis submitted by

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ABSTRACT

This work-based project investigated the relationship between leg strength—bodyweight ratio and agility performance in adolescent females participating in competitive Australian Football League Women's in Queensland. This demographic has been shown to have a higher risk of Anterior Cruciate Ligament injuries as compared to their male counterparts and some research suggests improved agility may contribute to mitigation of this risk. The project investigated these relationships in-the-field to address some of the barriers reported by adolescent females to regular participation in strength and conditioning programs which may be beneficial to them. 23 volunteer adolescent females were separated into two groups. All participants were tested for anthropometric, unilateral leg strength measures and agility before Group 1 (n=11), undertook a six-week, leg strength intervention program while Group 2 (n=12) continued a normal training protocol. The intervention took place three times per week and was conducted at the training ground. Both groups then participated in the same post-intervention testing battery. Results indicate both Group 1 ($t = 2.14$, $p = 0.06$) and Group 2 ($t = 2.35$, $p < 0.05$), improved left leg strength and Group 2 improved aggregate leg strength ($t = 2.20$, $p = 0.05$). Improvement in agility for Group 1 was statistically significant ($t = -4.84$, $p < 0.001$). Significant negative correlations between bodyweight and leg strength for all participants were observed ($r = -0.44$, $p < 0.05$) and leg strength and leg strength-bodyweight ratio were correlated with agility performance ($r = -0.47$, $p < 0.05$). Implications for future work-based practise suggest a group-led, field-based strength program may benefit adolescent female agility and, by extension, injury risk.

CERTIFICATION OF THESIS

I James Anthony Stubbs declare that this thesis entitled ‘A work-based study of leg strength and agility performance in adolescent female athletes participating in competitive Queensland Australian football: Implications for future practice’ is not less than 25,000 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.

Date: 20th July 2022

Endorsed by:

Dr Lee Fergusson
Principal Supervisor

Dr Annette Brömdal
Associate Supervisor

Student and supervisors’ signatures of endorsement are held at the University

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ACL – Anterior Cruciate Ligament

AE – Athlete Exposures

AFHP – Academy of Fitness and High Performance

AgT – Agility T-Test

AFL – Australian Football League

AFLW – Australian Football League Women’s

ASCA – Australian Strength and Conditioning Association

ASIS – Anterior Superior Iliac Spine

BSS – Bulgarian Split Squat

CODS – Change of Direction Speed

CV – Curriculum Vitae

FIFA – Federation Internationale de Football Association (International Federation of Association Football)

G1 – Group 1

G2 – Group 2

HPE – Health and Physical Education

HQ – Hamstring Quadricep

Kg – Kilograms

LSBWR – Leg Strength to Body Weight Ratio

MD – Movement Discrimination

MAT – Modified Agility Test

NRL – National Rugby League

NSCA – National Strength and Conditioning Association

PH – Player Hours

PHV – Peak Height Velocity

RM – Rep Max

RSI – Relative Strength Index

RTO – Registered Training Organisation

S&C – Strength and Conditioning

SMR – Sexual Maturity Rating

SRL – State Rugby League

WBL – Work-Based Learning

CHAPTER 1: INTRODUCTION

1.1 Introduction

On Friday, February 3rd, 2017, the Australian Football League Women's (AFLW) played its first professional National League match at Princes Park (Kirby, 2018). It was representative of a change in attitude and approach to female participation and professionalism in Australian sports. This followed growth in the most popular global sport, soccer. In 1971, three female teams played a total of two soccer matches; by 2010, 141 teams played 512 matches. The International Federation of Association Football (FIFA) (2021) Women's Football Strategy, published in October 2018, outlines objectives to double the number of female players to 60 million by 2026.

Football Australia report that "Women make up 22% of Australia's participation base…set to rise with Football Australia's gender and equality Action Plan which aims to have 50% gender participation split by 2027" (FootballAustralia, 2022). With Australia due to host the 2023 FIFA Women's World Cup, interest and participation are set to increase. In other sports too, female participation is increasing. World Rugby reports female participation levels are at an all-time high with 2.7 million players globally. More than a quarter of the overall playing population is now female, and there has been a 28% increase in registered players since 2017 (Rugby, 2021) and Rugby Australia have announced fully-funded women's youth development XV's matches, as recently as March 2022 (Rugby, 2022). Indeed, the Rugby Seven's squad recently defended their Olympic Gold Medal at the postponed Tokyo Olympics next year.

Leading the aspirational charge, though, are the AFLW who, in their “Women’s Football Vision 2021-2030” (AFL, 2021) set out a target to be the number one sporting choice for females where players will be paid better than any other female domestic code in Australia by 2030. With 69,829 female athletes playing community football according to the 2019 AFL census, up from 14,820 in 2014, the figures indicate the progress and participation aspirations are not misplaced.

This acute and rapid change does, however, bring both reward and risk. An increase in competitive female sport, especially in professional participation, arguably brings increased pressure to perform in order to maintain professional status, and to help a team achieve success (Thorpe & Dumont, 2018). Pressures are financial and social, and spread beyond the individual athlete to the support staff, coaches, trainers, strength and conditioning staff, and management. Training loads, then, take on a more significant role since the success of the athlete is inherently related to the success of the wider team.

With an increase in physical activity comes an increase of physical loading and stress on the human body. Along with the increased physical demands, there has been an increase in physical injury, and whilst some early research reported that injury was more sport-related than sex-specific (Ivković et al., 2007; Sallis, 2001), later research indicated that not only is the severity of injuries different for female athletes versus male athletes (Brant et al., 2019; Von Rosen et al., 2018), but also the volume of injuries, with some research suggesting that female athletes are up to nine times more likely to suffer an Anterior Cruciate Ligament (ACL) injury playing sport than males (Arendt et al., 1999; DeHaven & Lintner, 1986; Hewett et al., 2005).

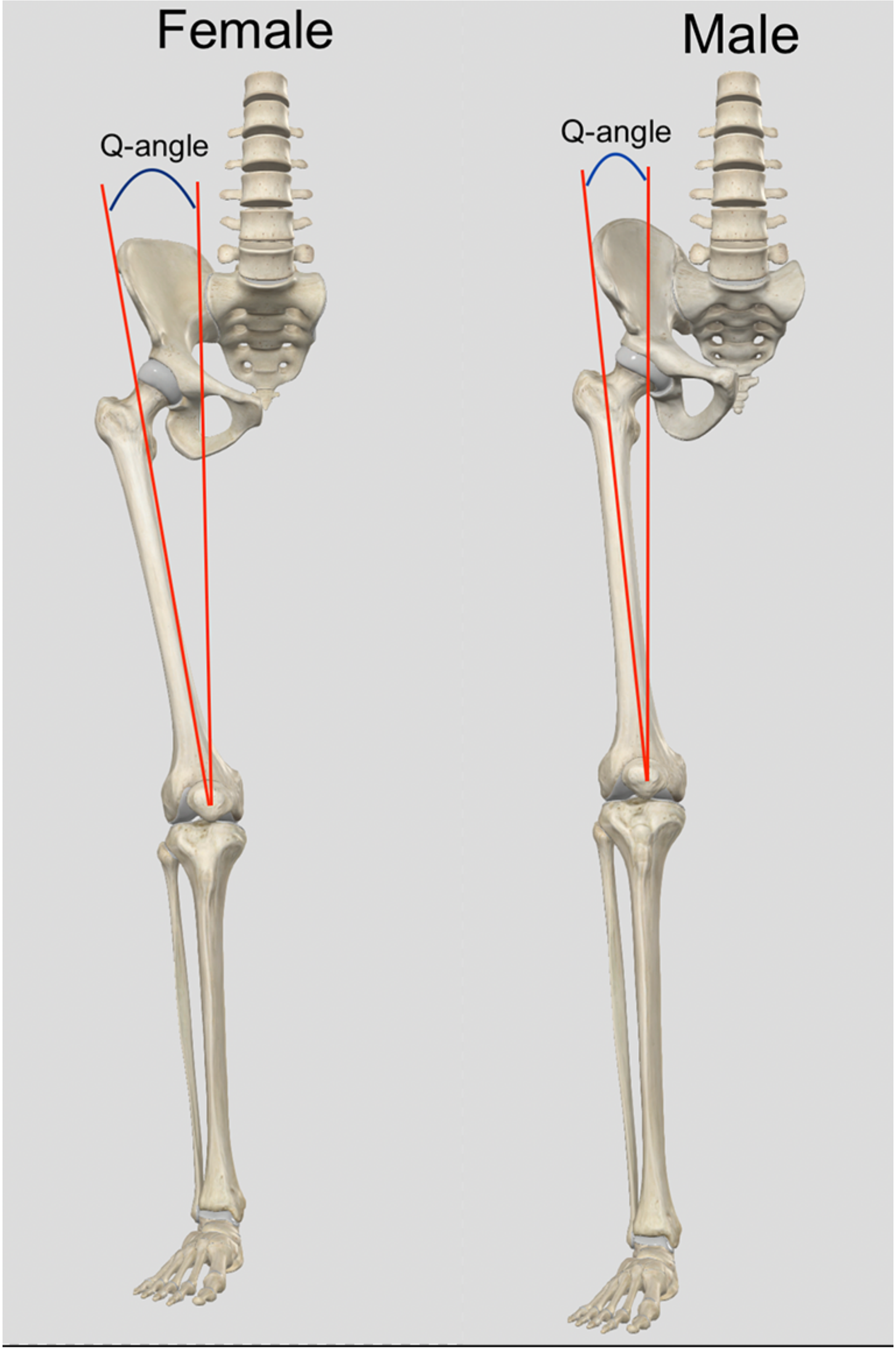

Figure 1 - Q-Angle for Female Versus Male Anatomies

There may be several contributing factors to this phenomenon and reported reasons include neuromuscular, biomechanical and strength differences (Lephart et al., 2002; Šiupšinskas et al., 2019). A large anatomical and biomechanical contributor may be the greater so-called 'Q-angle', (i.e., the line of force of the quadriceps), made by connecting a point near the Anterior Superior Iliac Spine (ASIS) to the mid-point of the patella, as shown in Figure 1. This is typically 12°-14° in males, but 15°-17° in females (Woodland & Francis, 1992). There is also the consideration of a relatively smaller ACL in females, even after adjusting for body size and weight (Anderson et al., 2001). The Q- angle in female athletes places increased demands on the joints of the lower limbs, especially the knee joint, when absorbing and regenerating forces rapidly, under load, in multiple directions and under the pressures of time and space. This, it is proposed, generates the significant and acute risk of ACL rupture.

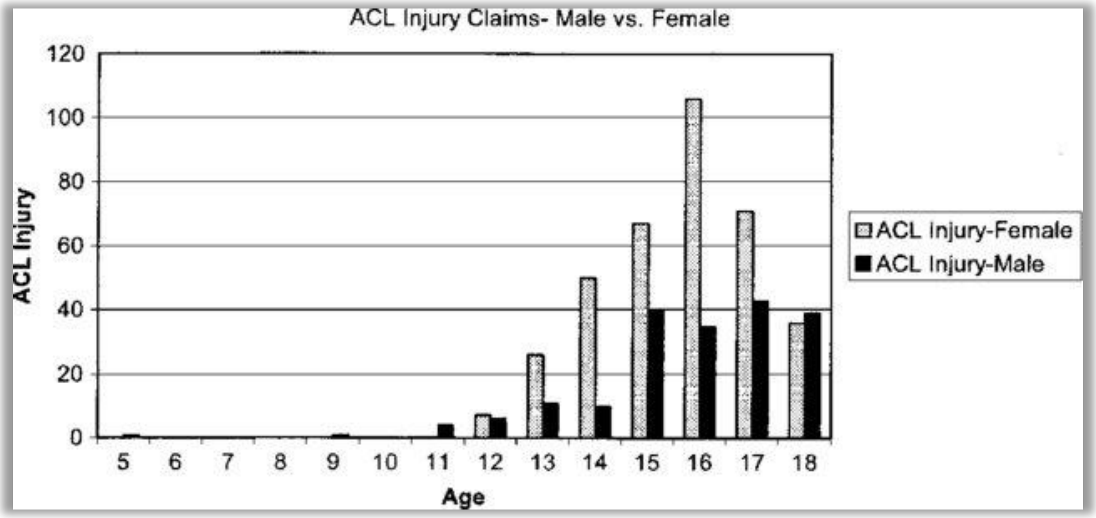

Figure 2 - ACL Injury Claims for Female versus Male Youth Soccer Athletes (Shea et al., 2004)

The number of ACL injury claims made over a five-year period (1995-1999) for youth soccer league participants in the United States, as shown in Figure 2, demonstrates a greater relative risk for adolescent female athletes (15-17 years old) over adolescent male athletes (Shea et al., 2004) with a total of 363 claims for female participants versus 190 claims for male participants between the ages of five and 18. In addition, some research shows previous injury can result in increased risk of re-injury of 30-40 times greater than for those previously uninjured (Barber- Westin & Noyes, 2020; Caine et al., 2008; Kucera et al., 2005; Meeuwisse et al., 2003; Wiggins et al., 2016). For some sports the risk of injury can also be 3.7 times higher in a game than during practise (Meeuwisse et al., 2003).

1.2 Research Purpose and Aims

The researcher, as a strength and conditioning (S&C) coach, has observed an increase in adolescent female participation of traditionally ‘male-dominated’ sports, such as soccer, rugby (League and Union), and Australian rules football. Moreover, he has also recognised many new recruits to these sports do not have experience or education in some of the fundamental training strategies that have been delivered to their male counterparts for many years. Coaches are often male, and training is comprised largely of field-based work on skills and sports-specific activity without consideration of some of the critical anatomical, physiological, and psycho-social differences for female athletes. The research within this discourse suggests female adolescents participating in competitive team sport are in a high-risk category for ACL injury and that prevention of injury in the first instance should be a priority for this demographic. The research suggesting injury risk is higher in a game than during practice, leads to the question of whether the common approach of measuring static strength and applying these measures to injury risk is sufficient. It is questionable whether it adequately accounts for the dynamic and competitive environment in which injuries occur, be they non-contact injuries in training or contact injuries during competitive games.

Structured, targeted, S&C programming is not regularly or comprehensively applied for the demographic in question and there are multiple contributing reasons for this:

- **Coaches** (of both sexes) are often still amateur. While the elite level of female sport is progressing, with access to professional strength coaches, dietitians and psychologists, the levels below that – at state, regional, school and club level – are still staffed by volunteers with little or no official education in S&C and even less education on specific considerations for adolescent female athletes;
- **Time** can be a limiting factor. Most sporting codes having only one or two training sessions per week and many participants in this age group rely on family members for transport. Compounding family commitments may therefore restrict availability;
- **Facilities** to conduct S&C exercise sessions are often unavailable or costly, providing a geographical and financial barrier for many participants; and
- **Cultural views** of participants, and in many cases, clubs and organisations, towards S&C for female athletes are still naïve and an underlying fear of excessive muscle growth pervades.

This work-based research project has been motivated by these professional but anecdotal observations, with the intention to observe to what extent a physical intervention program, designed for delivery in a workplace setting, can stimulate a specific physical adaptation that will support improved performance and mitigate injury risk for female adolescents participating in competitive Australian football.

The study will be conducted in the field of leg strength and agility performance as it pertains to injury risk within the industry context of Strength and Conditioning coaching. This research project therefore aims to specifically investigate agility performance and the relationship of leg strength-bodyweight ratios in adolescent female athletes competing in multi-planar sports, specifically in the Australian football in Queensland.

1.3 Research Questions

Some of the concerns with current injury patterns relate to long-term health and well-being and an increased risk of re-injury. For individual female adolescent athletes, this may threaten their participation, remuneration (in a professional context), and quality of life. Professionally, the costs linked to these injuries and risks of re-injury include costs of rehabilitating injured players (Garrick & Requa, 1993; Hickey, Shield, Williams, & Opar, 2014), performance risks with key players unable to play, and potential negative reflection on the integrity of sporting bodies and the welfare of their athletes.

Considering these concerns, the purpose of the present work-based research project is to examine to what extent a work-based leg strength intervention can influence leg strength-bodyweight ratio and if this demonstrates a relationship with agility performance in adolescent female athletes. If research supports the notion that improved agility can contribute to mitigation of ACL injury risk, then this may have implications for future practise. A training intervention, designed to be implemented ‘in the field’, to improve leg strength and dynamic agility performance which contributes to injury resilience, might help to address the above concerns, and provide coaches, parents/guardians, and Health and Physical Education (HPE) teachers with valuable information and a tool with which to implement the desired changes.

Focusing on adolescent female athletes in Queensland, competing in sports requiring lower-limb agility, specifically Australian football, the overarching research questions to be addressed in this study are:

> RQ1: To what extent is there an optimum leg strength-bodyweight ratio which relates to better performance in agility testing?

RQ2: Can a field-based physical intervention program be used to improve leg strength in a way that positively influences leg strength-bodyweight ratio and agility performance?

RQ3: Do changes in leg strength-bodyweight ratio and agility performance suggest a possible mitigation of non-contact lower-limb injury?[1]

Figure 3 illustrates how this project intends to approach the relationships of these physical variables, setting the context and purpose for the intervention explained in the methodology.

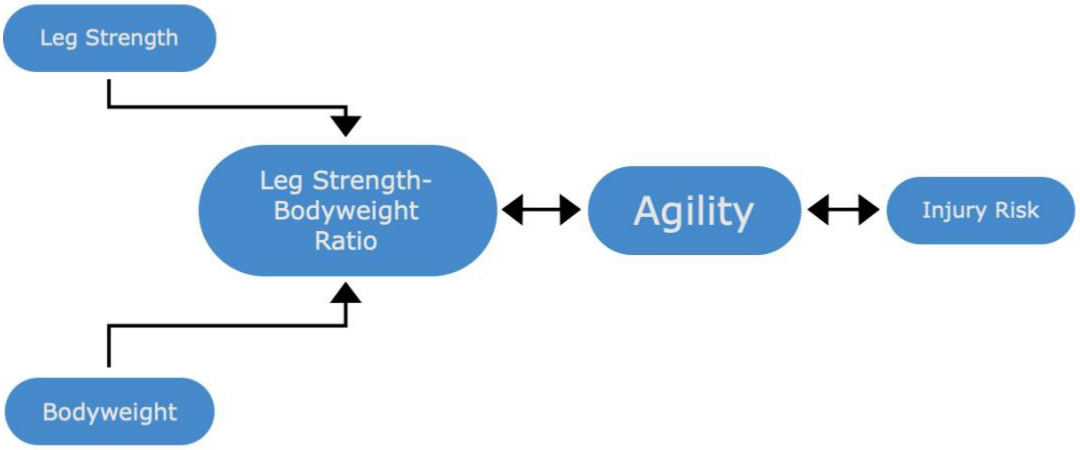

Figure 3 - Relationship between Leg Strength, Bodyweight, Agility and Injury Risk

1.4 About the Researcher

1.4.1 – Experience

I have 26 years of professional practise, stemming from a Bachelor's degree in Sport Studies from Brunel University in the United Kingdom. With continuing educational credits in widespread aspects of health

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[1] RQ3 has been modified to account for disruptions caused by COVID-19 which prevented injury data from being collected as discussed in section 3.4.6.

and fitness, and further qualifications in the specific field of strength and conditioning (specifically relating to female athletes and training),

I have embarked on the Professional Studies program with particular interest and enthusiasm.

As a practitioner, I have been engaged in many levels of the health and fitness industry both professionally and as a volunteer, including practice as:

- Gym instructor;
- Personal trainer (general population);
- Strength and conditioning coach (athletic population);
- Emerging athlete coach (squad and individual);
- Community coach (tennis and Rugby League);
- Department head;
- Business owner (fitness facility and fitness RTO); and
- Educator

1.4.2 The Professional Studies Program

"Professional studies is a personalized, self-designed and self-directed program of work-based learning (WBL) and research, which seeks to deliver 'triple dividend' contributions to professional practice knowledge, work domains and the self (i.e. the personal and professional life of the practitioner)" (Fergusson, Shallies, et al., 2019).

At it's core, Professional Studies recognises that society is changing and that the roles, needs and integrations of the workplace and higher education are also changing.

> Postgraduate education has always been important to universities for a number of reasons but primarily in the area of research and/or professional development. The emergence of

> professional doctorates presented universities with a unique challenge: how to translate the advanced practice needs of professionals into postgraduate programs. The result was mostly more advanced theoretical knowledge and case studies with a minor research component. Building on these professional degrees, a 'third-generation' postgraduate research approach has emerged focused on critical reflective practice and cognitive development enabled by research conducted in professional practice. (van der Laan & Ostini, 2018, p. 4)

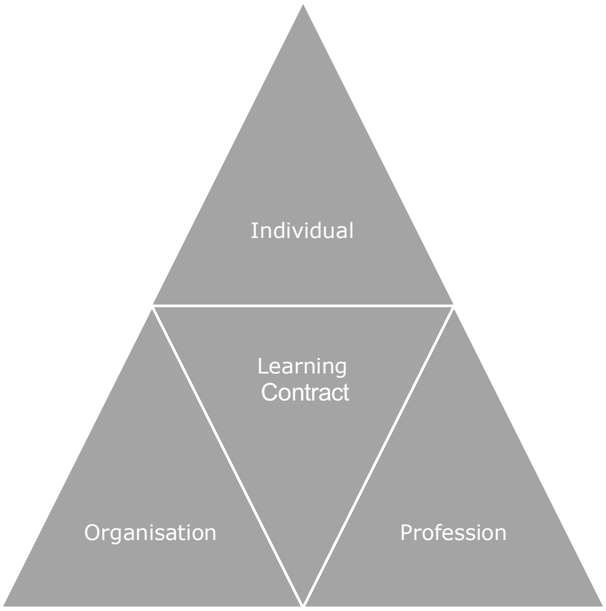


Figure 4 - The Triple Dividend of Professional Studies

Through WBL and research, it acknowledges that the workplace itself, provides an environment for learning and that that environment can provide relevant, flexible and accessible learning structures as well as the opportunity to implement learning outcomes in an environment where they can be beneficial. The 'triple dividend' of Professional Studies (Fergusson et al., 2018) expresses the relationship between individual, organisational and professional domains, and how the learning contract benefits all three entities, as illustrated in Figure 4.

The individual will benefit personally by developing the areas highlighted in the learning objectives and professionally through an improved skill set which can be applied in the workplace. The organisation will benefit through the identification of data which can materially shape workplace practises and directly through access to a more skilled and experienced practitioner to help implement the identified changes. The project will contribute to the profession by undertaking research not yet conducted and so will have another reference when considering the training protocols and workplace practises with particular emphasis on their implementation as a tool specifically designed to be used in the workplace.

As a practitioner, I have attended dozens of professional conferences, delivered thousands of hours of physical training and taught hundreds of students in formal industry education. Across these realms, I have often found a disparity between what the research says can be achieved, versus the practical application of the research and what the athlete or student can absorb and utilise in the real-world workplace. Much of the research can only be applied sparingly or in principle because of the inconsistency, interruption, and changeable environment of the professional. The Professional Studies program provides an opportunity to allow for, even embrace, these challenges and to use experience to identify a problem, learn how to address it through reflective practise and critical thinking, and design and implement a potential solution.

As a process of identifying, and to some extent quantifying, the value of experience and how to use that to apply structured learning, the practitioner can engage in the process of reflective practise. By looking back at past experience and placing it in the current workplace, it is easier to see how current practise can be improved to create a more effective and efficient work environment. I feel that the integration of my knowledge and experience in the field, combined with the process of research into the profession through an academic lens can make a significant contribution to professional practise and the professional studies program.

The use of the Curriculum Vitae (CV) Tool (van der Laan, 2017) to reflect on my own prior learning and professional practice, suggests that I embody high professional and industry knowledge, cultural intelligence, and communication skills. In context, these are the skills required to excel in the actual workplace. It also reveals areas, such as the fields of systemised information gathering, objective judgement, work methods and process logic, as well as technology adoption, where further learning would be beneficial. Placing this into context reflects the way in which the skills necessary to complete the day-to-day requirements of the job often suppress the requirements and application of the very skills that were studied and valued so highly when entering the profession as a novice practitioner. This aligns closely with the observations of the Australian Industry and Skills Committee, as noted by Fergusson et al. (2020) reflecting on the changing type and nature of work. The learning objectives, then will be grounded in;

- systemised information gathering
- application of objective, as opposed to solely intuitive, judgement
- applying defined work methods and process logic to address an identified problem
- identifying if, where and how, technology can be adopted to improve workplace practise

I believe this variety of roles and longevity of service presents the opportunity to view WBL through a unique, informed and experienced lens, which can benefit the individual, the organisation and the profession, thus fulfilling the 'triple dividend' associated with the Professional Studies program (Fergusson et al., 2018).

CHAPTER 2: LITERATURE REVIEW

The subject of human movement is diverse and complex. When considering dynamic movement under physical stress, there are many contributing factors. Cognitive skill, load, strength, stability, flexibility, power, expertise, experience, age of the athlete, and training versus competition represent areas which can affect performance levels and injury risk. For this work-based project, it has been necessary to narrow the focus of the research to determine to what extent a particular physical relationship (leg strength-bodyweight ratio), can influence a particular performance outcome (agility performance test), in a specific demographic (competitive, adolescent female athletes aged 15- 17 years old, playing AFL). The broader themes of research therefore relate to female versus male lower-limb injury risk discrepancies; adolescent population; lower-limb injury risk and mechanics; leg strength and bodyweight; and agility and performance.

The literature review will position the research in the context of relevant literature and will aim to critically examine and highlight the gaps in the research within this discourse that warrant further investigation in exploring leg strength-bodyweight ratios in relation to agility scores and use of this as a contributing factor for injury resilience in adolescent female athletes.

2.1 Female Versus Male

2.1.1 Injury Risk Discrepancies

The risk of lower limb injury is significantly higher for female athletes than it is for their male counterparts (Arendt et al., 1999; Chandy & Grana, 1985; Ford et al., 2003; Hewett et al., 2005; Mandelbaum et al., 2005; Myer et al., 2005; Powell & Barber-Foss, 2000; Zazulak et al., 2007). Despite this being common knowledge within the profession and academically for several decades (DeHaven & Lintner, 1986) the rise in competitive female participation and professionalism has thrown a sharp focus on the need to find a way to mitigate the risk of injury. In 2016, the AFL launched a female professional league and summary of participation data from their website showed an increase in female participation of 19% compared to the previous year, and a 56% increase in female community club teams (AFL, 2016). The 2019 AFLW injury report shows that the ACL injury incidence per 1000 player hours in 2018 was 6.47, compared to 1.11 per 1000 player hours in the AFL (AFLW, 2019). A meta-analysis of 10 articles by Gornitzky et al. (2016), including 700 ACL injuries in 11,239,029 exposures found that although high school boys had a higher overall volume of ACL tears, the rate per athletic exposure was "approximately 1.6-fold greater…in high school females than in males" (p.2716) and that girls soccer had the highest injury rate at 1.11%, compared to a rate of only 0.30% for boys soccer. The highest recorded injury rate for boys, in American Football, was also lower at 0.80%.

A factor that appears regularly in research is the consideration of the female propensity for a quadricep-dominant muscular recruitment pattern, particularly in post-pubertal girls (Ahmad et al., 2006). This dominance has the effect of reducing knee flexion on landing, reducing energy absorption and pulling the tibia forwards in the knee joint without concomitant recruitment of the hamstrings which places excessive strain on the ACL (Pollard et al., 2010).

A study on knee joint motion patterns in male athletes and female athletes in selected athletic tasks, notably running, side-cutting and cross cutting, showed that "alternated knee motion patterns of women tend to increase the load on the anterior cruciate ligament" (Malinzak et al., 2001, p. 438). More recent research by Romanchuk et al. (2020)

using kinematic technology to research and evaluate whole body biomechanics and lower limb energy absorption during landing, concludes that in adolescent females, "the greater reliance on distal joints indicates a less effective force absorption strategy and may increase the risk for sustaining a non-contact ACL injury" (p. 110064). A study on a single-leg landing in badminton whilst backstepping with a concurrent overhead strike (Tseng et al., 2021) is of particular interest for AFL since this is a movement pattern closely associated with catching the ball overhead, often moving backwards in the process. Consistent with other research, results showed increased knee valgus in females over males and that concomitant kinematic and kinetic changes at the hip, knee and ankle joints played a role in the higher incidence of ACL injuries in female athletes.

While providing an insight into movement patterns closely related to AFL, these studies do not speak directly to contact sports an uneven landing surfaces. They also do not offer conclusions on leg strength-bodyweight ratios.

A narrative review on these sex differences supports the broader narrative found in the research and concludes that despite the volume of research available, there is still a relative lack of information pertaining to female adolescents, their lower limb muscle activation patterns and preventative intervention strategies (Bencke et al., 2018) – some of which this project aims to address.

2.1.2 – Menstrual cycle

An area of recent research, almost certainly as a direct result of the increase in participation and professionalisation of female sport, is the menstrual cycle. Hormonal fluctuations may influence a female's response to a training stimulus and by extension have implications for performance on any given day and for injury risk (Chidi-Ogbolu & Baar, 2019).

In relation to performance, some research (Borkar & Borkar, 2022; Igonin et al., 2022; Julian et al., 2021; Kami et al., 2017) suggests that physical performance, in particular functional performance associated with speed, stability, strength and power, may be impaired in the menstrual phase of the cycle, with the implication that training for these activities may be most effective in the luteal phase of the cycle. A study on 1RM, however, finds no significant difference during the cycle (García-Pinillos et al., 2022) and other research suggests that the anabolic properties of estrogen may mean the follicular phase is more suited to resistance training than the luteal phase (Kissow et al., 2022). Indeed, a systematic review into the effects of the menstrual cycle on elite athlete performance concludes that although the hormonal fluctuations of the cycle may affect sports performance, the parameters, magnitude and direction are largely inconclusive (Meignié et al., 2021).

As it pertains to injury, and in particular ACL injuries, several reviews and meta-analyses have found that the pre-ovulatory phase is highly correlated with the suggestion that laxity in the joints is a contributing factor (Herzberg et al., 2017; Hewett et al., 2007). There are others that show joint laxity is not a significant contributor in ACL injury (Somerson et al., 2019).

It is important to mention that this research is still in relative infancy and while contributions are increasing the body of knowledge, there is much variation in methodology and subject selection. It is also interesting to see a note of caution flagged that correlation between menstruation and joints should not be misconstrued as causation (Legerlotz & Nobis, 2022). In consideration of these factors and the placement of this project in the workplace, it is the opinion of the researcher that coaches should themselves be aware, and perhaps make their athletes aware, of the potential influences that a menstrual cycle may have on performance and training factors. However, in terms of practical application, it would be impractical in a team scenario to make considerations for every athlete in this regard, except perhaps at the most elite level where resources and expertise may allow for it.

2.1.3 – Social and cultural influences

There are social and cultural preconceptions about not only what women could *not* do or be in relation to sport but also what they *should* be in society. Media has driven the popular and acceptable form of women for centuries, and historically the drive has been an aesthetic appreciation of form rather than function.

It is at this point that cultural perceptions and performance requirements collide. Whilst physical attributes relating to female anatomy and physiology are testable and measurable in isolation, part of the reason that there has been (relatively) so little research in this area to date, can be traced to social and cultural factors surrounding female athletes and participation in organised, competitive sport.

The first modern Olympic games did not include women. It's founder, Baron Pierre de Coubertin, was vociferous until his death (in 1937), about his opposition to women's participation, saying "women's sport was against the laws of nature" and "the most unaesthetic sight human eyes could contemplate" (Simri, 1979, p.12-13 in Hargreaves, 1994, p. 209)

Female participation began at the Games in 1900 with only 2.2% (twenty-two) female competitors. That figure rose to 20% at the Winter Olympic Games in Squaw Valley, United States in 1960 and was at 45% for the Olympic Games in Rio de Janeiro, Brazil in 2016.

It was only in 1991 that the IOC stipulated that "any new sport seeking to be included on the Olympic program had to include women's events" (IOC, 2021). The release in September 2019 of the film 'Ride Like a Girl', based on the story of Michelle Payne becoming the first female jockey to win the Melbourne Cup in 2015 demonstrates that it is still new, unusual, and newsworthy when women succeed in professional sport.

When participation in a sport requires a specific physical training program to improve performance and reduce injury risk, but the content and demands of that program conflict with what is culturally and socially driven for an aesthetic ideology, there will always be resistance to adherence. The demographic of this project as adolescent female athletes will be under particular pressure and scrutiny by their peers.

Resistance training can be defined as "a specialised method of conditioning whereby an individual is working against a wide range of resistive loads to enhance health, fitness and performance" (Haff & Triplett, 2015b, p. 139) typically involves conditioning the skeletal muscles and nervous system by creating conditions where it cannot complete a specific task and must adapt to meet the new demands placed upon them. This very scientific definition places resistance training in a less intimidating framework, yet it is still often misunderstood and misrepresented to those who are not directly involved and as such, convincing an adolescent female that resistance training will not result in a powerlifters physique can raise barriers.

Even more challenging might be notion that a powerlifters physique should be admired because of the hard work and dedication committed. This sits in opposition to a body shape that does not meet the media-fuelled definition of aesthetic beauty. Research into barriers to resistance training amongst college-aged women, seeking to identify what the barriers might be, and how they differed between those currently involved in resistance training, and those who are not (Peters et al., 2019), reports that three out of the top four barriers are based around social factors. Those such as feeling uncomfortable in the environment, worry about how others will view them and not wanting to look big and bulky. In all categories, however, those currently undertaking resistance training have lower agreement scores compared to those who are not, leading to the conclusion that education might be important in preventing females who engage in resistance training from feeling like they are "violating gender expectations" (p. 6).

Furthermore, because the demographic is adolescent, the influence of the responsible adults in their life must also be considered and informed of the actual versus the perceived notion of female athletes in sport and the physical preparation for those sports at the highest level. As the dialogue around aesthetics versus functional physique continues to expand and it is hoped that a greater body of research to support evidence that function (which is defined by the activity) does not necessarily compromise aesthetics (which is defined by the individual and the associated societal and cultural influences), will encourage more females participating in athletic activity will consider the benefits of structured and targeted fitness programs to prevent injury. This project seeks to address some of these concerns by conducting the research in the more social context of squad training and in the more familiar environment of the home training venue. Already at risk as a female, research also demonstrates that adolescents are in a higher risk category.

2.2 Adolescent Population

As early as 1978, Jackson et al. (1978) identified that "reducing potentially disabling injuries among young athletes is a compelling stimulus to identify and possibly control the responsible factors" (p. 6). A systematic literature review by Emery (2003) identified that a lack of pre-season training was an important risk factor for injury in child and adolescent sport, although with sporting seasons crossing over, finding time for a dedicated pre-season is becoming increasingly difficult. A 2008 study entitled "Epidemiology of Injury in Child and Adolescent Sports: Injury Rates, Risk Factors, and Prevention" surmised that there was:

> evidence that periods of rapid growth, poor coaching, poor dynamic balance, and previous injury are associated with an increased risk for injury… There is evidence supporting the use of injury prevention strategies in children and adolescents that includes preseason conditioning, functional training, education, and strength and balance programs that are continued throughout the playing season. (Caine et al., 2008, p. 45)

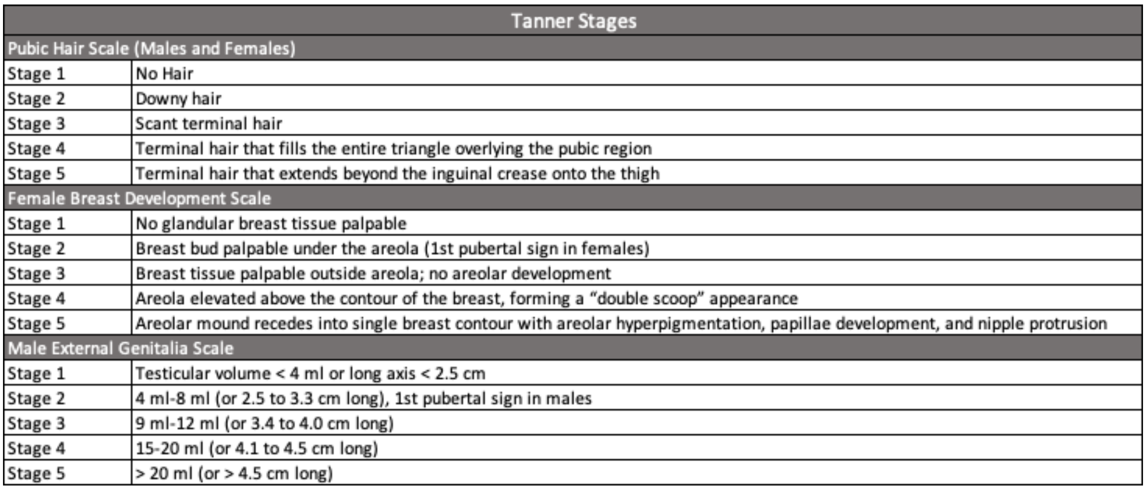
In 2007 (updated 2017), recognising the special requirements of resistance training in the younger population, the Australian Strength and Conditioning Association (ASCA) issued a position stand, to address the more general information that had previously been issued on the subject (ASCA, 2017). In it they discuss and detail methods and modalities of appropriate styles of resistance training for different age groups, separating them into 'levels' (ASCA, 2017, p. 9):

- Level 1: 6-9 years of age
- Level 2: 9-12 years of age
- Level 3: 12-15 years of age
- Level 4: 15-18 years of age

The document distinguishes between male and female with regards to nutritional requirements and for testing protocols and categories but does not make distinction for training considerations, even in the 12-15 and 15-18 years categories, where pubertal development might be expected to have an effect. It is noted that the overlap of ages from one group to the next “reflects the fact that different children will mature at different rates and thus may well progress at various times” (p. 9).

Seminal papers detailed the differing pubertal patterns of boys and girls (Marshall & Tanner, 1969, 1970) and from this, scales were developed (Table 1) (also known as Tanner Stages or Sexual Maturity Rating – SMR), which are used by clinicians around the world to ensure that they account for biological as well as chronological age differences in children.

Table 1 - The Tanner Stages of Development



Tanner Stages	
Pubic Hair Scale (Males and Females)	
Stage 1	No Hair
Stage 2	Downy hair
Stage 3	Scant terminal hair
Stage 4	Terminal hair that fills the entire triangle overlying the pubic region
Stage 5	Terminal hair that extends beyond the inguinal crease onto the thigh
Female Breast Development Scale	
Stage 1	No glandular breast tissue palpable
Stage 2	Breast bud palpable under the areola (1st pubertal sign in females)
Stage 3	Breast tissue palpable outside areola; no areolar development
Stage 4	Areola elevated above the contour of the breast, forming a “double scoop” appearance
Stage 5	Areolar mound recedes into single breast contour with areolar hyperpigmentation, papillae development, and nipple protrusion
Male External Genitalia Scale	
Stage 1	Testicular volume < 4 ml or long axis < 2.5 cm
Stage 2	4 ml-8 ml (or 2.5 to 3.3 cm long), 1st pubertal sign in males
Stage 3	9 ml-12 ml (or 3.4 to 4.0 cm long)
Stage 4	15-20 ml (or 4.1 to 4.5 cm long)
Stage 5	> 20 ml (or > 4.5 cm long)

The rate of growth changes mean hormonal and physical differences between two subjects of the same chronological age can vary enormously and some research has correlated higher injury rates with higher Tanner Stages (Linder et al., 1995). Furthermore, Matava et al. (2022) report that concomitant injuries of cartilage damage and meniscal tears in children who suffered ACL injuries are higher in those with a higher Tanner stage and that for each additional Tanner stage, the odds increase by 1.6 (cartilage damage) and 1.3 (meniscal tear). Granados et al. (2015) researched peak height velocity (PHV - which identifies the rate of growth) and Tanner staging, reporting that the majority of girls (69.1%) had reached PHV by Tanner stage 3, whereas the majority of boys (58.9%) did not reach PHV until Tanner stage 4. Mean age for PHV in girls was 9.8cm per year at 12.1 (±1.4) years and 11.3cm/year at 13.7 (±1.4) years for boys. This is important because PHV has been associated with increased injury risk (Steidl- Müller et al., 2020) and increased injury rates have been found in similar age groups (Le Gall et al., 2006). Other research shows higher risk in a six month period after the PHV (Bult et al., 2018) and a three- year study on soccer players who differ in the timing of their peak height velocity by Van Der Sluis et al. (2014) found that "talented soccer players maturing at an older age experience significantly more overuse injuries than their earlier maturing counterparts, both before PHV and during PHV" (p.355).

A study on high school basketball players by Plisky et al. (2006) using the Star Excursion Balance Test (a well-established and validated as a predictive tool for lower limb injury (Gribble et al., 2012)), reported:

> that players with an anterior right/left reach distance difference greater than 4 cm were 2.5 times more likely to sustain a lower extremity injury. Girls with a composite reach distance less than 94% of their limb length were 6.5 times more likely to have a lower extremity injury (p. 911).

This both highlights the importance of accounting for growth rates and biological ages, as well as complicates the application of this consideration. It would be impractical and unethical for fitness trainers, strength and conditioning coaches or sports coaches to be assessing children using the Tanner stages, but a broad concept of what it is and how it might affect the children they are responsible for might help in the consideration of appropriate exercise prescription.

A study titled "The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a meta-analysis" (Myer, 2013) noted that, when compared to boys, "there has not been significant evidence of this sex difference in injury incidence or altered biomechanics in prepubertal female athletes, but only post pubertal female athletes" (p. 3) and concluded that neuromuscular training was most effective in reducing injury risk for female athletes in the mid-to-late teens.

Thus, the combination of biological age and sex places the female adolescent athlete in a very high category of risk, exacerbated by pressures associated with competitive and professional potential.

2.3 Lower Limb Injury

2.3.1 Definition

Defining 'injury' can be one of the more contentious considerations, but in the case of ACL injury and its relation to sport, it is sensible to use the paradigm that injury causes loss of match time (Lai et al., 2018; Lathlean et al., 2018; Orchard & Hoskins, 2007; Orchard et al., 2013; Saw et al., 2018). A study on AFL injuries that spanned 19 years, between 1997-2016, identified that compared to training injuries, the risk of match injuries was significantly higher with a 2.8 times higher incidence per season, per club, per player and that match injuries resulted in 1.9 times more missed matches (Hoffman et al., 2019). The 2019 AFLW injury report also shows that 67% of ACL injuries are sustained during a match and 33% during training (AFLW, 2019). Reporting on the elite junior game, Lathlean et al. (2018), reports 50.9% of injuries originate from contact, 26.0% from non-contact and 23.1% from overuse. Of all the injuries, the majority (60.4%) come from the lower limb with 11.7% occurring at the knee. Furthermore, it is found that the severity of the injuries is increasing over time (Lathlean et al., 2018).

2.3.2 Mechanism of ACL injury

One way of describing the fundamental roles of the joints of the body is the joint-by-joint approach. In his book 'Advances in Functional Training' Boyle (2010), mentions a conversation he had with a physical therapist colleague, Gray Cook, and noted "In his mind, the body is just a stack of joints. Each joint or series of joints has a specific function and is prone to predictable levels of dysfunction. As a result, each joint has particular training needs" (p. 549). Figure 5 illustrates the concept, which has applications for much of the research surrounding the mechanisms behind lower limb (and specifically ACL), injury.

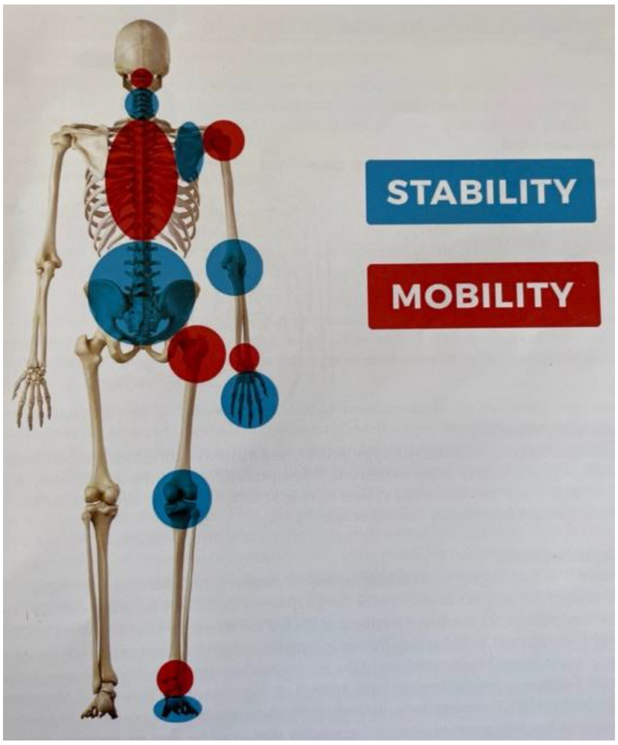


Figure 5 – Joint-by-Joint concept (Cook 2018)

The natural movement of the knee, operating as ‘stable’ joint, is to hinge so the joint either flexes (bends) or extends (straightens), but does not allow rotation until there is 20-30 degrees of flexion. Figure 6 shows the structure of the knee joint and the location of the ACL to help illustrate the position and relative size of the supporting structures. The cruciate ligaments are fibrous tissue structures, serving to keep the joint aligned and stable during movement and the ACL prevents the femur from sliding backwards on the tibia to keep the knee from hyperextending. The knee joint is the most stable when it is in the extended position and under no load because the medial and lateral collateral ligaments are tight, rotational forces placed upon it are absorbed by the more mobile joints of the ankle (below) or the hip (above) and there is no lever to provide stress or shear force through the joint. In his research, Boden (2000), noted that ACL injury seemed to be more highly correlated to situations where the knee is extended and the athlete is landing unilaterally, particularly noting mechanical observations of unanticipated single leg landing tasks

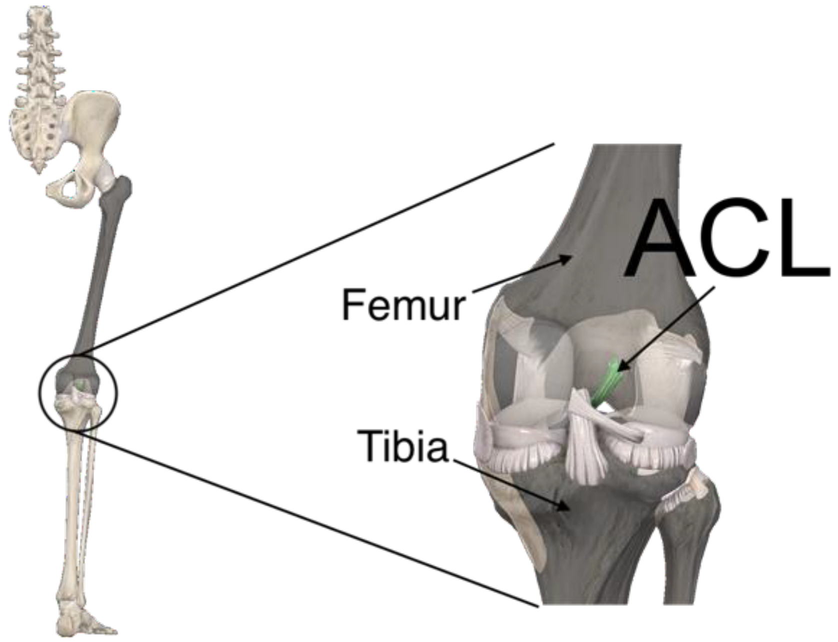


Figure 6 - Structure of the Knee and Position of the ACL

suggesting that the peripheral and central processing mechanisms were severely degraded compared to anticipated single leg landing tasks. This indicates that elements of experience (i.e., learning to land with an appropriate amount of flex in the knee) and control of the joint upon landing (leg strength and neuromuscular control) might help in stabilising the knee joint and in mitigating injury risk (Koga et al., 2010). When the knee is flexed, the angle created at the joint exposes the support structures to mechanical stress because of the lever effect of the long bones in the upper and lower leg. If we apply downward force onto the bent knee (such as when landing after a jump, as shown in Figure 7), when the strength and neuromuscular control is poor, the joint is at risk of excessive dynamic valgus (Figure 8), where the knee collapses medially (inwards).

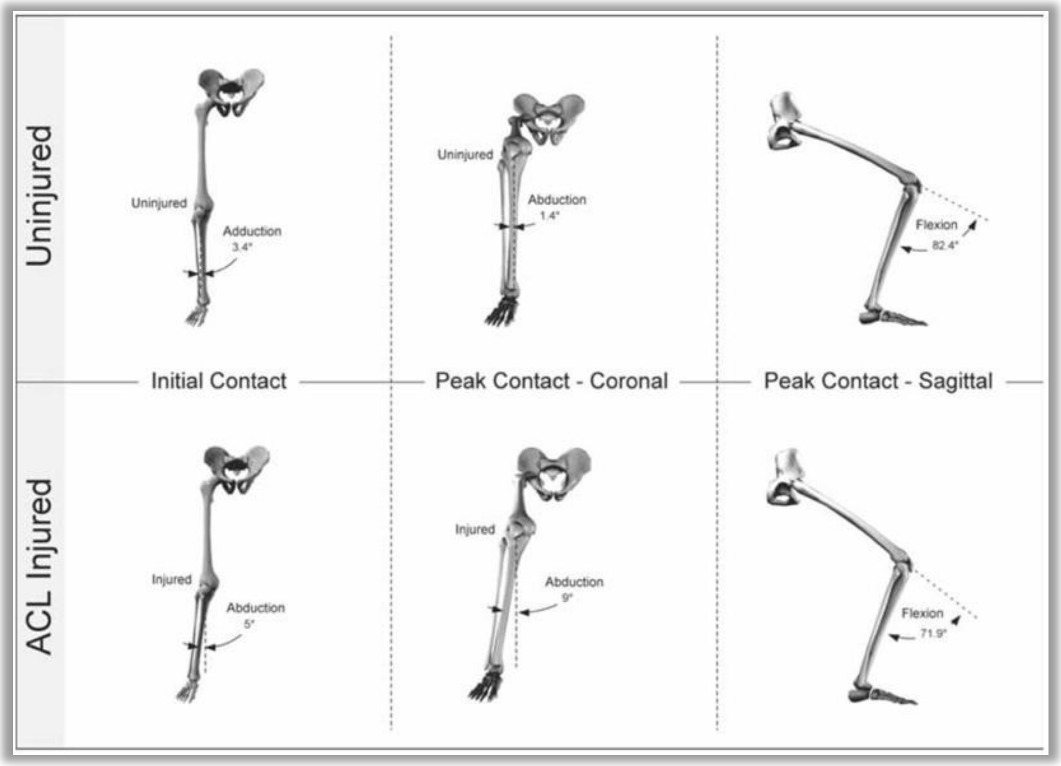


Figure 7 - Mechanics of Knee Angles When Landing for Injured versus Uninjured ACL

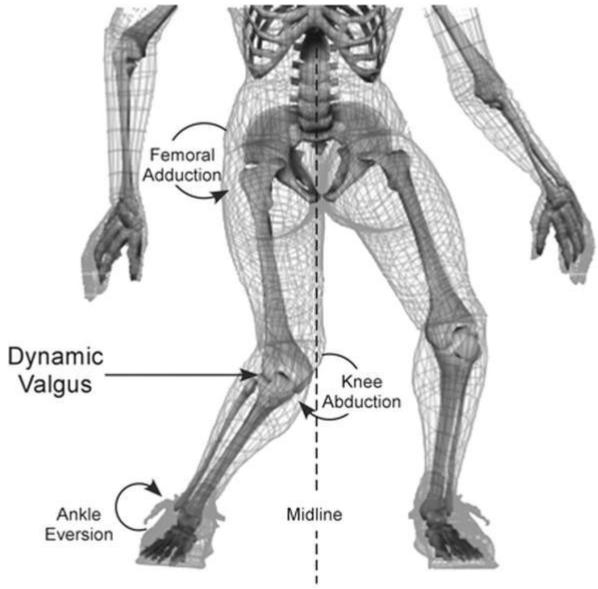


Figure 8 - Anatomical Contributions to Dynamic Valgus

If the foot is anchored and rotational stress is added (such as when changing direction suddenly and at speed – Figure 9), then the ACL is exposed to severe mechanical stress and at high risk of rupture.

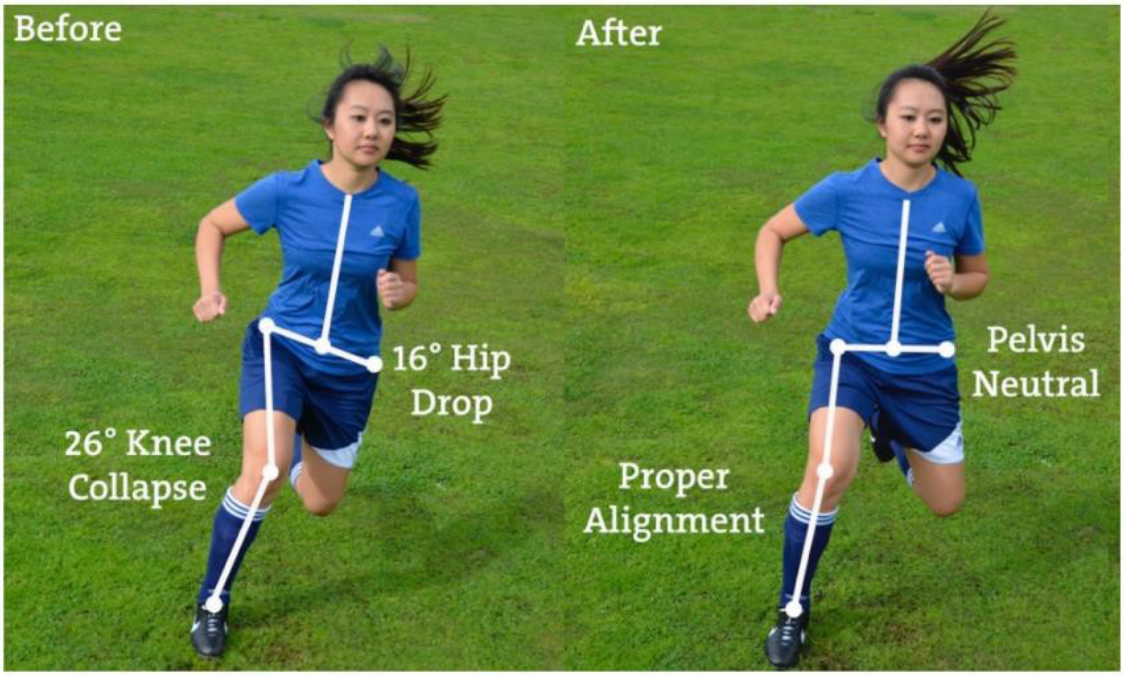


Figure 9 - High Risk versus Low Risk Change of Direction

2.3.3 Risk factors for injury

Lower limb injury risk is greater in sports that contain this element of unpredictability and reactivity to external factors such as opponents and/or objects. In a paper reporting on ACL reconstructions performed in Australia from 2003-2008, Janssen et al. (2012) reported that the highest incidence of ACL rupture came from skiing. Considering the joint-by-joint model and the mechanics of injury as described above, it is logical that the loss of the mobility at the ankle joint (caused by the ski boot), combined with the speed and load placed through a flexed knee joint and additional lever forces applied by the length of the skis themselves, creates an extremely high-risk environment for ACL rupture. Aside from skiing, though, AFL, rugby, netball, and soccer showed the highest incidence of ACL reconstruction. A systematic review, meta-analysis and best evidence synthesis in 2021 concluded that prior injury, older age, greater body mass and greater Body Mass Index (BMI) are risk factors for lower limb injury in female athletes, whilst there was limited evidence for agility (Collings et al., 2021). None of these papers, however, investigated leg strength-bodyweight ratio. in respect to these markers.

Biomechanical abnormalities have been heavily researched and has shown, "limitation of range of ankle dorsiflexion, limitation of range of hip eversion, excessive joint laxity, leg length discrepancy, an excessively supinated or pronated foot, excessively high or low arches of the foot and a large Q-angle are risk factors for injury" (Neely, 1998, p. 395). Other research considered the effect of fatigue and unpredictability (Borotikar et al., 2008) while others have concluded that an imbalance of thigh muscle strength is predictive of hamstring injury (Cameron et al., 2003). With respect to AFL, the study by Cameron et al. (2003) investigating motor control as a possible contributing factor in hamstring injuries, concluded that "both a lower

MD (leg swing movement discrimination) ability score for the backward swinging leg and an imbalance of thigh muscle strength were predictive of hamstring injury” (p. 159). This demonstrated a ratio-relationship across muscle groups but not a gross relationship with overall bodyweight. A meta-analysis by Kim et al. (2016) noted:

> both the quadriceps and hamstring muscles lose strength in limbs with ACL tears. The loss of quadriceps strength was approximately three-fold greater than the loss of hamstring strength. The uneven reductions in the strengths of these thigh muscles resulted in a slight increase in hamstring-quadricep (HQ) ratio in ACL deficient knees. (p. 11)

Other research supported the notion that strength differences between muscle groups contribute to lower limb injuries and reported:

> hip adduction strength was 18% lower in players who subsequently sustained an adductor injury compared with that of uninjured players. Moreover, a player was 17 times more likely to sustain an adductor strain if his adductor strength was less than 80% of his abductor strength (Tyler et al., 2001, p. 127).

Tyler and colleagues (2001) found that flexibility was not significant (in relation to injury risk), and while they recorded mean age, height, and weight of the participants, they did not report on or identify a strength-bodyweight ratio. A review of eight studies (Hrysomallis, 2009) across different sports relating to hip adductors’ strength, flexibility and injury risk, found that different sports demonstrated different relationships between muscle strength, imbalance and injury type and risk. This illustrates that the demands of any given sport represent their own unique parameters and it is not surprising, that there is evidence that neuromuscular training can reduce biomechanical injury risk (Hewett et al., 2005).

Beyond the immediate stresses of time away from the sport and the potential financial implications, there is the consideration of recovery, future performance, and risk of reinjury to contend with. Many children return to sport after ACL injury, but research shows that this can be associated with higher risks of re-injury or injury to the contralateral limb (Kay et al., 2018; Webster & Feller, 2016). If recovery was complete and did not affect these factors, then the conversation, research and application of evidence might provide a different landscape. The focus might lean more towards rehabilitation and return-to-play rather than prevention. Brockett et al. (2004) tested peak torque angles during eccentric loading of athletes with a previous history of unilateral hamstrings injuries, comparing the previously injured leg against the non-injured leg and against other athletes with no history of injury in either leg. Brockett and colleagues (2004) concluded that "The shorter optimum of previously injured muscles makes them more prone to damage from eccentric exercise than uninjured muscles and this may account for the high reinjure rate" (p. 379). In one study, return-to-play figures for athletes after initial ACL injury is recorded as 77%, the reinjury rate to either knee is recorded as 30% and is especially high in players 21 years and younger, at 50% (Lai et al., 2018). Webster and Feller (2016) also found that there was a higher subsequent ACL injury rate in those who underwent surgery when they were younger than 18 years compared to those in an 18-19-year group. While the quality of the rehabilitation and recovery protocol will always influence the future quality of performance, it remains likely that previous injury is a significant risk factor for future injury. To that end, there is much to suggest that an intervention which helps in the prevention of injury should be a consideration in any training program.

Collectively, these research findings highlight the many variables which can contribute to injury risk. However, despite demonstrating some biomechanical and physiological variables associated with injury, these do not directly factor in leg strength-bodyweight ratio.

2.4 Leg Strength and Body Weight

2.4.1 Definition and Context

In the Strength and Conditioning (S&C) industry, ‘strength’ is a broad term and needs more clarity in relation to its application. For the purpose of this work-based research, strength is considered in the context of three main categories:

1. Absolute strength - maximum load a person can lift once (1RM);
2. Relative strength - 1RM expressed as an index in relation to bodyweight;
   weight lifted ÷ bodyweight = Relative Strength Index (RSI)
   For example, an 80kg person lifting 80kg would have an RSI of 1.0 whereas a 60kg person lifting the same weight would have an RSI of 1.3; and
3. Endurance strength – sometimes called muscular endurance, where strength is represented by the number of repetitions completed up to muscular fatigue.

Strength testing can be separated into static and dynamic strength, where static is measured as force applied against a non-moving resistance and dynamic where there is movement of body parts against a resistance (Brzycki, 1993). This is echoed in the book Advanced Fitness Assessment & Exercise Prescription which states:

> strength is defined as the ability of a muscle group to develop maximal contractile force against a resistance in a single contraction…. Maximal force is produced when the limb is not rotating. As the speed of the joint rotation increases, the muscular force decreases. Thus, strength for *dynamic*

> movements is defined as the maximum force generated in a single contraction at a specified velocity. Muscular endurance is the ability of a muscle group to exert submaximal force for extended periods (Heyward, 1997, p. 105).

More recently, in Essentials of Strength and Conditioning (Haff & Triplett, 2015a) it is noted that "though it is widely accepted that strength is the ability to exert force there is considerable disagreement as to how strength should be measured" (p. 25). This demonstrates advances in the thinking and application of testing whereby the body of research is becoming more diverse and specific, using more sophisticated and specific tools and techniques to be more accurate about what and how they are testing and measuring strength and conditioning.

Despite discussion about the methods for strength testing and their application for training, performance and injury considerations, there are fundamental constants that can be agreed to. In some way, 'maximal force' and 'single repetition' have been consistently used as benchmarks and are referred to as the 'one rep max', denoted commonly as '1RM'. It has implications for the selection of exercise protocols in resistance training because the external force on a muscle and the number or repetitions that can be performed against that force determine the muscular adaptation. This is a fundamental principle in S&C. It is impossible, because of the confounding factors associated with human anatomy, physiology, and psychology, to be exact about the amount of work (e.g., the number of sets and repetitions) required to stimulate a specific response, but Figure 10 shows the widely accepted ranges for different muscular adaptations.

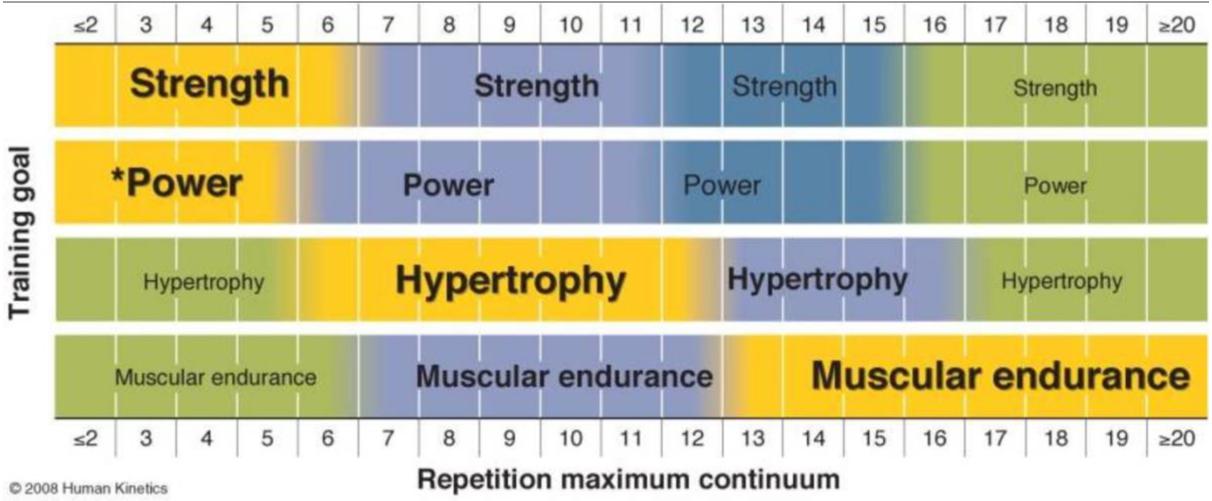


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Figure 10 - Repetition Max Continuum

Adaptations at the absolute and relative-strength ends of the continuum rely on lower repetitions and heavier loads to stimulate a nervous system response which recruits more muscle fibres, essentially making the existing structure more efficient. This is compared to hypertrophy, which is designed to stimulate increases in the size and number of muscle fibres, which will result in increased strength because of greater capacity. The significant limitation of 1RM testing for strength is that the necessarily extreme stress it places on the musculoskeletal system is often too great to be considered safe for certain demographics.

A study conducting maximal strength testing in children (mean age 9.3 ± 1.6 years), found that testing was safe with no reported injury or soreness, but noted “the findings from this study may not be applicable to children with disease, adolescents, or to cases where strength tests are administered by inexperienced teachers, coaches, or health care providers” (Faigenbaum et al., 2003, p. 164). Since the demographic in this project are adolescents, 1RM testing has been deemed inappropriate. With respect to adolescent female athletes, it might also be an intimidating approach considering the social and cultural elements described in section 2.1.3.

Furthermore, in a review on Youth Resistance Training, Faigenbaum et al. (2013) noted that “The available data indicate that training-induced strength gains in children are primarily related to neural adaptations (e.g., a trend toward increased intra- and intermuscular coordination) and possibly intrinsic muscle adaptations rather than hypertrophic factors” (p. 594). Figure 11 shows how the different contributing performance factors consolidate around adolescence and highlights how important neuromuscular conditioning is (particularly in pre-adolescence), in the mature performance potential.

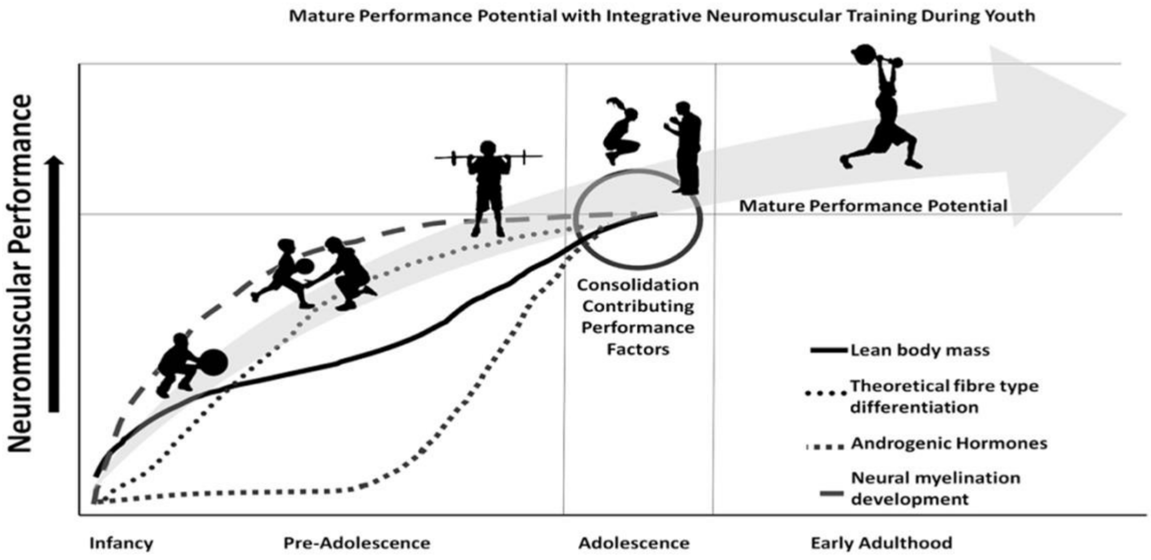


Figure 11 - Interactive Model for the Integration of Factors Related to the Potential for Muscle Strength Adaptations and Training Induced Performance Gains During Preadolescence, Adolescence and Early Adulthood

Finally, since the application of the research in a workplace environment requires a testing protocol that is safe, easy to administer and requires minimal equipment, using strength relative to bodyweight is, it can be argued, a more appropriate choice.

2.4.2 Literature

Highlighting the gaps in the literature 20 years ago, a review by Jaric (2002) noted that many strength studies did not normalise for body size or that normalisation protocols were inconsistently applied.

Clarke (1957) had earlier reported a significant correlation of 0.74 for leg lift with body weight was observed, indicating that anthropometric measures could be shown to be significant for physical performances. This simply demonstrated some relationships but did not contextualise to sports performance or relate to injury risk. Researching whether muscle power in the leg was related to running speed with change of direction, Young et al. (2002) later found that while bilateral power was only moderately correlated and unilateral power was not significantly correlated, reactive strength was significantly correlated to straight line and some change of direction sprints.

The aforementioned research by Baker and Newton (2008) showed maximal strength correlates with linear speed while a study on wrestlers by Çimen Polat et al. (2018) (whose loading patterns and movements are similar to those involved in contact sports such as AFL and rugby), concludes that "injury risk increases with the additional impacts of loss of strength" (p. 35).

Further research which retrospectively investigated lower limb injuries and relative strength as related to pre-season back squat performance (Case et al., 2020) concludes that males with relative squat strength below 2.2 and females below 1.6 in these sports (males – American Football, females – volleyball and softball), could be more susceptible to lower extremity injury over a season. Brorsson et al. (2010a) researched maximal strength in one leg squat (Bulgarian split squat), acceleration and agility using a male cohort (mean age 24 ± 2 years) of athletes engaged in intermittent sports and found significant correlation between maximal strength and sprint capacity in the 5 and 10 metres sprints as well as agility. They also found maximal strength relative to bodyweight correlated significantly with sprints capacity and agility and that agility correlated with all the sprints (Brorsson et al, 2010b). Comparing traditional strength training and contrast strength training (a hybrid of strength and power training), Hammami et al. (2017) reports that both types of training produce positive results relating to linear sprint performance as compared to a control group, but the contrast strength training produces a greater change in change of direction speed (CODS). This does not speak directly to a relationship with body weight but does speak to control of joints and forces running through joints which are increased at speed and under greater load.

The research serves to highlight the broad nature of the relationships of strength, sometimes related to bodyweight, with some performance outcomes of linear speed and CODS, without specifically speaking to a leg strength to bodyweight ratio.

Lipps et al. (2013) spent time researching ACL injury from a different perspective, hypothesising that rather than a single event causing an ACL rupture, perhaps repeated sub-maximal knee loading (as a pivot landing), could cause fatigue and eventual failure (defined as anything from permanent elongation to complete tear). They used 10 cadaveric pairs of knees (five females, five males) of similar age, height and weight and the results showed that "eight of the 10 knees failed under 4x bodyweight after 21 cycles, while five out of 10 knees failed under 3x bodyweight after 52 cycles" (Lipps et al., 2013, p. 5). Lipps and colleagues (2013) also noted that "a smaller ACL cross-sectional area was significantly associated with fewer loading cycles to ACL failure" (p. 5). Research on isokinetic and ballistic performance in relation to torque produced in leg extensor muscles (Bosco et al., 1983) found that “the power output during ballistic activities was much higher than the power measured during zero acceleration performances” (p. 357). Considered collectively, this has relevance for the investigation of leg strength-bodyweight ratios in a sport such as AFL where athletes are jumping and landing repeatedly, both in a game and during training. Basing further research on these findings, Wojtys et al. (2016) replicated the Lipps et al. (2013) model and investigated the effect of the range of internal hip rotation and its relationship to ACL injury risk. Wojtys and colleagues (2016) reported that “a 30° reduction in left hip internal rotation was associated with 4.06 and 5.29 times greater odds of ACL injury in the ipsilateral and contralateral limbs, respectively” (p. 2065).

Specifically relating to bodyweight, a three-year prospective study of female high school basketball and handball players reports that greater bodyweight is a significant risk factor in ACL injury, even after normalising for bodyweight (Nakase et al., 2020). Of the 30 injured knees reports in the study, “18 occurred during competition and 12 during practise, but 27 resulted from non-contact activity” (p. 36), reinforcing the value of this research in the context sports performance and injury mitigation.

Referring to the joint-by-joint model (Figure 5), it is evident that control of the joints helps prevent injury and that relative strength, as opposed to just maximal strength, may be more important in sports and activities where landing and CODS are fundamental characteristics.

2.5 Agility – Definition and Relationship to Injury Risk

A literature review on agility by Sheppard and Young (2006) found that although *classically* defined "as simply the ability to change direction rapidly" (p. 920), there was no universally recognised definition of agility, rather that there were components of agility that could be used to determine classifications. Today, in a sports context, agility is considered to also include an element of cognitive function and unpredictability. The definition of *universal agility* is "spatial and temporal uncertainty", an example of which is soccer, whereby participants "cannot anticipate with certainty when or where opposition players will move to" (Sheppard & Young, 2006, p. 921), which matches the physical attributes of AFL well. Figure 12 shows how complex and broad the components that contribute to agility are, and where this research project focusses its attention.

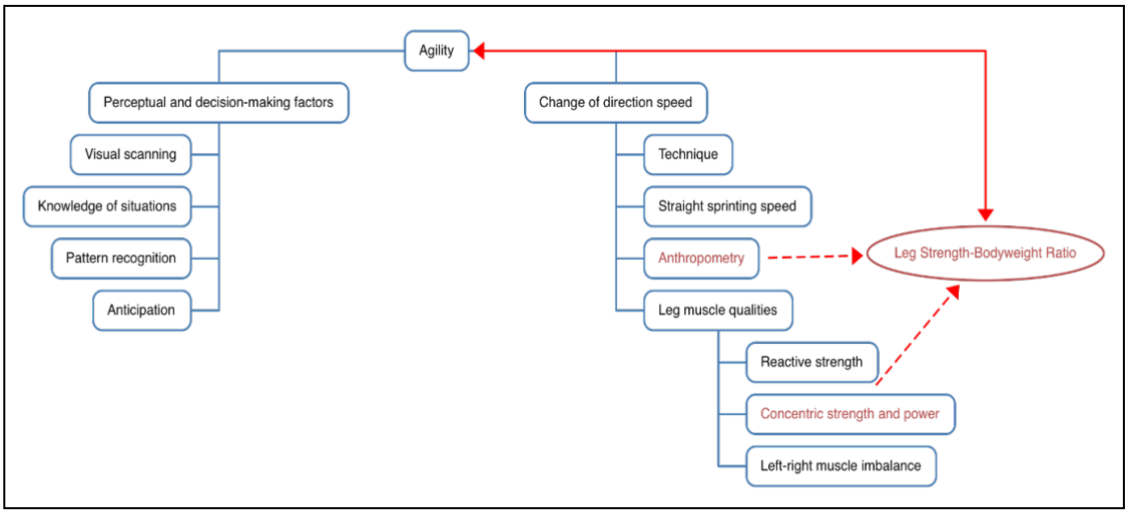


Figure 12 - Universal Agility Components, Highlighting Areas of Research in this Project (modified from Young and Farrow, 2006)

Due to the very nature of the activity, designing a single test for agility which can be both 'valid and reliable' (Haff & Triplett, 2015b, pp. 250-251) is impossible. Therefore, to *predict* injury or performance using the strict term of agility, is very difficult. This goes some way to explaining why there are mixed reports on whether agility and injury risk are related, with some studies reporting a positive relationship, some reporting no relationship and a review on performance tests and injury reporting both positive *and* negative (Goodall et al., 2013; Noyes et al., 2012; Spiteri et al., 2014; Young & Farrow, 2006).

There are several tests which can be used to measure agility. It should be noted that although referred to as agility tests, they are technically CODS tests because they follow a pre-determined route and do not contain the cognitive unpredictability commonly attributed to modern definitions. The term 'agility' in this study refers to the classic definition and to CODS when measured against the current definitions and elements identified as contributing to agility.

T-Test

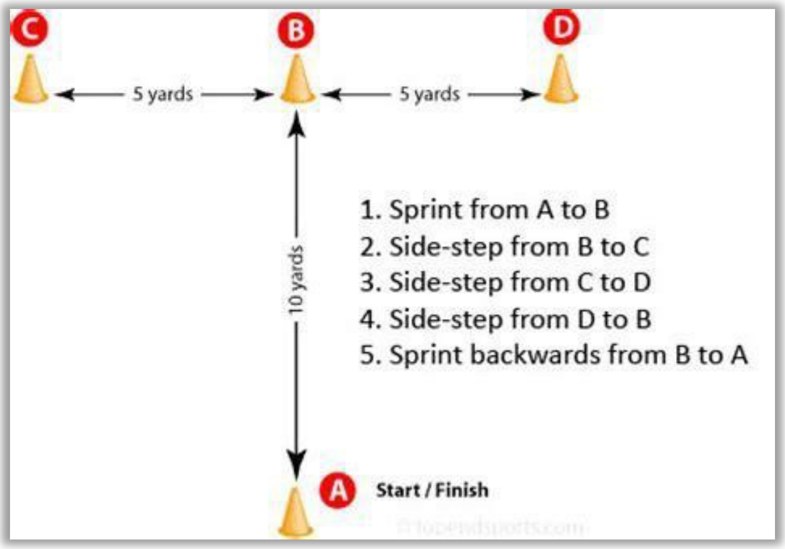


Figure 13 - Agility T-Test

In this test the athlete moves forwards, sideways and backwards through a set pattern, always facing the same direction and has their time recorded. The biggest advantage this test has over other agility tests is that movement is multiplanar, including running backwards, which lends itself to activities in which an athlete may need to travel backwards whilst looking forwards and requires little time, space or equipment (Wood, 2010). AFL, soccer, tennis and to a lesser extent, cricket (in the field), would all contain this activity.

Hexagon Test

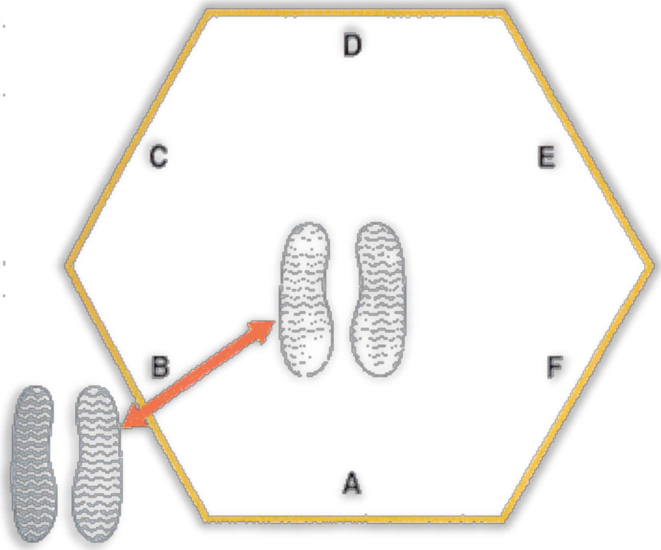


Figure 14 - Hexagon Test

In this test, shown in Figure 14, the athlete hops with two feet into and out of a hexagon across each edge always facing the same direction and has their time recorded. This test lends itself well to sports in a confined space or smaller court such as badminton, table-tennis, or squash. As a test that requires the athlete to keep the feet together, however, its practical application is questionable in most sporting activities.

Pro Agility Test

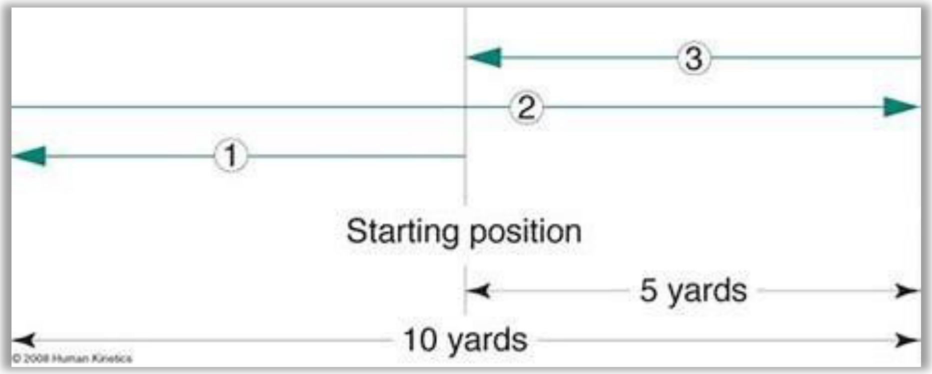


Figure 15 - Pro Agility Test

In this test, shown in Figure 15, the athlete begins straddled across a centre line and then sprints to a line 5 yards away, turns and sprints back across the centre line to another 5 yards in the other direction, turns and sprints back across the centre line at which point their time is recorded. The athlete faces the direction of travel for this test. Since this test involves travelling laterally in relation to the direction the athlete begins facing, it is used in the NFL (Nation Football League - American Football), combine (Wood, 2010). In this sport players will use these running patterns to drag the opposition out of position to create space for another player or for themselves to run forwards.

505 Agility Test

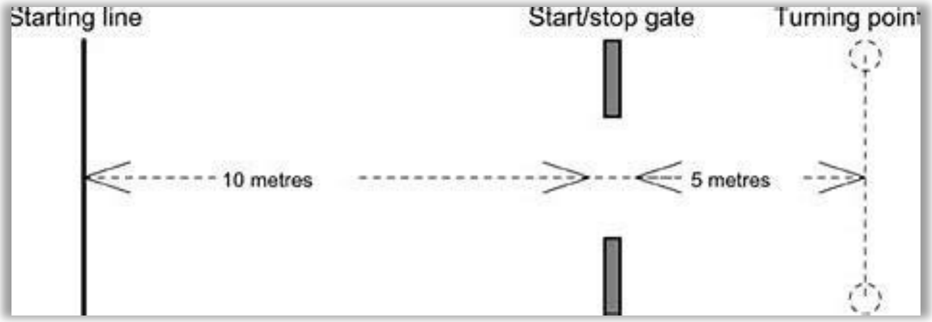


Figure 16 - 505 Agility Test

As shown in Figure 16, in this test the athlete runs in a straight line for 15 metres, passing through a timing gate at the 10metre mark. At the 15m mark, the athlete turns and accelerates back in the direction they came from, passing back through the timing gates at which point the time is recorded. The athlete faces the direction of travel for this test. Because of the length of run before the timing gates and the relatively short distance beyond it, this test is ideal for measuring an athlete's ability to decelerate, turn and accelerate (Wood, 2010). A trait common to many sports, but only containing one change of direction and so more of a pure CODS test.

Illinois Agility Test

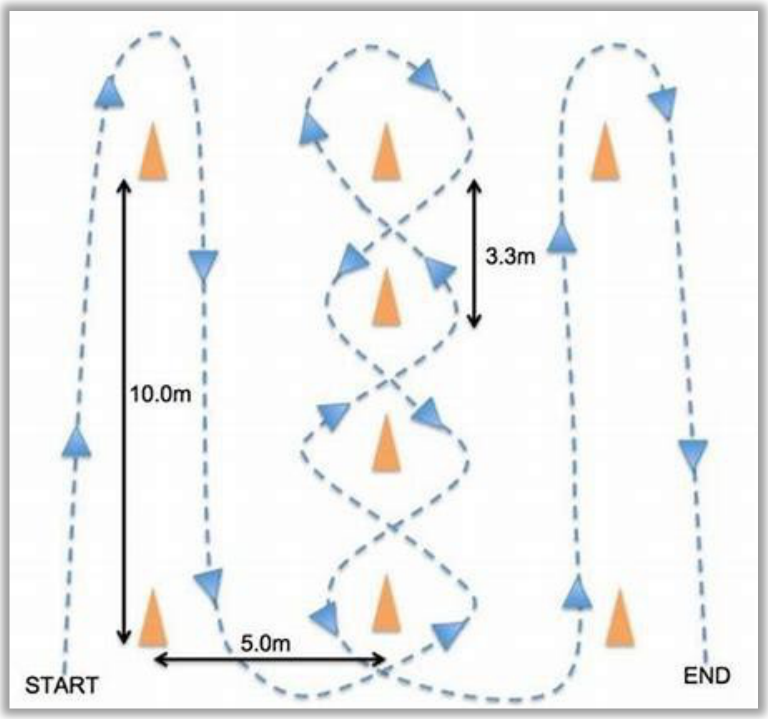


Figure 17 - Illinois Agility Test

In this test eight cones are set out as displayed in Figure 17. The athlete sprints around a cone 10 metres away and as they return, they travel towards the centre cones. They then zigzag around the cones out and back over 10 metres, sprint out and around another cone 10 metres away and back past the final cone at which point their time is recorded. The athlete faces the direction of travel for this test. This test can be used in field sports where the athlete is travelling larger distances and will be changing direction several times in response to external factors. The distance covered introduces an element of duration which other agility tests do not but also muscular fatigue which may override data which informs purely based on change of direction speed.

AFL Agility Run

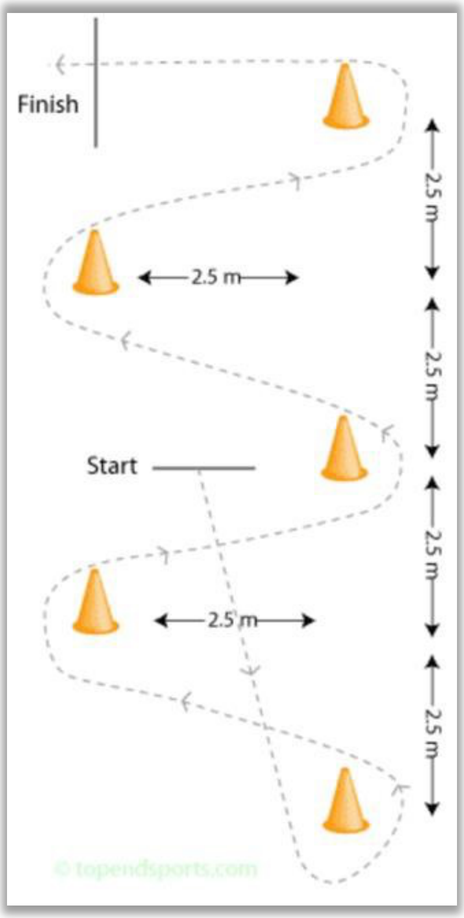


Figure 18 - AFL Agility Run

A test specifically designed for the AFL combine, the design of this test is like the Illinois Agility test above with regards to movement patterns but covers about half the distance. The athlete zigzags around the five cones as shown in Figure 18 trying not to touch or disturb them. Two trials are completed with 2-3 minutes rest between trials. The best time recorded, to two decimal points, from the two trials counts as the score.

It may seem logical to select the AFL agility run as the most appropriate test for a project directly relating to that sport, however, despite the introduction of the male combine in 1994, a female combine was only introduced in 2017, meaning that datasets are much smaller and less directly related to the demographic of the project. For this reason and considering the multi-dimensional movement patterns and strain on the joints in different angles, it is considered that the T-Test represents a good option for validity and reliability as well as for the opportunity to compare results against a larger dataset. It has been identified that leg speed correlates highly with performance in the T-Test (Paoule et al., 2000) and that it was "found to be a valid predictor of level of sport participation…because it discriminates among intercollegiate athletes, recreational athletes, and nonathletes" (p.449). The test itself can be administered in a relatively small space with little specialised equipment. It also eliminates the element of muscular fatigue that might otherwise push us towards the Illinois agility test.

Particularly relevant information regarding leg strength and agility performance, determined that maximal leg strength correlates significantly with acceleration capacity and agility (Brorsson et al., 2010b). While the range of weight of the subjects is often recorded, there is no indication whether there is a relationship between leg strength-bodyweight ratio and agility. In line with this argument, Arin et al., have suggested "maximal unilateral squat strength and maximal unilateral leg press strength are good predictors of CODS and linear sprint performance. Unilateral resistance training could be a method for increasing linear sprint and CODS performance for soccer and ice-hockey players" (Arin et al., 2012, p. 31). It is also interesting to note that the study chose to use unilateral leg strength tests (unilateral smith squat and unilateral leg press) as opposed to a standard bilateral test to accommodate the notion that in most multiplanar sports, an athlete is often only loading off one leg at any given time. A study on AFL agility (Hart et al., 2014), supports this notion and suggests "change of direction capabilities should therefore be examined bilaterally to eliminate bias toward athletes with particular leg dominance profiles and to provide a limb deficit measure for enhanced athletic profiling outcomes" (p. 3552).

When evaluating plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength (Fatouros et al., 2000), identified that a "combination training group produced improvements in vertical jump performance and leg strength that were significantly greater than improvements in the other two training groups (plyometric training and weight training)" (p.470). A more recent study by Bogdanis et al. (2019) compares the effects of unilateral and bilateral plyometric training on single- and double-leg jumping performance and strength reports that "Unilateral plyometric training was more effective at increasing both single- and double-leg jumping performance isometric leg press maximal force and RFD [rate of force development] when compared with bilateral training" (p. 639). While not measuring neuromuscular control directly, there is a greater degree of neuromuscular control required in stabilising the leg unilaterally compared to bilaterally and this has been indicated in other research as a significant contributing factor to the disparity between male and female ACL injury rates (Griffin et al., 2000). A meta-analysis performed by Gagnier et al. (2012) on eight cohort studies and six randomised trials found that various types of neuromuscular and educational interventions appear to reduce the incidence rate of ACL injuries by approximately 50%, but the estimated effect varied appreciably among studies and was not able to explain most of that variability. The analysis showed a stronger effect for studies that were not randomised, suggesting that specific methodologies might favour particular outcomes.

In 2008, a study on national and state rugby league players reported "NRL [National Rugby League] players were significantly heavier…and older than their SRL [State Rugby League] counterparts. Further the NRL players were stronger…more powerful…and produced greater momentum...Acceleration, maximal speed, and agility were not significantly different between the two groups" (Baker & Newton, 2008, p. 155). This research does not comment on strength to bodyweight ratios, although it might be considered that an equal strength to bodyweight ratio in a heavier individual would be a benefit in this particular sport, due to the nature of the collisions between players. It is interesting to note that agility was not significantly different between the two groups, since this would suggest that strength, in isolation, is not correlated with agility.

In all field and court sports, agility competence is a fundamental requirement, with associated speed and intensity of this requirement increasing as the level of competitiveness increases. Poor results in components of agility such as leg strength, power and neuromuscular control (which may collectively represent an absence of agility competence), may increase the risk of lower limb injury, with consequences for both the individual and the team.

Part of the purpose of this work-based study is to help identify the biomechanical load risks associated with a leg strength to bodyweight ratio and its relationship with agility performance.

2.6 Intervention

Despite the high incidence of injury, it has been shown that interventions can effectively reduce the risk. For example, a 2005 study showed that implementing a neuromuscular training program in female youth soccer players contributed to an 88% reduction in ACL injury compared to a control group (Mandelbaum et al., 2005). This finding was later supported by a study (Hrysomallis, 2009) which showed that an intervention for six weeks pre-season to strengthen adductors resulted in a “4.5 fold reduction in adductor strain incidence” (p. 1516). A four-season study on female basketball players (Nagano et al., 2011) where an injury prevention program was implemented showed that “during the third intervention season, the rate of ACL injuries in the teams that complied was 0.011/1000 PH, while the rate in the teams that did not comply was 0.032/1000 PH” (p. 365), leading the researchers to conclude the program had tended to decrease the frequency of ACL injuries.

A longer 12-year prospective intervention study on the effect of a hip-focused injury prevention program for non-contact ACL injury rates reports a significant reduction in relative risk during an eight-year intervention period as compared to a 4 year observation period (Omi et al., 2018) with ACL injury rates dropping to 0.08/1000 athlete exposures from 0.21/1000 athlete exposures. Covering multiple aspects of injury mechanism including education on landing manoeuvres, improving hip strength and balance exercises, this provides strong evidence for interventions in addressing the long-term health of female athletes and with an 89% compliance rate also indicates an appetite to adhere.

Not all the research in this area is positive. Goodall et al. (2013) concluded in their study of balance and agility training on army recruits, that not only was there no statistically significant benefit with respect to knee injuries, but that the additional training load and associated fatigue caused by the program may even increase injury risk in that environment. This highlights the importance of context and application for any intervention program and encourages any practitioner in the workplace to approach the implementation of an intervention with caution and consideration.

2.7 Conclusion

This literature review has explored the position of current research pertaining to the project title. It has sought to identify areas where the literature is deep and comprehensive, and highlighted where the research has gaps and inconsistencies this work-based research project seeks to address.

The depth and breadth of research surrounding lower limb injury is extensive. The increasing body of knowledge, specifically relating to female athletes and to adolescents speaks to some overarching commonalities and some divergence. The physical mechanism for ACL injury or rupture is quite clearly defined, however the way the mechanism is activated is the subject of the increasing body of knowledge. There two main triggers:

- Unilateral landing, particularly with the knee extended; and
- Sudden and unpredicted change of direction at speed.

The landing trigger relates directly back to the anatomy of the knee joint, where the supporting ligamentous structure is pulled tightly across the joint in the extended position, thus limiting the influence of the muscular system as a supporting structure. Unilateral landing in certain sports means the foot is in a fixed position as the weight of the player (and potential opposition players) applies extreme downward force. Coupled with the likely rotational forces and often uneven landing surface, the inelastic ligamentous structures cannot withstand the force and subsequently tear or rupture.

The change of direction trigger is grounded in the same anatomical landscape but is likely more influenced by physiological factors such as strength, neuromuscular control, and experience of the athlete. With respect to these factors, it is controlling the movement of the knee under speed and load that has the greatest effect. This places neuromuscular control at the forefront of the discussion since strength is derived from a combination of intra- and intermuscular coordination in the first instance, followed by sheer volume of lean muscle mass.

The research shows there are compounding elements which create a higher risk for female athletes with respect to this specific injury compared to their male counterparts. Anatomical factors of skeletal structure increase joint angles in the knees of females, a reported bias towards quadriceps dominance in female landing mechanics and some reports that the follicular phase of the menstrual cycle has a negative effect on physical performance, collude to create a high-risk environment for ACL injuries in females. A lingering social and cultural aversion to resistance training for female athletes remains, hindering the advancement of physical training components that surround the increase in participation and professionalisation of female sport. This is partly due to barriers around education of the subject and partly due to the relative infancy of the female athletic landscape.

Adolescent female athletes are in a particularly precarious position. Menarche, differing rates of growth as evidenced by the Tanner stages, increased social awareness, and sheer volume and intensity of activity mean the requisite physical education and structural training that should accompany female athletics are currently being overlooked.

The research has shown that agility is not only challenging to define, but also challenging to assess in a reliable and predictable manner, since most agree that true agility must contain an element of unpredictability. This is important because this element is also a significant factor when considering injury risk. Due to this, agility research has mostly been a measure of CODS, where anatomical mechanics can be observed and measured, and performance metrics collected. Cross referencing this information allows some opinion on the extent to which ‘agility’ performance is a significant factor in injury risk, but because agility itself is multi-factorial is can only be considered as a conduit that measures the component parts in their entirety. With respect to this, the concept of investigating an optimum leg strength-bodyweight ratio, measured, and tested in the workplace environment is unique.

Research of interventions looking to improve sports performance and manage injury risk has for the most part been positive. Although there are few consistencies which might allow definitive comparisons and conclusions to be drawn, most agree that an increase in absolute strength, regardless of bodyweight, leads to an improved performance in linear and power metrics, but do not find parallels in agility/CODS. Neuromuscular training has shown some positivity in relation to agility/CODS and while a handful of studies report on leg strength-bodyweight ratio, they report based on 1RM (or predicted 1RM) measures collected using resistance equipment typically only available in a gym facility. Researching the design and implementation of an intervention that can be carried out in the workplace, removing some of the participation barriers to adolescent female athletes can be considered valuable and worthwhile.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter presents the paradigm, method, research design, and processes undertaken to investigate the research questions previously identified. Section 3.2 explains the research paradigm, method and research design applied over the course of the project; section 3.3 reviews the research setting; section 3.4 reports the study population, including expressions of interest, recruitment, inclusion and exclusion criteria, as well as reviewing the impact of the COVID-19 pandemic on recruitment, selection and participation; section 3.5 details the physical assessment, performance testing and specific instrumentation used for the collection of data and its application; section 3.6 provides specific detail of the intervention process, including rationale for selection of tools and exercises followed by information on protocols used, including frequency and duration of sessions; section 3.7 reviews the methods for data collection; and 3.8 indicates the data analytic techniques applied and their rationale in relation to the research questions. Section 3.9 outlines the research project's validity and reliability, with section 3.10 presenting the study's ethical considerations.

3.2 Paradigm, Method, and Research Design

3.2.1 Research Paradigm

As a work-based research project, a Pragmatist paradigm has been adopted. More specifically, pragmatic knowledge claims are "problem centred…oriented toward real-world practise…not committed to any one philosophy" (Creswell & Creswell, 2017, p. 5). This paradigm relates most closely to the purpose and setting of the project. Pragmatism specifically embraces the gaps between the more tightly controlled empirical approach found in the Positivist paradigm, and the more subjective, interpretive approach found in the Constructivist paradigm by specifically "looking for the weaknesses in the study and to strengthen it using a mixed methods approach" (Rahi, 2017, p. 1).

Often the research questions, and the methods adopted to try and answer them, provide as much useful information as the data they return and are particularly useful in social science. This project is quantitative in nature, and yet is set in a real-world workplace. The Pragmatist paradigm thus offers the best viewpoint from which to address the research questions (RQs) considering the factors involved.

3.2.2 Method

The project was quantitative in nature and adopted a quasi-experimental research design. More specifically, through six phases this study utilised a quasi-experimental research design through a non-randomised controlled trial where anthropometric, strength and agility testing were conducted on 23 adolescent female athletes participating in Australian football in Queensland. As a work-based research project, designed specifically to investigate a physical intervention in the area of a field based sport, data collection occurred in a sporting environment where athletes and coaches train and play. The data collected were used to investigate the research questions related to leg strength, body weight and physical performance in agility testing initially, and then used to further inform the context as applied to injury risk in the study cohort.

3.2.3 Research Design

The motivation for the project was to investigate whether there is a relationship between leg strength-bodyweight ratio (LSBWR) and agility performance – RQ1. In addition to this, is the question of whether a physical training intervention, carried out in the field, as opposed to in a facility, could generate a specific training effect (to improve leg strength) and by extension influence LSBWR positively – RQ2. Furthermore, could a training effect on a static performance measure (i.e., Bulgarian Split Squat - BSS), influence a dynamic performance outcome (agility) with reported benefits in mitigating risk of exposure to lower-limb injuries in a specific demographic.

The research questions have driven the design of the project, so that the study first identified and selected appropriate participants. Since the application to participate in the project was only offered to a specific demographic and from this participants were deliberately separated into specific cohorts, it cannot be considered a 'randomised' trial, which leads to the quasi-experimental design with non-equivalent groups and the pre-test/post-test design (Price et al., 2015).

As a project with a physical intervention aspect, with pre- and post-intervention data collection, it is inherently a quantitative, longitudinal research design, requiring a pre-determined timespan to provide the opportunity for the intervention to have an influence as defined in 3.6. Data collected was subjected to statistical analyses and so inclusion and exclusion criteria were applied for validity.

Application of the quantitative results of the intervention program into a performance criterion then allowed for interpretation beyond the simply quantitative measure of whether the intervention has had an influence. It also places the project in an observational and cross-sectional framework (Mann, 2003) to observe implications in the broader context of the workplace in question, offering guidance for RQs 2 and 3, contributing to the body of knowledge in the industry and functioning as a preliminary, investigative project upon which further research could be based.

The research design was separated into six phases as illustrated in Figure 19.

Phase One - Due to the nature of the intervention and the demographic identified, phase one comprised of gaining approval from the University of Southern Queensland Human Research Ethics department. Following clearance, a process of collaboration with the club involved allowed for consultation with a potential study population where an outline of the project was presented and an invitation for questions was extended. Collection of assent and consent forms, along with a Participant Information Sheet about the project, from potential participants and parents or legal guardians were completed prior to phase two.

Phase Two – This phase involved refining the applicants for the study based on the inclusion and exclusion criteria set out in sections 3.4.3 and 3.4.4 below, before undertaking collection of initial, pre-intervention anthropometric and physical performance testing data with successful applicants. This approach provided information intended to answer RQ1.

Phase Three – Participants consisted of 23 female Australian football players, drawn from one club and one age group (15.75 ± 0.50 years). These were then divided into two groups, allocated by the club, based on ability. Group 1 (G1, *n*=11) were identified as a A-grade players (and therefore perceived to be of a better ability), and Group 2 (G2, *n*=12) were identified as reserve grade. This allowed data collection to be related back to the specific demographic for which the results would be the most useful as identified by the club. G1 underwent physical testing, a physical strength intervention program lasting six weeks with three training sessions per week, followed by a retest. The intervention program initially comprised two different exercise programs - A and B - spread across three sessions per week, each lasting between 30-45 minutes. Programs were alternated to maximise efficiency, limit fatigue or overuse and, as explained in section 3.6 below, one of the programs (A), was modified to become program C after week three to account for participants familiarisation and adaptation to some of the more foundation-level movements originally included. G2 underwent physical testing, continued with normal training as prescribed by the club and were then retested six weeks later to align with G1. Whilst not addressing the question directly at this stage, the intervention provides the basis for data collected to answer RQ2 and infer for RQ3.

Phase Four – Here, all participants underwent a repeat of the battery of tests as for the pre-intervention testing in phase two.

Phase Five - Data were collated and analysed as explained in sections 3.7 and 3.8 below, providing quantitative data to apply to RQ2 and for review of RQ1.

Phase Six – Collection, interpretation and analyses of lower limb injury data for participants collected across the competitive season. This phase was interrupted by COVID-19, details of which can be reviewed in section 3.4.6.

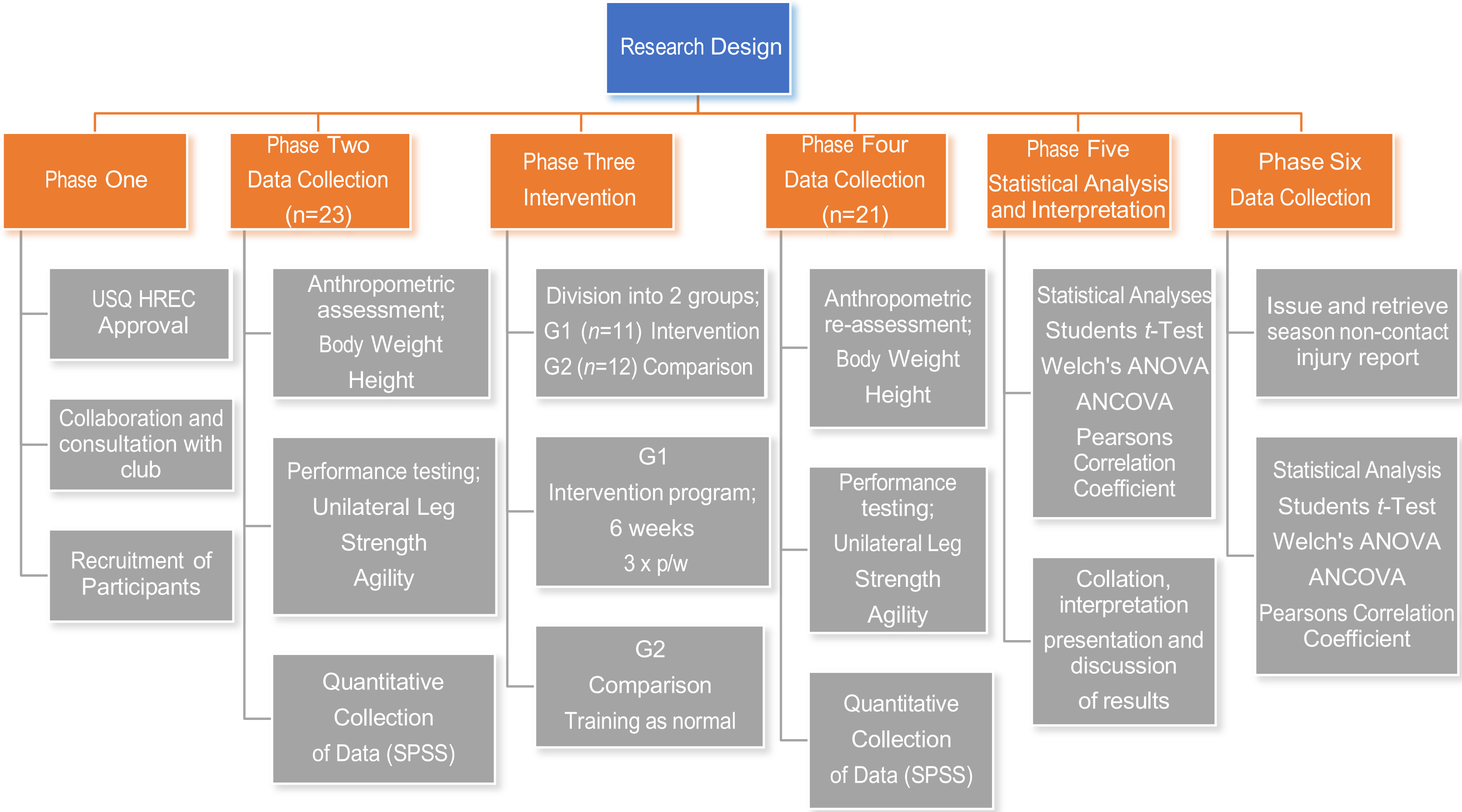


Figure 19 - Research Design

3.3 Research Setting

The research was conducted at the training grounds of an AFL junior club on the Gold Coast in Queensland. Anthropometric data was collected on-site, and performance data were collected on an area of astro-turf at the training ground to allow for consistency in surface underfoot during trials. Instrumentation was used as described in section 3.5.

3.4 Study Population

The study population had specific requirements in order to provide salient and relevant data to inform the RQs.

3.4.1 Selection Criteria

Participants were female adolescents (identified as 15-17 years of age), participating in competitive Australian football. In this case, all participants were playing members of a junior Gold Coast Australian football team.

3.4.2 Interest (recruitment)

Participants were identified by invitation, via the club, to an information session, where parents and coaches were also able to attend, explaining the purpose and scope of the research. Those that could not attend the information session were sent a copy of the proposal and the researcher also attended a training session to speak directly with athletes under the supervision of coaches. They were provided with information on the particulars of the research, the requirements from themselves in terms of commitment to the intervention and availability for testing both pre- and post-intervention.

3.4.3 Inclusion Criteria

Applicants were required to meet the criteria of female adolescents (15-17 yrs. old) who were members of a junior AFL club and actively participating in competitive Australian football in Queensland. All participants were required to provide a consent form from a parent/guardian and to complete an assent form themselves.

3.4.4 Exclusion Criteria

Since previous injury represents a high risk of re-injury, any participants with any previous history of ligamentous lower limb (hip, knee, or ankle), injury would have been excluded from the project, although there were none reported.

3.4.5 Adherence

Challenges for this demographic include a reliance on parents for transport alongside competition for time with other activities and school. It was decided, in consultation with the club, that participants would be most able and most likely to attend if sessions were aligned with other club activity and so sessions were conducted on Monday and Wednesday afternoons immediately before regular club training. The third training session was to be completed at the discretion of the individual around their own schedule but was recorded on the

Teambldr strength and conditioning app (see section 3.5.6) to track completion. Since the project was conducted over a relatively short time – six weeks – a minimum program adherence of 90% was required for G1 intervention results to be considered for inclusion. All participants achieved this (except for one who underwent surgery which resulted in 11 volunteers reduced to 10 participants in G1), with eight out of the ten recording 100% adherence.

This did help to achieve the goal of facilitating group attendance and places the project firmly in the space of a field-based study, promoting the notion of a training program that can be implemented by a coach in a real-world workplace environment.

3.4.6 Impact of COVID-19 Global Pandemic

A process of recruitment, consent and initial data collection was undertaken in March 2020. 19 participants were initially tested before COVID-19 caused cessation of the playing season and all associated training sessions. This caused a delay to the project and a second recruitment process began at the end of 2020 with a view to running the intervention prior to the commencement of the following season. Continued interruptions caused by COVID-19 and flooding delayed the initial testing of the second cohort until April 2021. These delays meant that running the intervention program in the pre-season period, as intended, was impossible and it was decided, with the research team, to complete the intervention program during the playing season rather than wait for the beginning of the next competitive season in 2022. The result of this decision is that it was not possible to track injury data across a season and relate it back to any data collected as a result of the intervention program. As such, the project narrowed in focus slightly and became an opportunity to observe if there could be a physical change because of an on-field physical intervention and if that change could be translated to a performance modality. Relation back to mitigation of lower-limb injury risk, therefore, remains theoretical with reference to appropriate literature, as discussed in the literature review.

3.5 Physical Assessment, Performance Testing, and Instrumentation

Each participant underwent a pre- and post-intervention battery of physical assessment and testing to provide data for analyses;

- Bodyweight
- Height
- BMI
- Leg strength
- Agility

3.5.1 Bodyweight > scales

Digital bathroom scales were used to collect bodyweight data recorded in kilograms (kg). The same scales were used for all participants for pre- and post-intervention testing. Protocol for both tests was for participants to wear full, club-issue training gear (socks, shorts, tops) and no footwear. Scales were placed on a flat, concrete surface outside the changing rooms at the club for consistency between participants and between tests.

3.5.2 Height > tape measure

A changing room wall was used to measure participants' height in metres (m). The wall was pre-marked in cm intervals and protocol was to stand in full kit (excluding socks), with heels, shoulders and back of the head against the wall. Any long hair was hanging down and measurement taken from the top of the head.

3.5.3 Body Mass Index (BMI)

BMI was calculated using the equation - weight in kilograms divided by height in metres squared:

$$BMI = Weight\ (kg) \div Height\ (m^2)$$

Typically, this measure is used by clinicians and applied to the general population as an indication of bodyfat using a weight to height ratio. Table 2 shows standard classification of BMI values. It is worth noting that as one draws down from the general population towards individuals, BMI can become a less reliable health indicator on its own and should only be considered in conjunction with other variables. In the athletic population it is very common for BMI to indicate an individual as overweight against the health scale when their actual bodyfat percentage is normal (Riewald, 2008), because the athletic population is often more muscular and leaner than the general population. Even if BMI measures are similar (some athletes are lighter because of their sport), the bodyfat percentages can be quite different. Ode et al. (2007), for example, found that the mean BMI of male athletes was 26.9 with bodyfat of 13%, against a non-athletic population whose BMI was also 26.0, but with a bodyfat of 17.7%. Additionally, BMI does not account for the generally higher bodyfat percentages in females than in males. The same study showed athletic females with a mean BMI of 24.6 and bodyfat of 25.2%, against the non-athletic female population with a mean BMI of 23.4 and bodyfat of 28.5%. This pattern of difference between the sexes was also found in a more recent study by Ehrampoush et al. (2017), where a large population of males (*n*=580) and females (*n*=780), show mean BMI of 25.7 and 26.3 with bodyfat of 24.5% and 35.8% respectively.

Whilst not used with respect to bodyfat and disease risk in this project, BMI does represent another easily identifiable, highly reported, and relevant variable for consideration and comparison.

Table 2 - BMI Classification

Body Mass Index	
BMI	Weight Status
<18.5	Underweight
18.5 - 24.9	Normal weight
25.0 - 29.9	Overweight
30.0 - 34.9	Obesity class I
35.0 - 39.9	Obesity class II
≥40	Obesity class III

3.5.4 Leg strength > bench and foam pad

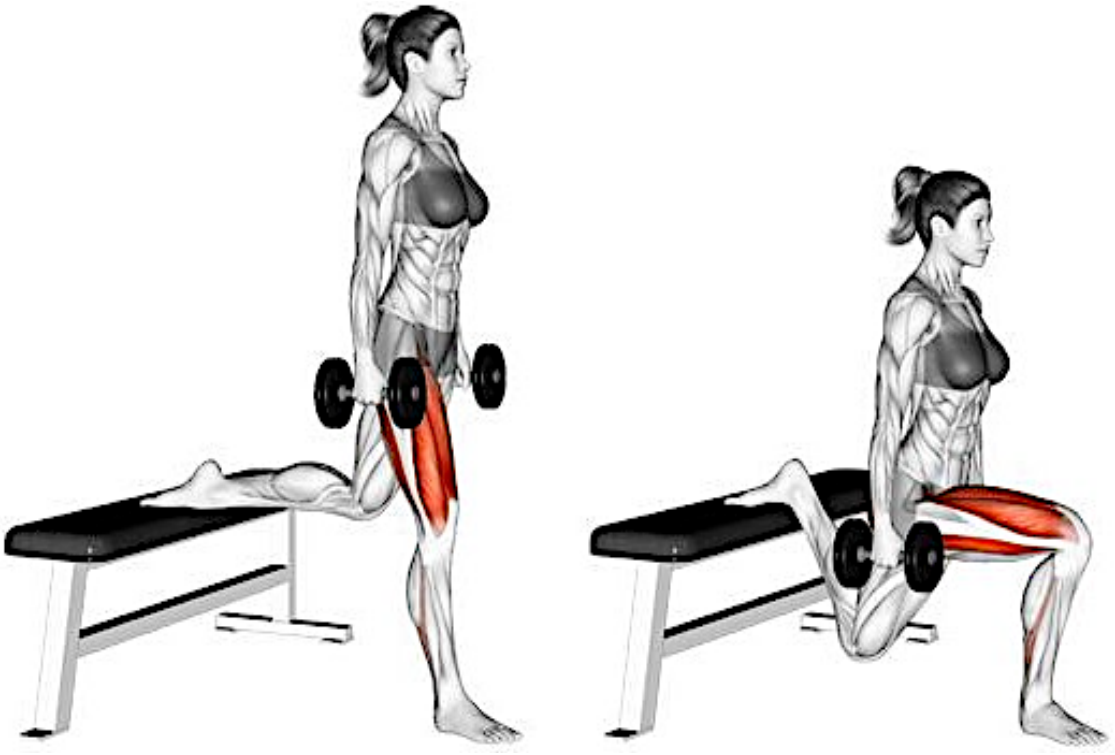


Figure 20 - Example of How a Bulgarian Split Squat (BSS) is Performed

Leg strength can be measured in many ways but to maintain consistency, limit the influence of skill input, compare data, and reflect the desire to make the study as relevant as possible to sports performance, Bulgarian Split Squat (BSS) was used. In this exercise, the athlete places one leg behind them on a bench and drops the knee of that leg to the floor as shown in Figure 20. This tests the supporting front leg, thus when recording data as left or right leg, this referred to the front leg with the foot on the floor. All participants tested left leg first and then right for consistency. While it is acknowledged that the height of the bench should be ‘about knee height’, it is impractical to accommodate this and so a 30cm high bench was used for all participants. A 6cm thick foam pad was placed below the knee of the rear leg so that participants could maintain consistent form by touching the pad with the knee on each repetition without risk of injury. Full range of motion was defined as touching the pad with the back knee on the downward phase and full extension of the front leg in the upwards phase. The start position was standardised so that the rear knee was resting on the pad and the front knee was at a ninety-degree angle. Each participant had two practice repetitions to familiarise and then performed one set on each leg to failure (where the required full range of motion cannot be completed) with 60s rest between legs. The last full repetition was recorded as the result. This protocol created as much consistency as possible across participants and tests.

The BSS was deemed most appropriate in this project because it met various criteria:

- It is unilateral in design, which some research suggests is more relevant for multi-planar sports (Arin et al., 2012; Hart et al., 2014).
- As the demographic is not at full maturity it would be ethically inappropriate to use a 1 Rep Max (RM) protocol to measure leg strength. While there is a predictive formula (Kuramoto & Payne, 1995), for women aged 40-50 (*1RM = (1.06 x weight lifted in kg) + (0.58 x repetitions) – (0.20 x age) – 3.41),* it still relies on the subject reaching failure under load and there is not a comparable formula for adolescent females. Furthermore, since the design of the project is to investigate strength and bodyweight in relative terms, it was decided not to give any additional load to the participants, but to allow them to reach failure with bodyweight alone.
- The equipment required to conduct this test is minimal, allowing for practical application in the workplace beyond the bounds for the project itself, one of the questions related to RQ1.

Failure was indicated by an inability to complete more than two consecutive repetitions with full range of motion at any stage, a loss of balance requiring replacement of the rear leg off the bench to stabilise or a voluntary cessation by the participant.

Each participant had two practice repetitions to familiarise and then performed one set on each leg to failure (where the required full range of motion cannot be completed). The aggregate score (left and right leg added together), was used to calculate the leg strength-bodyweight ratio (LSBWR) using the formula below:

Aggregate leg strength score (reps) ÷ Bodyweight (kg) = LSBWR

Using this formula results in a LSBWR that is easy to read and understand for coaches and participants. In the example below, two different participants recorded the same aggregate leg strength score of 100, but one (*A*), weighed 65kg and the other (*B*) weighed 75kg:

$$A - 100 \div 65 = 1.53$$

$$B - 100 \div 75 = 1.33$$

As indicated above, *A* has a better LSBWR as represented by the higher number. The application for this in the project and beyond is based around simplicity of interpreting results for coaches in the field.

3.5.5 Agility > Freelap Timing System

As elaborated previously, the definition applied to the term 'agility' has been refined and developed over time. The inherent uncertainty of testing true 'agility' whereby a course is not pre-determined, but also contains elements of randomness and response to external stimuli make it very difficult to compare athletes and so most agility tests that are used to collect and compare data are, strictly, change of direction tests. In 2017, the AFLW introduced an annual combine draft that includes the same battery of tests as the men's combine, which has been running since 1994. In this battery of tests is an agility test specifically designed for the AFL and AFLW (Wood, 2010) so the initial thought was to adopt this as the relevant test for the project. However, since there is relatively little data overall, only data on elite female athletes since 2017 and no data at all for adolescent females, it was deemed by the researcher that a different, more widely used, agility test would be more appropriate and more useful for comparison and discussion in the broader context of the project.

There are varying options with the Strength and Conditioning (S&C) testing spectrum with regards to agility tests. Some are sport-specific, some have a predetermined course, and others are in response to an external stimulus, such as a whistle or light. Since the project, whilst using AFLW as a conduit, is also exploring a much broader subject matter, the agility T-test developed in 1990 (Semenick, 1990) provides a good choice in the opinion of the researcher. The reasons for this are:

- It is an internationally recognised test;
- As a standard, it provides a reliable basis for comparison both for initial and subsequent testing and across multiple participants; and
- The database of recorded values is large, offering a good comparison for baseline testing to see how participants compare with other athletes in their demographic using normative data.

Figure 21 shows the setup and protocol for the T-Test and the link (Vives, 2017) shows a video of the test in action. Each participant undertook their own warm-up so that they felt confident to perform at maximum effort and the test was conducted on a flat, AstroTurf surface in trainers.

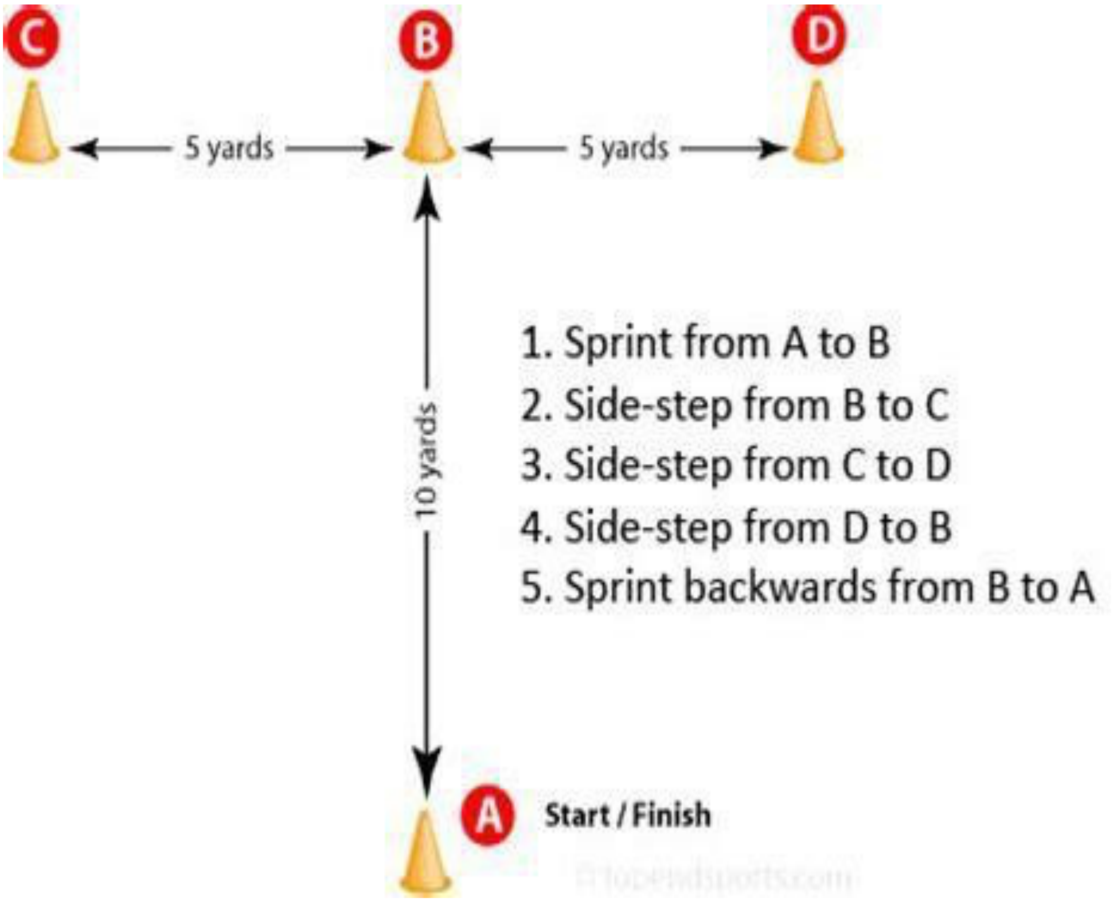
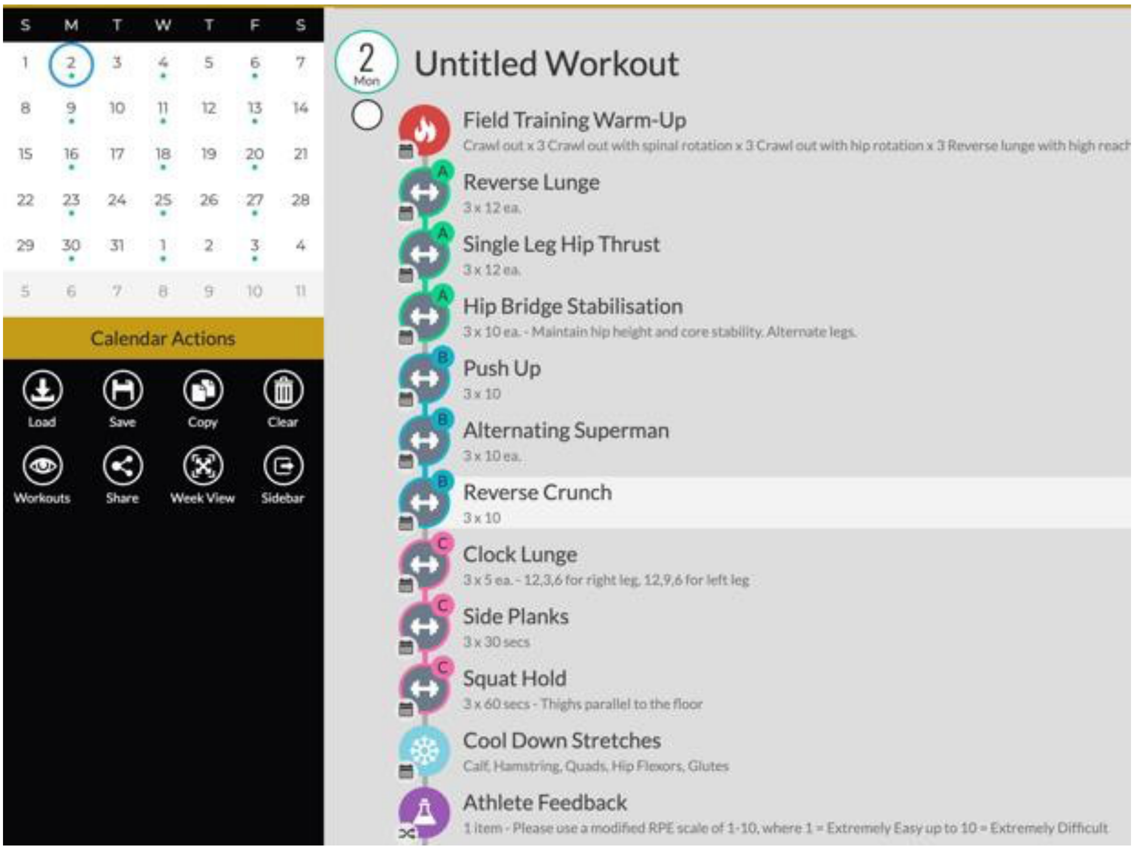


Figure 21 - How the Agility T-Test was Conducted

To record accurate times, the Freelap Timing System (Freelap, 2020) was used. A receiver was set up at station ‘A’ and participants wear a transmitter which starts the timer, by releasing a button. As they pass the receiver on their return at the conclusion of the trial, the clock stops. Each participant was given an orientation run, where they jogged through the route for familiarisation. After this, they were given three trial runs with 60s rest between runs. Since it is a short test, and athletes are operating at maximum velocity, slips or stumbles were common and so the best trial, as opposed to an average time of the three trials, was used as the reference time in data analyses.

3.5.6 Intervention Program Design and Records > Teambldr app



Untitled Workout

Field Training Warm-Up
Crawl out x 3 Crawl out with spinal rotation x 3 Crawl out with hip rotation x 3 Reverse lunge with high reach

Reverse Lunge
3 x 12 ea.

Single Leg Hip Thrust
3 x 12 ea.

Hip Bridge Stabilisation
3 x 10 ea. - Maintain hip height and core stability. Alternate legs.

Push Up
3 x 10

Alternating Superman
3 x 10 ea.

Reverse Crunch
3 x 10

Clock Lunge
3 x 5 ea. - 12,3,6 for right leg, 12,9,6 for left leg

Side Planks
3 x 30 secs

Squat Hold
3 x 60 secs - Thighs parallel to the floor

Cool Down Stretches
Calf, Hamstring, Quads, Hip Flexors, Glutes

Athlete Feedback
1 item - Please use a modified RPE scale of 1-10, where 1 = Extremely Easy up to 10 = Extremely Difficult

Figure 22 - Example of a Screenshot from the TeamBldr Strength and Conditioning App

An online training app, TeamBuildr (2012-2020), shown in Figure 22, was used to provide every participant of G1 with a personal account where they could login, view the program and record completion data. This created clarity and transparency for all participants, but also enabled ownership and accountability, which was particularly useful in adherence of participants and for overview of completion records by the researcher throughout the research project.

3.6 Intervention

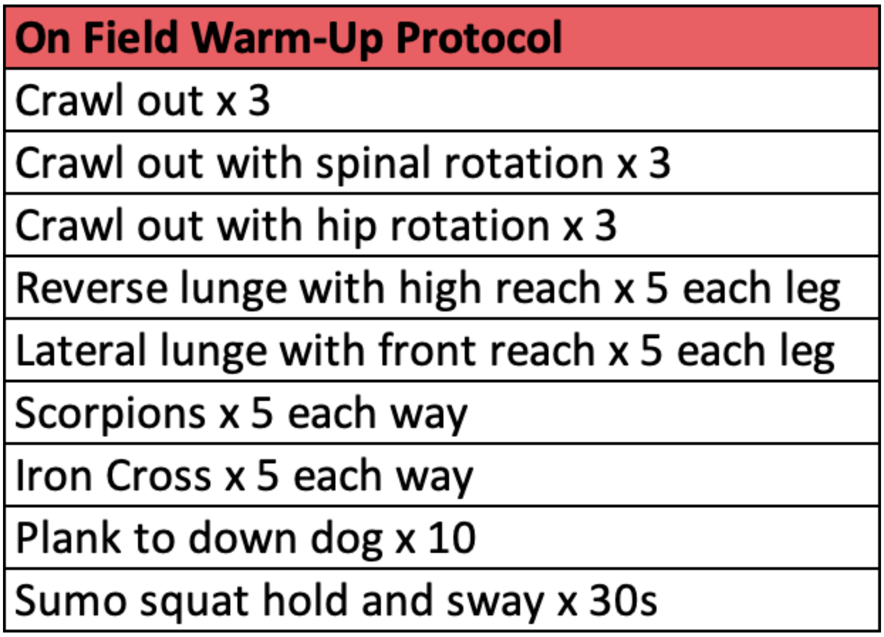
The intervention program (G1) was designed for participants to train three times per week over a period of six consecutive weeks. Training was conducted by the researcher on-site at the club two days per week (typically Monday and Wednesday afternoons), whilst the third session was either run by a coach (typically on a Friday afternoon) or undertaken by the participant at a time and venue convenient for them. The intervention was programmed into the Teambldr online training app (see section 3.5.6) for participants to access and record data.

The intervention comprised of three different programs – A, B and C (see Tables 4, 5 and 6). Program A was designed to be slightly more simple and slightly less intense than program B and after three weeks, program A was modified to increase complexity and intensity to create program C. All programs were designed to be completed in 35-45 minutes to minimise disruption and encourage adherence.

The design of the intervention programs was guided heavily by two main factors. The first was the requirement to provide enough stimulus for potential physical change. The fundamental context of the entire project relies upon stimulating a change in muscular strength of the participants, so this was of paramount and primary concern. The second major consideration was that the program had to be designed so that it could be delivered in the workplace, which in this context means 'in the field', where there will not be commercial fitness equipment available, and the training will most likely be delivered to an entire squad or team at the same time. This means there needs to be consideration for time and space if the intervention is going to provide a practical, useable tool for other coaches. The design of the program, therefore, relied a great deal on bodyweight exercises and the concept of group training. The design specifically allowed for large numbers of participants to be undertaking the same exercises at the same time making it efficient, motivating, and easy to coach. Manipulation of the movements and tempo (the speed at which an exercise is done) and alternating core exercises in between leg exercises allowed for almost continuous exercise without compromising the quality of leg work required. The additional benefit of this program design is that it relates directly back to the application of strength that is most useful to the participants in the context of their sport, a key consideration in RQ3.

It is widely accepted that dynamic warm-ups provide a better carry over for dynamic performance activity than a static stretch protocol (Chatzopoulos et al., 2014; Faigenbaum et al., 2005; Zmijewski et al., 2020), and the warm up (Table 3), was designed to meet the criteria of aerobic activity, multiple planes of motion, several lines of movement and full range of motion, whilst also being something that can be delivered to a large group by a single coach.

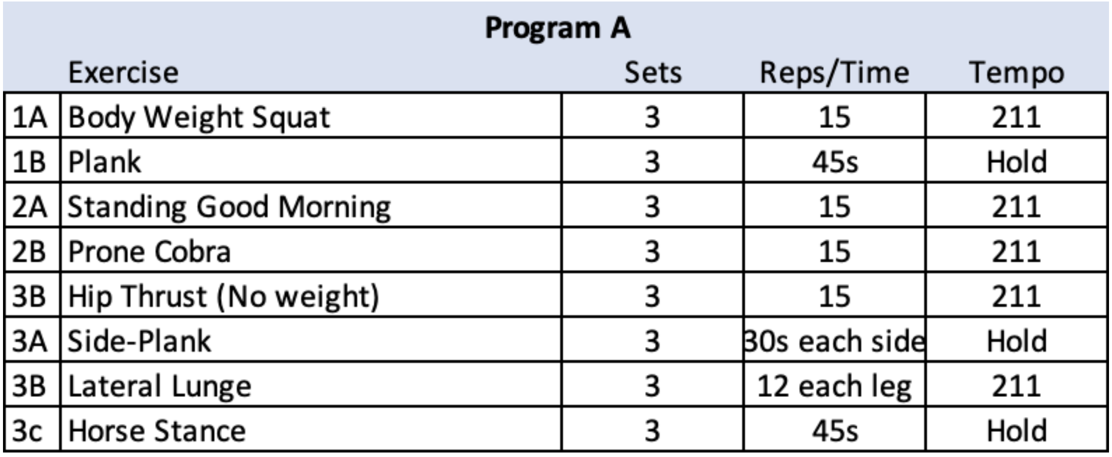
Table 3 - Description of an On-Field Warm-Up Protocol



On Field Warm-Up Protocol
Crawl out x 3
Crawl out with spinal rotation x 3
Crawl out with hip rotation x 3
Reverse lunge with high reach x 5 each leg
Lateral lunge with front reach x 5 each leg
Scorpions x 5 each way
Iron Cross x 5 each way
Plank to down dog x 10
Sumo squat hold and sway x 30s

Program A (shown in Table 4) was mostly bilateral in nature for the leg exercises, interspersed with isometric core exercises. The core exercises of plank and side plank were selected because they also challenge the lower body and the integration of different sections of the body. It was also designed as a precursor to the movement patterns in programs B and C (as shown in Tables 5 and 6), which introduced a more unilateral approach, challenging the legs independently and in a context with more transferable application to Australian football. Program C, which replaced program A after three weeks, introduced an element of plyometric activity, as bodyweight jump squats, designed to add some eccentric loading into the program and to help participants learn how to control load as they bent the knee into flexion.

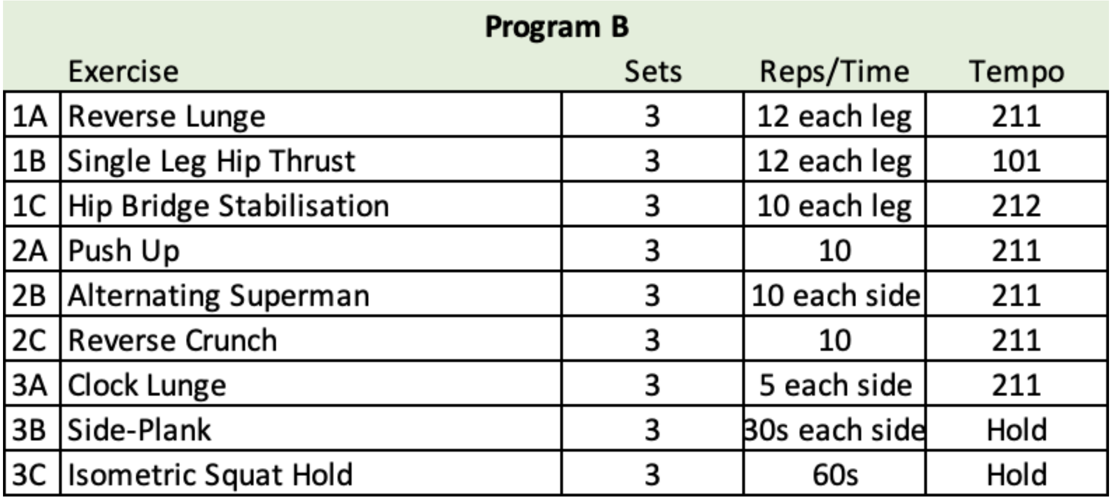
Table 4 - Description of Program A



Program A

	Exercise	Sets	Reps/Time	Tempo
1A	Body Weight Squat	3	15	211
1B	Plank	3	45s	Hold
2A	Standing Good Morning	3	15	211
2B	Prone Cobra	3	15	211
3B	Hip Thrust (No weight)	3	15	211
3A	Side-Plank	3	30s each side	Hold
3B	Lateral Lunge	3	12 each leg	211
3c	Horse Stance	3	45s	Hold

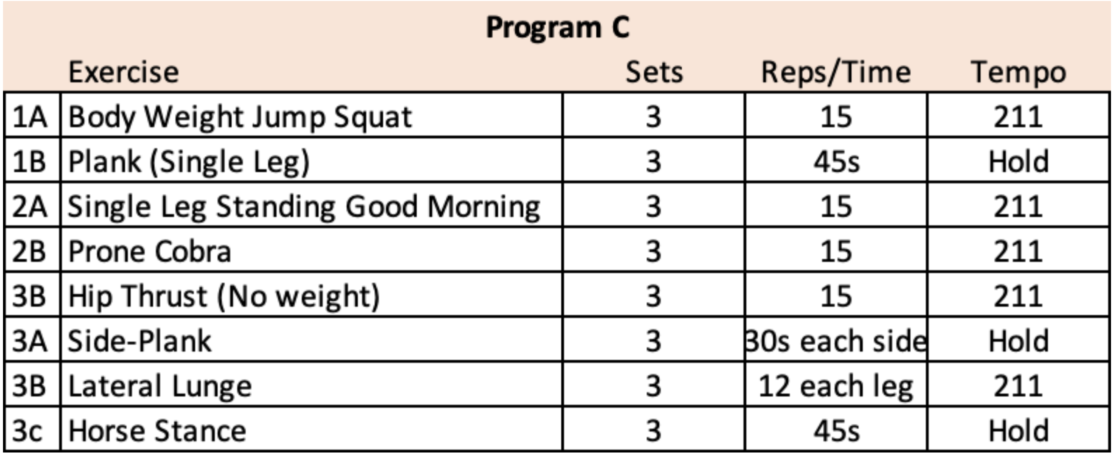
Table 5 - Description of Program B



Program B

	Exercise	Sets	Reps/Time	Tempo
1A	Reverse Lunge	3	12 each leg	211
1B	Single Leg Hip Thrust	3	12 each leg	101
1C	Hip Bridge Stabilisation	3	10 each leg	212
2A	Push Up	3	10	211
2B	Alternating Superman	3	10 each side	211
2C	Reverse Crunch	3	10	211
3A	Clock Lunge	3	5 each side	211
3B	Side-Plank	3	30s each side	Hold
3C	Isometric Squat Hold	3	60s	Hold

Table 6 - Description of Program C

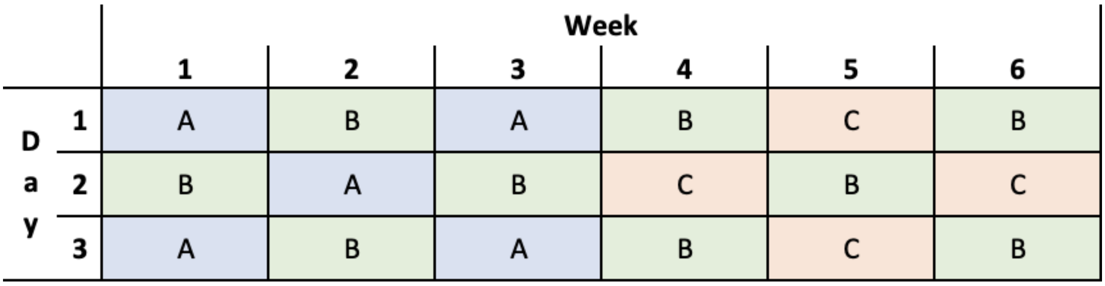


Program C

	Exercise	Sets	Reps/Time	Tempo
1A	Body Weight Jump Squat	3	15	211
1B	Plank (Single Leg)	3	45s	Hold
2A	Single Leg Standing Good Morning	3	15	211
2B	Prone Cobra	3	15	211
3B	Hip Thrust (No weight)	3	15	211
3A	Side-Plank	3	30s each side	Hold
3B	Lateral Lunge	3	12 each leg	211
3c	Horse Stance	3	45s	Hold

Programs were conducted in an alternating pattern (as shown in Table 7), so that in week one, program A was conducted on days one and three (Monday and Friday), with program B on day two (Wednesday). In week two, program B was conducted on days one and three (Monday and Friday) and program A on day two (Wednesday). This pattern repeated throughout the project. After three weeks, program C replaced program A, but program B remained.

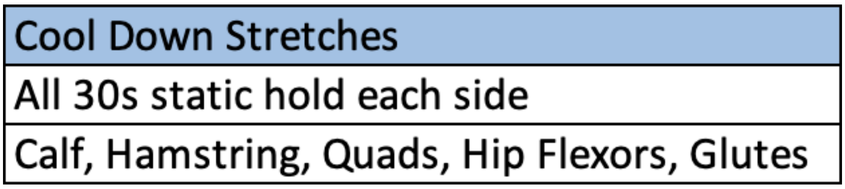
Table 7 - Description of Program Schedule



		Week					
		1	2	3	4	5	6
Day	1	A	B	A	B	C	B
	2	B	A	B	C	B	C
	3	A	B	A	B	C	B

The post-exercise stretches (shown in Table 8) were designed to be static, longer hold in nature, and were offered at the end of every session, however, participants were often continuing directly into a skills session with their team coach, which meant cooling down and stretching for long periods was unnecessary.

Table 8 - Description of Post-Exercise Cool-Down Stretches



Cool Down Stretches
All 30s static hold each side
Calf, Hamstring, Quads, Hip Flexors, Glutes

3.7 Data Collection

Initial assessment and testing data were collected over a period of two weeks, during which time participants were tested in pods of up to three people. This allowed for an efficient use of time, whereby the participants could rotate through the battery of tests, recovering as another participant was tested. It also added some flexibility in the event of some participants not being present on any specific training day at the club.

Post-intervention testing of anthropometrics (i.e., height, weight, BMI), leg strength (BSS) and agility (AgT), was conducted as per pre-intervention testing protocol, and completed within two weeks of the conclusion of the intervention program to minimise any decline in physical performance. G1 were prioritised for this reason, although G2 data were collected during the same period.

3.8 Data Analysis

SPSS statistical software (version 27), was used for all statistical analyses.

Descriptive data for each of the variables is presented in Chapters 4.2.1 – 4.2.4, showing mean values (including pre- and post-test mean changes), standard deviations, range, minimum and maximum values, skewness, and kurtosis. As well as providing insights into numerical changes, these provide the foundation values used in the analysis of variance (ANOVA), analysis of co-variance (ANCOVA), and correlational analyses applied in relation to addressing the RQs.

Skewness and kurtosis were recorded because statistical analyses such as these assume normality of data, yet the cohort size and athletic demographic may show deviations from normal distribution.

RQ1 requires the application of Pearson product-moment correlation coefficient analysis to observe correlational relationships between relevant variables and is shown in Chapter 4.5.1, as a correlation matrix (see Figure 29).

RQ2 required analysis of variance (ANOVA) as there is a pre- and post-intervention, measuring longitudinal change. This is not correlational but causative, although as both groups were not assigned randomly, only tentative causative conclusions can be drawn from the design.

ANOVAs were applied to all variables using the paired samples Students *t*-Test, comparing means for pre- and post-intervention testing. Due to the small and unequal group sizes between group means analyses were applied using a one-way Welch's ANOVA on changed values. An analysis of co-variance (ANCOVA) was used to moderate, or covary for, potential confounding variables where there was a noticeable difference between the groups in pre-test data. Confidence levels were set at 95% with a probability-value of $p \leq 0.05$ used to determine statistical significance.

3.9 Validity and Reliability

Two fundamental elements required when testing are validity and reliability, where "validity is the degree to which a test or test item measures what it is supposed to measure and where reliability is a measure of the degree of consistency or repeatability of a test. A test must be reliable to be valid, because highly variable results have little meaning" (Haff & Triplett, 2015b, pp. 250-251).

It was important, in the context of the project, that these measures could be used in a workplace environment and as such the instrumentation and testing protocols need to be carefully selected to meet the appropriate mechanical and procedural levels.

When considering the instrumentation of scales, for recording body weight, and tape measure, for recording height, both are reliable and can be repeated several times in quick succession to confirm validity of results. Using the same scales, tape, location, and surface for all participants in both pre-and post-test regulates the procedure providing consistency and reliability.

The BSS accurately measures leg strength in a way that is safe for the participants and meaningful for the purposes of context in the project. Because of the fixed and robust nature of the equipment involved (bench and pad) and the protocols outlined in section 3.5.4, the results drawn from the research can be considered valid. The consistency of the research setting and the researcher conducting all testing supports the notion of reliability.

The FreeLap timing system used for the AgT trials, declares an "accuracy of 2/100 seconds which is similar to single beam photocell timing systems for running events" (Freelap, 2020). This speaks to its validity from a mechanical and accuracy standpoint, and the protocol for recording three time trials per participant, per test day, using the best of those times for final data analyses, serves to eliminate any doubt. The T-Test itself has been shown to be reliable in research (Paoule et al., 2000) and provides a broad and deep pool of data from which to compare results and draw inferences.

Since testing was conducted outside, measurement was potentially subject to environmental inconsistencies, but all testing, on both days, were conducted in dry conditions, on the same surface. Participants were asked, where possible, to wear the same footwear and the researcher conducted testing on all occasions, creating a high degree of reliability.

3.10 Ethical Considerations

The risk category for the project itself was 'low risk' – there was potential for some muscular discomfort because of the intervention, but no risk of harm. There was an element of inconvenience – the project required significant time commitment from the participants, but the potential benefits of minimising injury risk (where injury is a significant barrier to participation in the sport) could be viewed as a reasonable mitigation. The UniSQ Human Research Ethics Committee granted approval for the project (H19REA170), and because the participants were minors, appropriate permission, endorsement and clearances from the relevant junior AFL Club President, coaches and parents/guardians were also collected.

The Information Privacy Act 2009 (Queensland Government, 2017), provided the basis for gathering, using, and storing personal information of the subjects. Information was collected in the form of personal data, informed consent, and relevant anthropometric and performance measurements. All participants were provided with an information sheet which detailed:

- The purpose of the study, including a background as to why it will be valuable in the professional space;
- The researcher's background and qualifications to conduct the study;
- The format the study will take and what will be expected of the participants to ensure the study remains reliable, consistent and credible;
- Benefits and any potential risks associated with the research project; and
- The expected outcomes of the study for the researcher, the profession, the organisation and the participants in question.

Although informed assent/consent were collected, it was also made clear that participants may withdraw from the study at any time without reason or consequence. In reporting the results of the study, all participants remain anonymous, and no data has been shared with third parties. Participants may, upon request, have access to their own data, but will not have access to any other data collected except as presented in the results wherein participants continue to remain anonymous.

Limitations

Some obvious limitations with the study can be observed, including:

> **Other influencing factors.** Although the aim of the study is to investigate the influence of a leg strength to body weight ratio on the performance of agility tests, the nature of the activity means there can be several other factors that may influence results;
>
> **Research setting.** It must be recognised that the research setting, as a workplace, presents some challenges that may affect consistency of control. All results must therefore take this into consideration and any interpretations made account for this in the context of the project as a whole.
>
> **Learning.** Subjects may improve agility performance simply because of knowing what the test entails and being more familiar with it on the retest, however, this threat to findings is somewhat mitigated by the presence of a comparison group.
>
> **Individual skill.** While we can measure any change in test performance after the physical intervention program, there may be some subjects who are simply better coordinated and perform the test better, regardless of leg strength-to-bodyweight ratio, however, this threat too is somewhat mitigated by the presence of a comparison group.
>
> **Participant individual wellbeing.** While protocols for testing

will be provided, the nature of the testing provides a snapshot of the individual and if they underperform due to illness (potentially unknown at the time) or personal issues which may affect motivation, then results may be affected.

Program adherence. Each subject had access to the intervention program on the Teambldr app. Two of the three recommended sessions were supervised, but the third relied on participant honesty and proficiency for completion.

Group size. The relatively low group sizes mean all conclusions can only be tentative and serve to indicate if further research in the area might be beneficial.

Agility as a predictor of lower limb injury. As stated above, there is little literature to indicate agility alone is a predictor of lower limb injury risk.

Expected Outcomes

The outcomes of the research, based on literature and the researcher's experience, are that there will be a correlational relationship of LSBWR and AgT performance. The unclear element at this point will be whether there is an *optimum* relationship. It seems logical that there would be an apex in the relationship where bodyweight becomes a hinderance to agility performance regardless of leg strength. Considering the group size, it seems unlikely that there will be enough datapoints to uncover this relationship. Additionally, the study population narrows the likelihood that the cohorts involved would reach that apex since, by definition, they are athletic, and natural selection would remove them from the demographic where bodyweight becomes a consideration in performance.

With respect to a field-based intervention program versus a traditional gym-based program with resistance equipment, the research design does not serve to compare the two but is designed to determine if benefits can be elicited without the use of traditional equipment to make the program more accessible to athletes and coaches. It is expected that there will be some improvement in leg strength performance in the intervention group over the comparison group.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results of the project through descriptive and inferential data. Section 4.2. presents descriptive data in tabular and figurative form. Section 4.3 provides within groups analyses before section 4.4 shows between groups analyses. Section 4.5 presents correlational data and scatterplots showing trend analysis between variables.

One subject in each group did not complete the project and could not participate in the post-testing. One of these subjects withdrew to have surgery and the other withdrew due to injury occurring from circumstances outside the influence of the project. Consequently, their data are excluded from the results.

4.2 Descriptive Statistics

In the following tables and figures, ‘pre-test’ indicates initial testing and ‘post-test’ indicates testing conducted after six weeks, during which G1 undertook the physical training intervention and G2 continued with their normal training regime. The change column shows differences between the two groups after the intervention. Figures show pre- versus post-intervention data for each group.

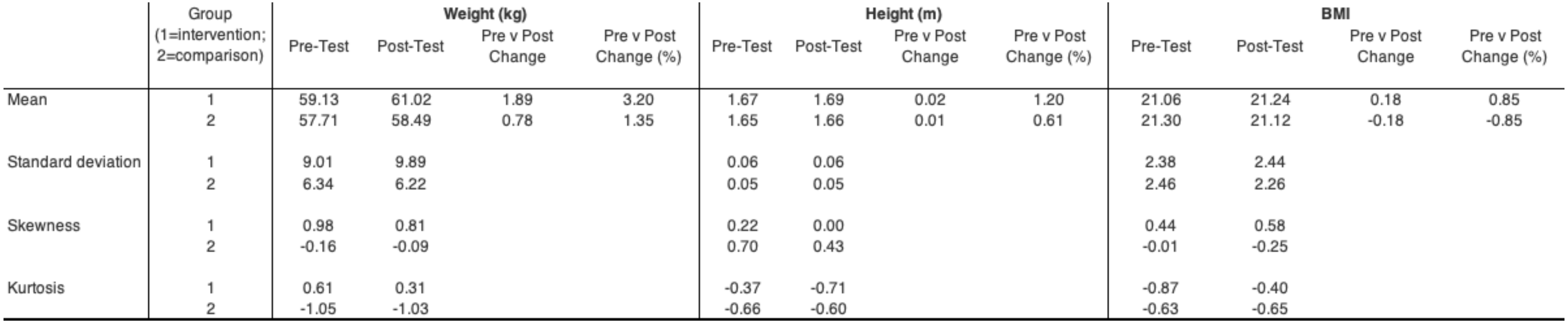
4.2.1 Weight, Height, and BMI

Weight is an important variable for consideration in this research project. When combined with leg strength it provides the foundation for the leg strength-bodyweight ratio used in conjunction with agility trials to allow analysis of RQ1. Height has been recorded as a common anthropometric measure, but also to aid the calculation of BMI, which is another way of inferring height versus weight as described in Methodology chapter 3.5.3.

Large changes in the weight, height and BMI of the participants were not expected and, as shown in Table 9 and Figures 23, 24 and 25, not observed, although G1 were on average, 1.42kg heavier at pre-test and 2.53kg heavier at post-test than G2. Participants in G1 were also 2-3cm taller, potentially accounting for some of the weight differences and resulting in a BMI that was similar for both groups.

The skewness and kurtosis data in Table 9 show mostly acceptable levels of parametric distribution in both groups for all variables, although less variability in the weight data for G2 can also be observed at both pre- and post-test.

Table 9 - Descriptive Data for Weight, Height and BMI



	Group (1=intervention; 2=comparison)	**Weight (kg)**				**Height (m)**				**BMI**			
		Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)
Mean	1	59.13	61.02	1.89	3.20	1.67	1.69	0.02	1.20	21.06	21.24	0.18	0.85
	2	57.71	58.49	0.78	1.35	1.65	1.66	0.01	0.61	21.30	21.12	-0.18	-0.85
Standard deviation	1	9.01	9.89			0.06	0.06			2.38	2.44		
	2	6.34	6.22			0.05	0.05			2.46	2.26		
Skewness	1	0.98	0.81			0.22	0.00			0.44	0.58		
	2	-0.16	-0.09			0.70	0.43			-0.01	-0.25		
Kurtosis	1	0.61	0.31			-0.37	-0.71			-0.87	-0.40		
	2	-1.05	-1.03			-0.66	-0.60			-0.63	-0.65		

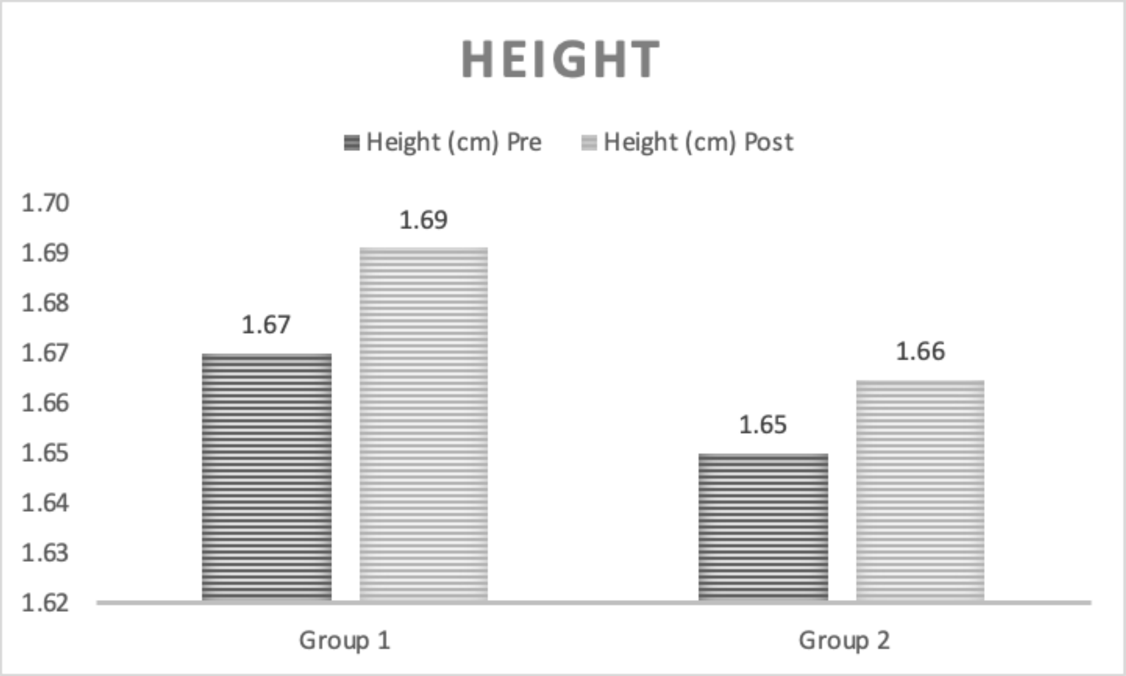


Figure 23 - Bar Chart Illustrating Pre versus Post Intervention Height for Groups 1 and 2

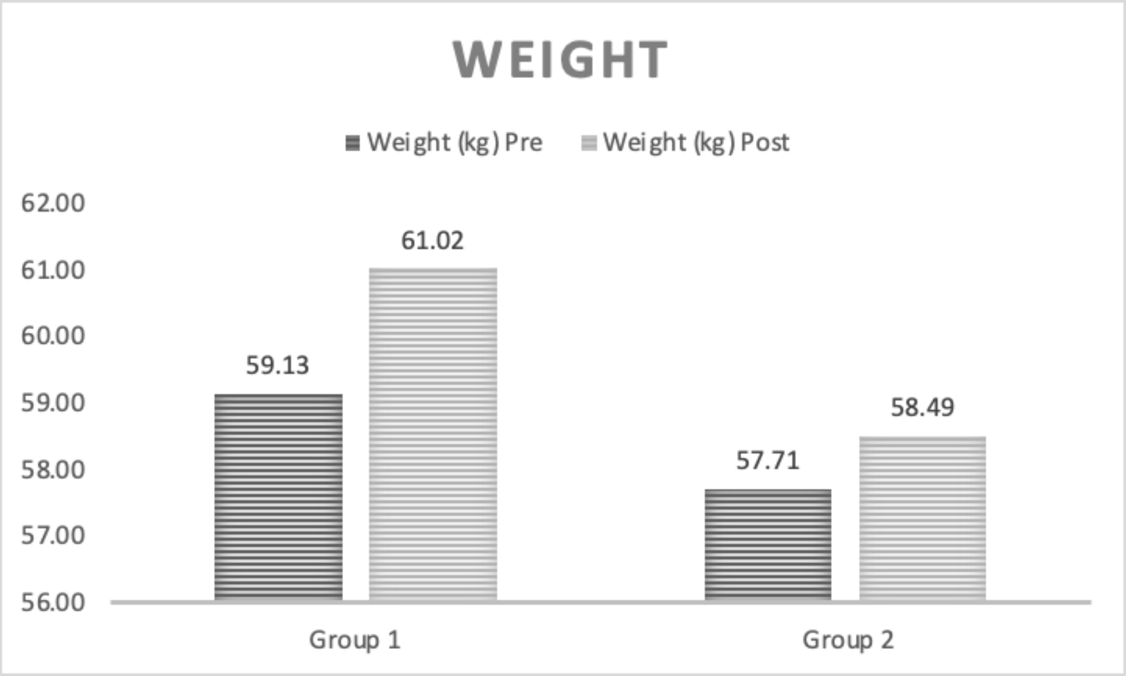


Figure 24 - Bar Chart Illustrating Pre versus Post InterventionWeight for Groups 1 and 2

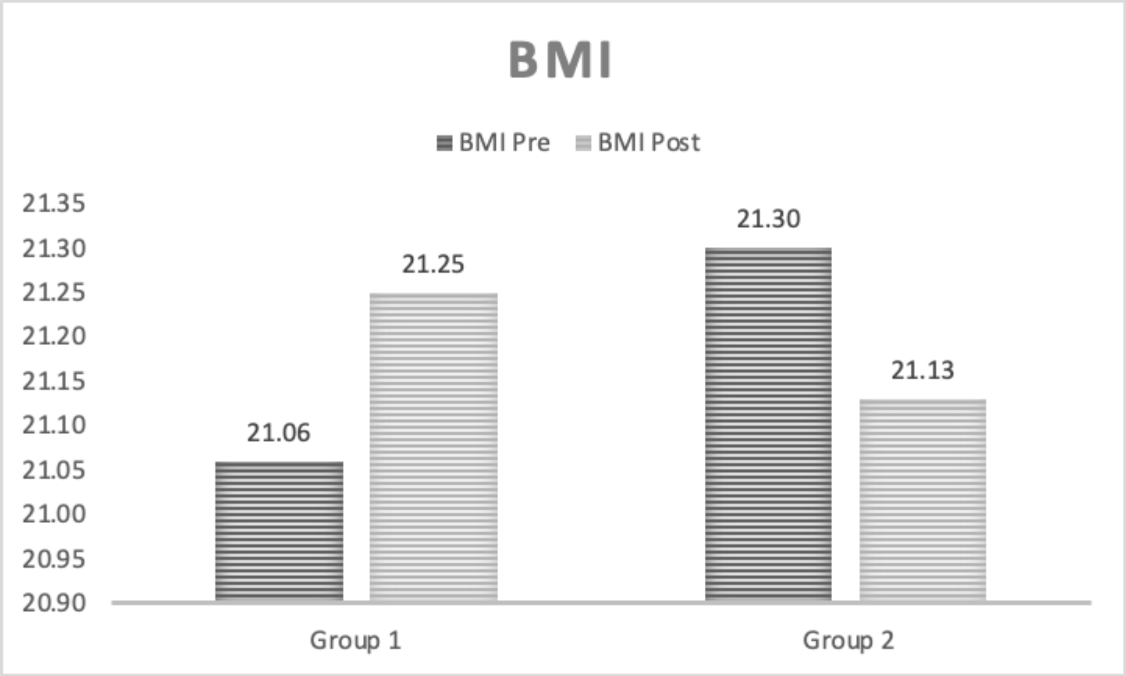


Figure 25 - Bar Chart Illustrating Pre versus Post BMI for Groups 1 and 2

4.2.2 Bulgarian Split Squat

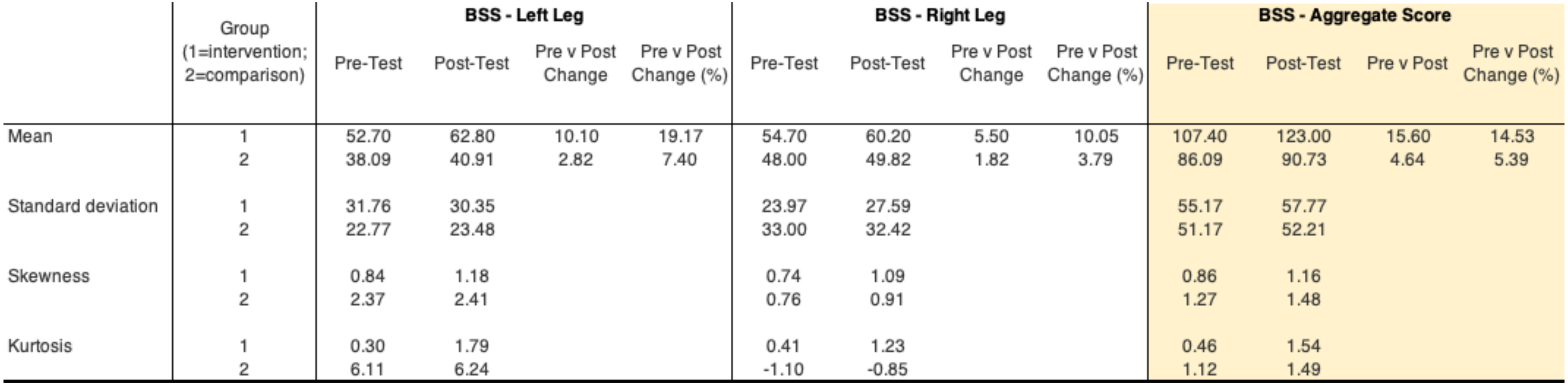
The Bulgarian Split Squat (BSS) was used as the measure for leg strength. In the context of the sport and relationship to injury risk, measurement of each leg independently contributes to an expanded discussion of the results and inferences in the conclusions. For both G1 and G2, an improvement in leg strength in both legs can be observed. G1 recorded a greater improvement in both legs than G2, and the increase in strength was better in both groups for the left leg than the right leg. G1 showed a 19.17% improvement in the left leg versus a 10.05% improvement in the right leg. G2 showed a 7.4% increase in strength on the left leg versus a 3.79% increase in the right leg.

For analysis in this project, as explained in the Methodology chapter 3.5.4, the aggregate value of both the left and right leg was used to calculate the leg strength-body weight ratio (LSBWR). An increase in the aggregate mean score for both groups was observed, with the increase for G1 at 14.5% and G2 at 5.4%. On average, G1 performed better on both pre- and post-tests, with a mean aggregate leg strength score of 21.3 more than G2 in the pre-test and 32.3 in the post-test.

The standard deviation was large in both groups at pre-test (G1-31.76, G2-22.77), but narrowed slightly in the post-test for G1 (30.35) and broadened slightly for G2 (23.48).

There was parametric distribution in G1 for the initial testing, but moderate positive skewness and leptokurtic distribution in the post-intervention test. G2 indicated strong positive skewness and strong leptokurtic distribution for both pre- and post-test results.

Table 10 - Descriptive Data for Bulgarian Split Squat



	Group (1=intervention; 2=comparison)	**BSS - Left Leg**				**BSS - Right Leg**				**BSS - Aggregate Score**			
		Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post	Pre v Post Change (%)
Mean	1	52.70	62.80	10.10	19.17	54.70	60.20	5.50	10.05	107.40	123.00	15.60	14.53
	2	38.09	40.91	2.82	7.40	48.00	49.82	1.82	3.79	86.09	90.73	4.64	5.39
Standard deviation	1	31.76	30.35			23.97	27.59			55.17	57.77		
	2	22.77	23.48			33.00	32.42			51.17	52.21		
Skewness	1	0.84	1.18			0.74	1.09			0.86	1.16		
	2	2.37	2.41			0.76	0.91			1.27	1.48		
Kurtosis	1	0.30	1.79			0.41	1.23			0.46	1.54		
	2	6.11	6.24			-1.10	-0.85			1.12	1.49		

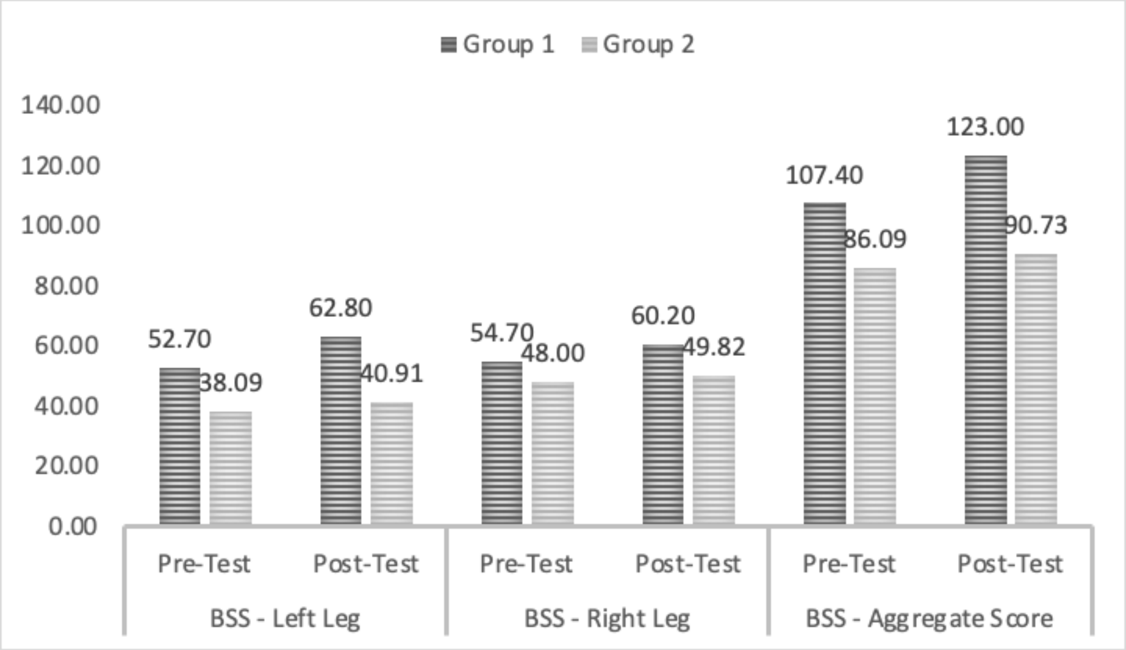


Figure 26 - Bar Chart Illustrating Pre versus Post Bulgarian Split Squat for Groups 1 and 2

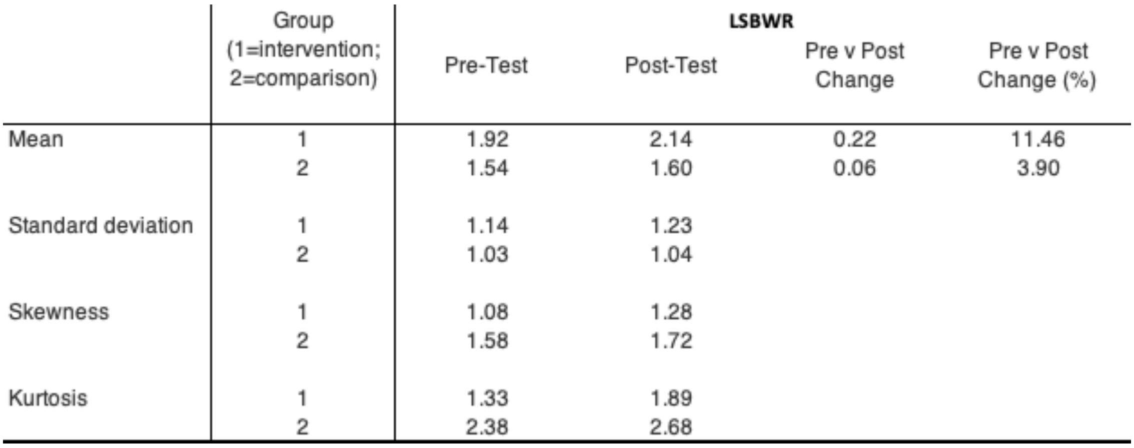
4.2.3 Leg Strength-Body Weight Ratio

The Leg Strength-Body Weight Ratio (LSBWR) ratio was created by dividing the subjects aggregate leg strength result by their weight. Thus, the higher the ratio, the greater the leg strength when related to body weight. Table 11 and Figure 27 show G1 recorded higher means in both pre- and post-test than G2 and although an increase in ratio number for both groups was observed, the increase for G1 was greater at 11.46% compared to G2 at 3.9%.

Standard deviation was wide in both groups at pre-test but showed negligible post-test change (G1 = 1.14 to 1.23; G2 = 1.03 to 1.04).

There is a slight positive skewness for both groups at pre-test, as well as leptokurtic distribution. The post-test results showed a shift towards a more positive skew and a higher leptokurtic distribution.

Table 11 - Descriptive Data for Leg Strength - Bodyweight Ratio



	Group (1=intervention; 2=comparison)	LSBWR			
		Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)
Mean	1	1.92	2.14	0.22	11.46
	2	1.54	1.60	0.06	3.90
Standard deviation	1	1.14	1.23		
	2	1.03	1.04		
Skewness	1	1.08	1.28		
	2	1.58	1.72		
Kurtosis	1	1.33	1.89		
	2	2.38	2.68		

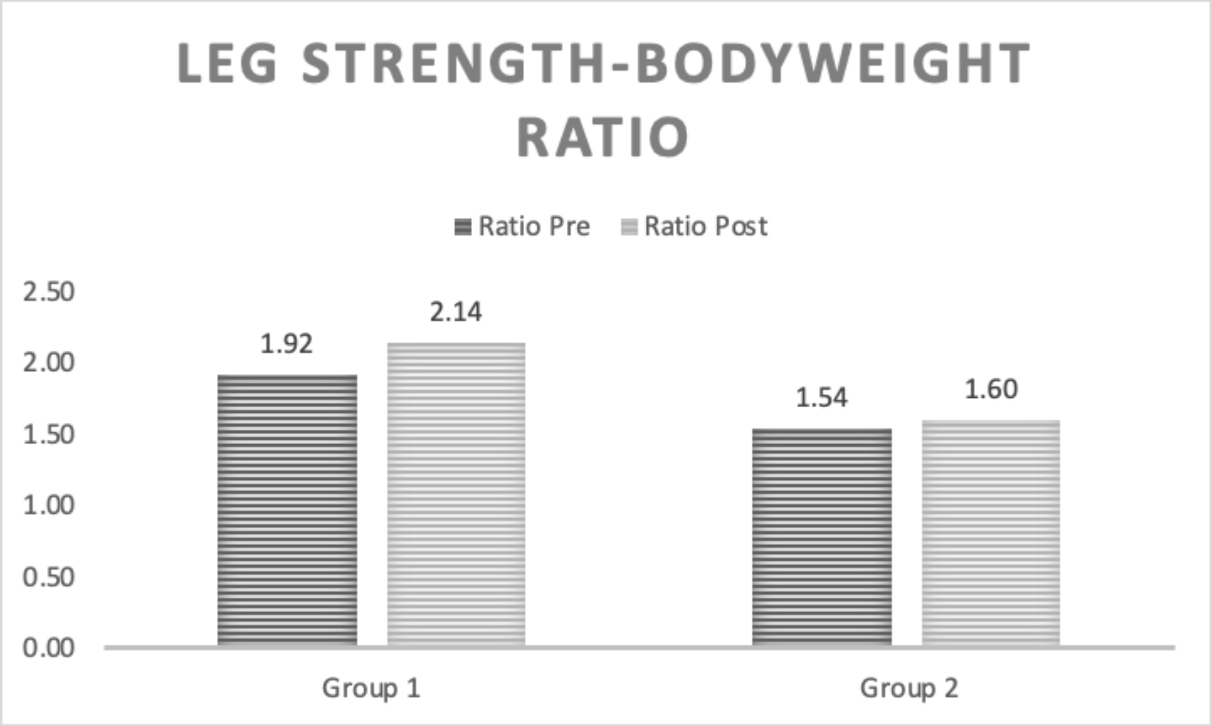


Figure 27 - Bar Chart Illustrating Pre versus Post Intervention Leg Strength - Bodyweight Ratio for Groups 1 and 2

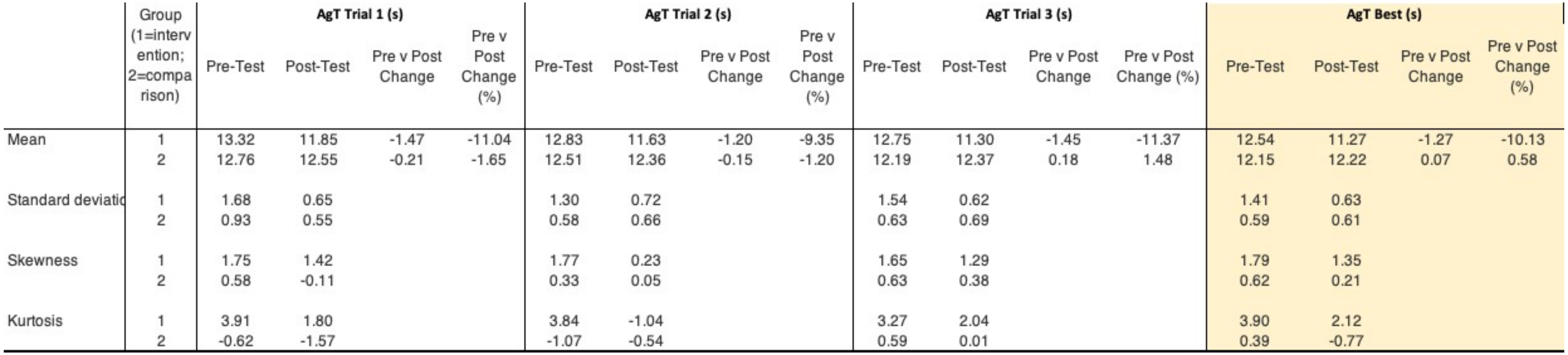
4.2.4 Agility T-test

The agility T-test (AgT) is not a statistical measure and is not related to the paired-samples *t*-Test reported later. Instead, this test is used as a measure of agility performance of the time taken to complete the course. Each subject ran three trials for each test day (pre- and post-intervention), with means recorded as AgT Trial 1, 2 and 3 respectively in seconds (s) in Table 12 below. The fastest (best) trial time recorded was used to calculate the 'best' mean score which was used for correlational statistical analyses. G1 show a 10.1% *decrease* in the time it took to complete the course. G2 show an *increase* in the time it took to complete the course of 0.6%.

Standard deviation is relatively small for the AgT in the pre-test (G1 = 1.41, G2 = 0.59), but G1 shows a large change in the post-test result (0.63), where G2 remain virtually the same (0.61).

There was a slight positive skew for G1 in the pre-and post-test, whilst G2 showed normal distribution. G1 results showed high leptokurtic distribution at pre-test, which reduced slightly at post-test, whilst G2 showed normal kurtosis in both pre- and post-tests.

Table 12 - Descriptive Data for Agility T-Test Trials



	Group (1=intervention; 2=comparison)	**AgT Trial 1 (s)**				**AgT Trial 2 (s)**				**AgT Trial 3 (s)**				**AgT Best (s)**			
		Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)	Pre-Test	Post-Test	Pre v Post Change	Pre v Post Change (%)
Mean	1	13.32	11.85	-1.47	-11.04	12.83	11.63	-1.20	-9.35	12.75	11.30	-1.45	-11.37	12.54	11.27	-1.27	-10.13
	2	12.76	12.55	-0.21	-1.65	12.51	12.36	-0.15	-1.20	12.19	12.37	0.18	1.48	12.15	12.22	0.07	0.58
Standard deviatic	1	1.68	0.65			1.30	0.72			1.54	0.62			1.41	0.63		
	2	0.93	0.55			0.58	0.66			0.63	0.69			0.59	0.61		
Skewness	1	1.75	1.42			1.77	0.23			1.65	1.29			1.79	1.35		
	2	0.58	-0.11			0.33	0.05			0.63	0.38			0.62	0.21		
Kurtosis	1	3.91	1.80			3.84	-1.04			3.27	2.04			3.90	2.12		
	2	-0.62	-1.57			-1.07	-0.54			0.59	0.01			0.39	-0.77		

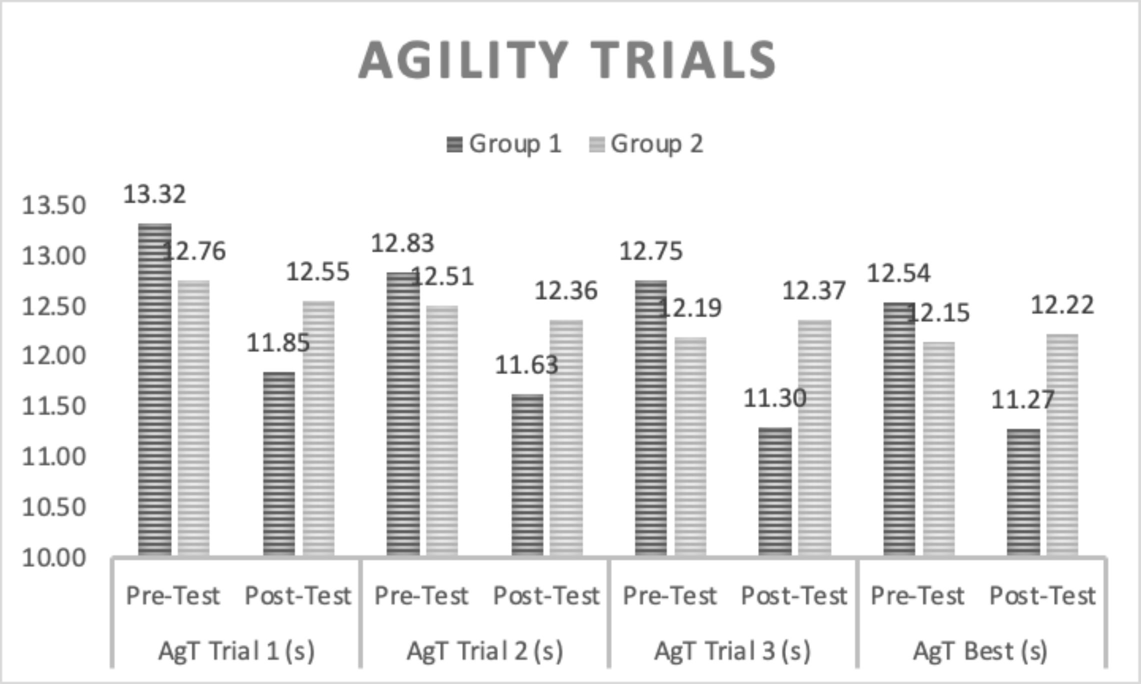


Figure 28 - Bar Chart Illustrating Pre versus Post Intervention Agility T-Test Trials for Groups 1 and 2

4.3 Within Group Analysis

Considering the group sizes and the research design, the most appropriate way to within group difference was to use a paired samples *t*-Test. This test was applied to analyse within group pre- versus post-intervention data, with confidence intervals set at 95%.

Excluded from these analyses are the results for weight, height, and BMI, since it is obvious there would be no significant change in these data. Statistical significant difference was observed for G1 in the left leg for BSS ($p < 0.05$) and in all AgT trials ($p < 0.001$). For G2, significant difference can be seen in left leg and aggregate BSS scores ($p < 0.05$) and in trial 3 for AgT ($p < 0.01$).

Table 13 - Results of a Paired Samples Student's *t*-Test for Means of Bulgarian Split Squat, Leg Strength - Bodyweight Ratio and Agility Trials (in seconds)

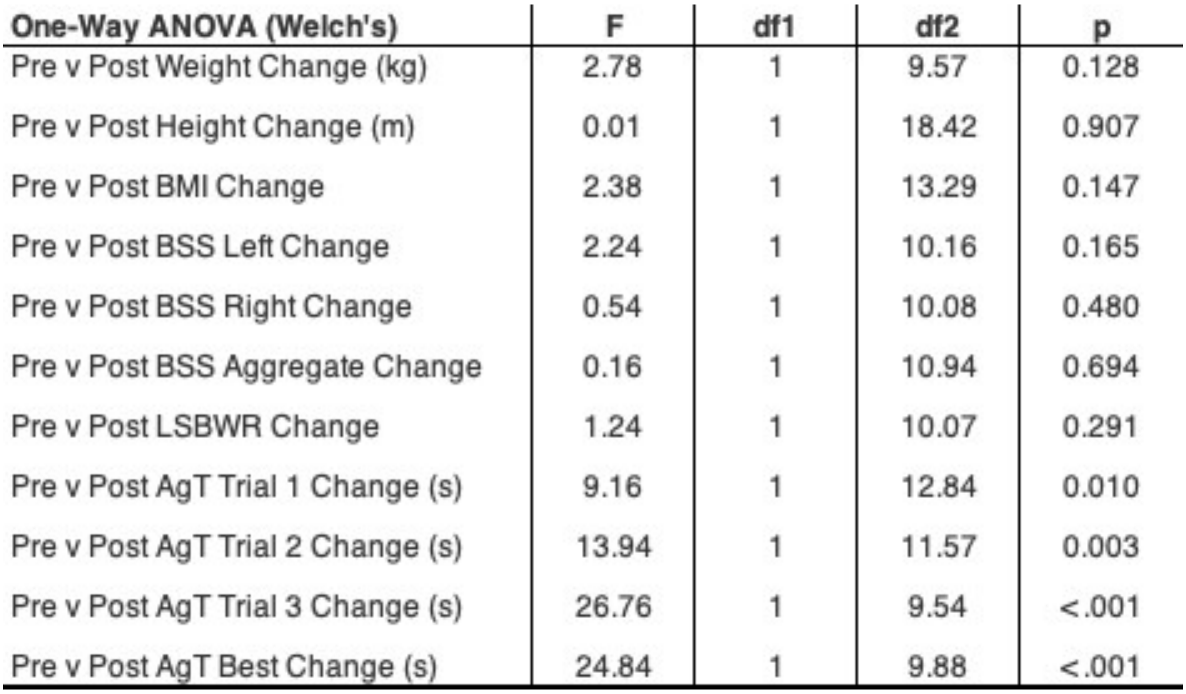
Paired Samples t-Tests	Group	t-statistic	df	p	Mean difference	95% Confidence Interval	
						Lower	Upper
BSS - Left Leg	1	2.14	9	0.061	10.1	-0.57	20.77
	2	2.35	10	0.040	2.82	0.15	5.49
BSS - Right Leg	1	1.13	9	0.289	5.5	-5.53	16.53
	2	1.52	10	0.160	1.82	-0.85	4.49
BSS- Aggregate	1	1.70	9	0.123	15.6	-5.11	36.31
	2	2.20	10	0.052	4.64	-0.06	9.33
LSBWR	1	1.57	9	0.151	0.22	-0.10	0.54
	2	1.73	10	0.114	0.06	-0.02	0.14
AgT Trial 1 (s)	1	-3.92	9	0.003	-1.46	-2.31	-0.62
	2	-1.24	10	0.245	-0.22	-0.61	0.17
AgT Trial 2 (s)	1	-4.53	9	0.001	-1.19	-1.79	-0.60
	2	-1.40	10	0.190	-0.14	-0.36	0.08
AgT Trial 3 (s)	1	-4.70	9	0.001	-1.45	-2.15	-0.75
	2	3.20	10	0.009	0.17	0.05	0.29
AgT Best (s)	1	-4.84	9	<.001	-1.27	-1.87	-0.68
	2	1.20	10	0.256	0.07	-0.06	0.20

4.4 Between Groups Analysis

4.4.1 Analysis of Variance

To analyse between group differences, a Welch's one-way ANOVA has been applied to the mean changes for each. Table 14 shows the analyses demonstrate statistically significant difference in all AgT trials, with the 'Best' AgT trial demonstrating high significance ($p < 0.001$). The remaining data does not demonstrate statistical significance.

Table 14 - Results of a Between Groups One-Way ANOVA

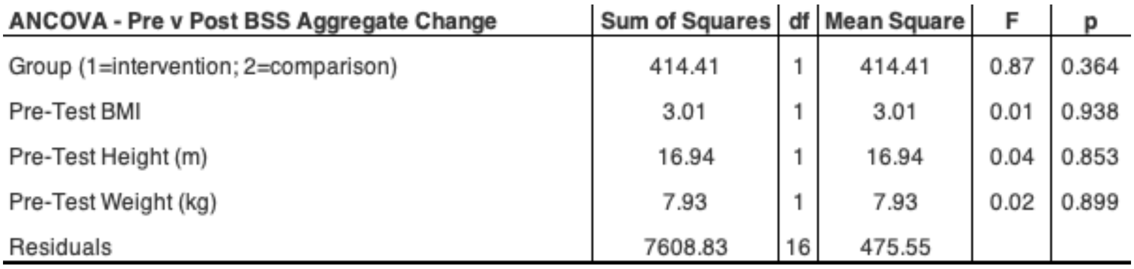


One-Way ANOVA (Welch's)	F	df1	df2	p
Pre v Post Weight Change (kg)	2.78	1	9.57	0.128
Pre v Post Height Change (m)	0.01	1	18.42	0.907
Pre v Post BMI Change	2.38	1	13.29	0.147
Pre v Post BSS Left Change	2.24	1	10.16	0.165
Pre v Post BSS Right Change	0.54	1	10.08	0.480
Pre v Post BSS Aggregate Change	0.16	1	10.94	0.694
Pre v Post LSBWR Change	1.24	1	10.07	0.291
Pre v Post AgT Trial 1 Change (s)	9.16	1	12.84	0.010
Pre v Post AgT Trial 2 Change (s)	13.94	1	11.57	0.003
Pre v Post AgT Trial 3 Change (s)	26.76	1	9.54	<.001
Pre v Post AgT Best Change (s)	24.84	1	9.88	<.001

4.4.2 Analysis of Covariance

There were no statistically significant changes in means for the performance data of BSS or LSBWR, but G1 presented consistently greater numerical data in the anthropometric measures of height and weight, therefore an ANCOVA was used to control for those initial differences to see how these might have affected the statistical significance in relation to BSS. Results shown in Table 15 indicate no changes in significance when G1 and G2 BSS data were covaried for BMI, height, or weight.

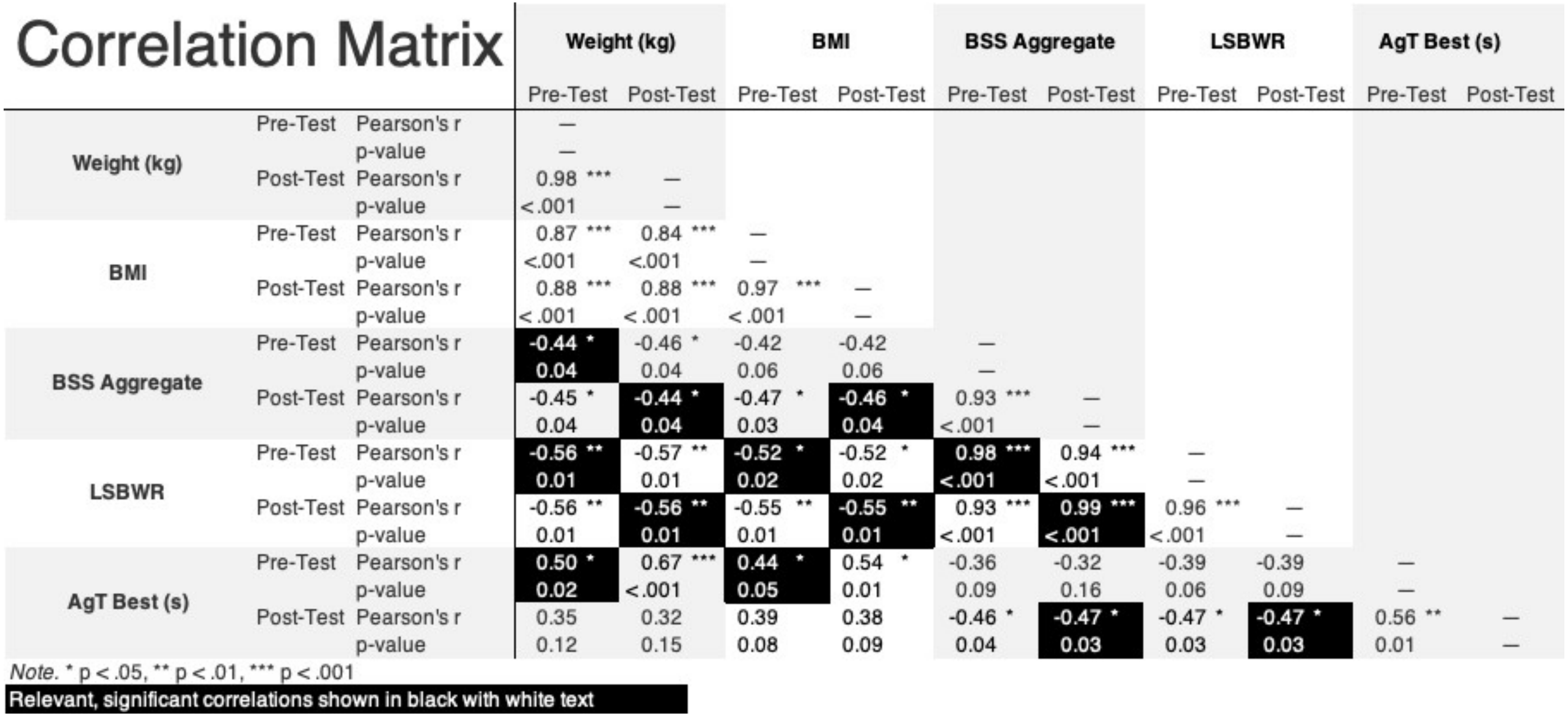
Table 15 - Results of ANCOVA Testing on Bulgarian Split Squat when Covarying for BMI, Height and Weight



ANCOVA - Pre v Post BSS Aggregate Change	Sum of Squares	df	Mean Square	F	p
Group (1=intervention; 2=comparison)	414.41	1	414.41	0.87	0.364
Pre-Test BMI	3.01	1	3.01	0.01	0.938
Pre-Test Height (m)	16.94	1	16.94	0.04	0.853
Pre-Test Weight (kg)	7.93	1	7.93	0.02	0.899
Residuals	7608.83	16	475.55		

4.5 Correlation Results

Pearson product moment correlation coefficients were calculated for correlations between all variables for the combined groups and results are shown in the correlation matrix in Figure 29.



Correlation Matrix

			Weight (kg)		BMI		BSS Aggregate		LSBWR		AgT Best (s)	
			Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Weight (kg)	Pre-Test	Pearson's r	—									
		p-value	—									
	Post-Test	Pearson's r	0.98 ***	—								
		p-value	<.001	—								
BMI	Pre-Test	Pearson's r	0.87 ***	0.84 ***	—							
		p-value	<.001	<.001	—							
	Post-Test	Pearson's r	0.88 ***	0.88 ***	0.97 ***	—						
		p-value	< .001	< .001	< .001	—						
BSS Aggregate	Pre-Test	Pearson's r	-0.44 *	-0.46 *	-0.42	-0.42	—					
		p-value	0.04	0.04	0.06	0.06	—					
	Post-Test	Pearson's r	-0.45 *	-0.44 *	-0.47 *	-0.46 *	0.93 ***	—				
		p-value	0.04	0.04	0.03	0.04	<.001	—				
LSBWR	Pre-Test	Pearson's r	-0.56 **	-0.57 **	-0.52 *	-0.52 *	0.98 ***	0.94 ***	—			
		p-value	0.01	0.01	0.02	0.02	<.001	<.001	—			
	Post-Test	Pearson's r	-0.56 **	-0.56 **	-0.55 **	-0.55 **	0.93 ***	0.99 ***	0.96 ***	—		
		p-value	0.01	0.01	0.01	0.01	<.001	<.001	<.001	—		
AgT Best (s)	Pre-Test	Pearson's r	0.50 *	0.67 ***	0.44 *	0.54 *	-0.36	-0.32	-0.39	-0.39	—	
		p-value	0.02	<.001	0.05	0.01	0.09	0.16	0.06	0.09	—	
	Post-Test	Pearson's r	0.35	0.32	0.39	0.38	-0.46 *	-0.47 *	-0.47 *	-0.47 *	0.56 **	—
		p-value	0.12	0.15	0.08	0.09	0.04	0.03	0.03	0.03	0.01	—

Note. * p < .05, ** p < .01, *** p < .001

Relevant, significant correlations shown in black with white text

Figure 29 - Correlation Matrix for all Variables, Including *r*-values and *p*-values

Figure 29 shows pre-test anthropometrics of weight and BMI correlated with other pre-test variables of BSS, LSBWR and AgT. Pre-test BSS confirmed an expected correlation with LSBWR, but neither BSS nor LSBWR indicated a correlation with AgT in the pre-test data.

In the post-test data, weight, and BMI correlated with BSS and LSBWR, but not with AgT. However, BSS and LSBWR both correlated with AgT. Viewing the data plotted on scatter graphs with trendlines helps to illustrate trends and highlight pre- and post-intervention differences.

4.5.1 Weight and Agility

Figures 30 and 31 show a general trend where lower bodyweight trends towards better AgT results. Figure 30 shows a slight increase in the steepness of the trend in G1 for post-intervention results, but Figure 31 shows no change in G2.

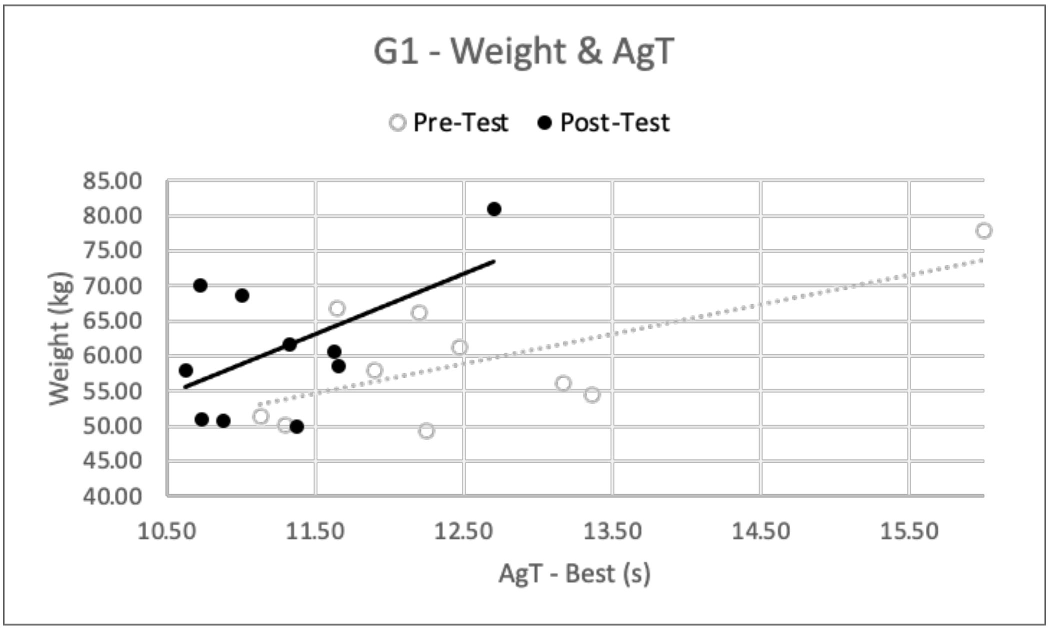


Figure 30 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Weight and Agility for Group 1

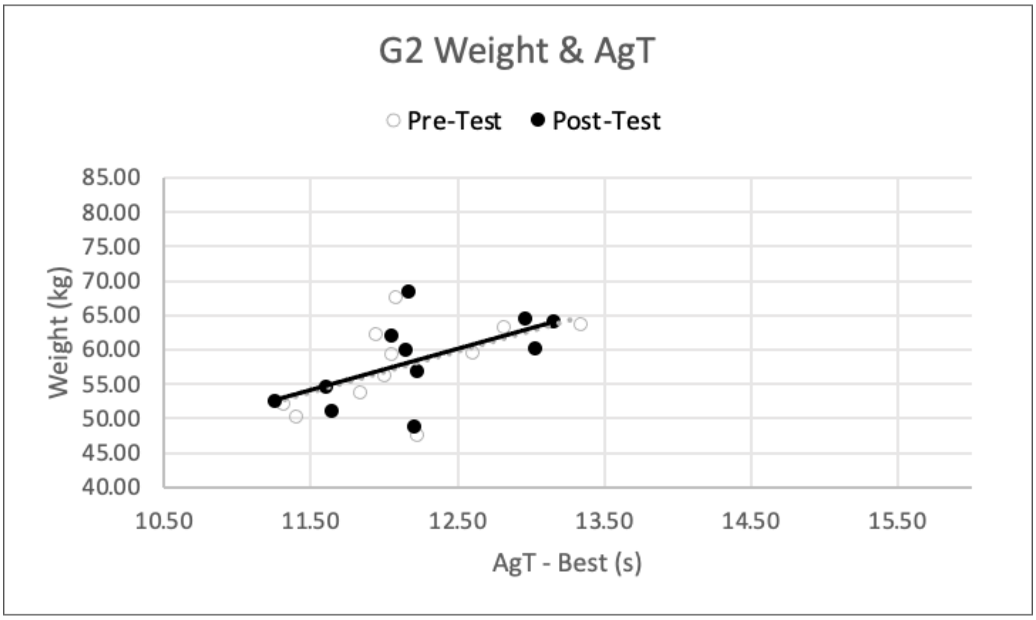


Figure 31 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Weight and Agility for Group 2

4.5.2 Bulgarian Split Squat and Agility

Figures 32 and 33 plot pre- v post- data for BSS against AgT for each group. Figure 32 shows an increased steepness in the trendline for the post-intervention data for G1, while Figure 33 shows no change for G2.

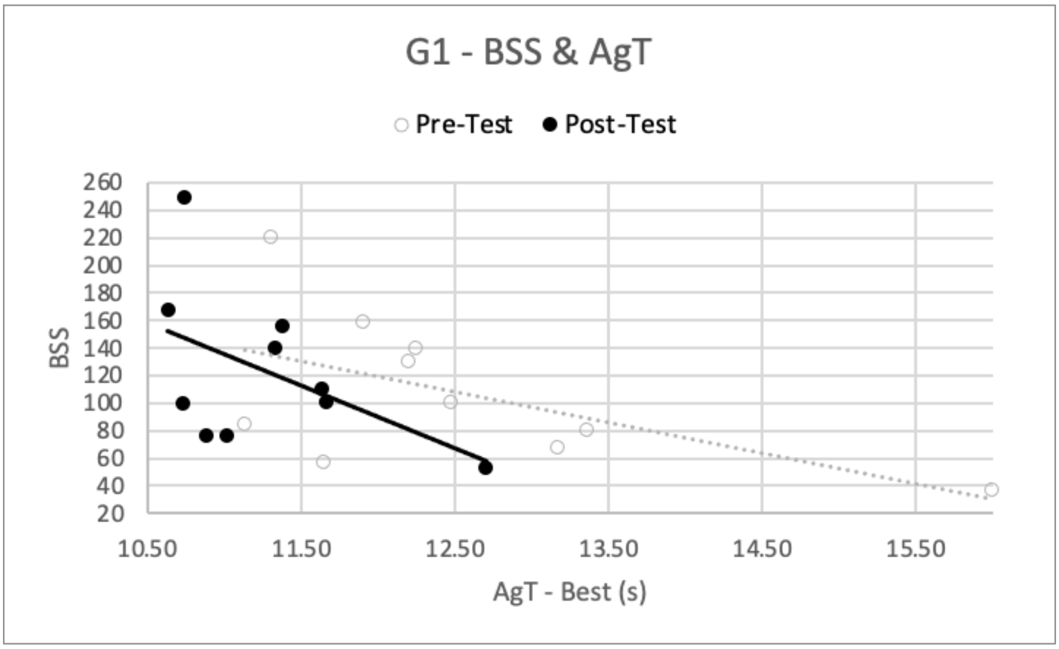


Figure 32 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Bulgarian Split Squat and Agility Time Score for Group 1

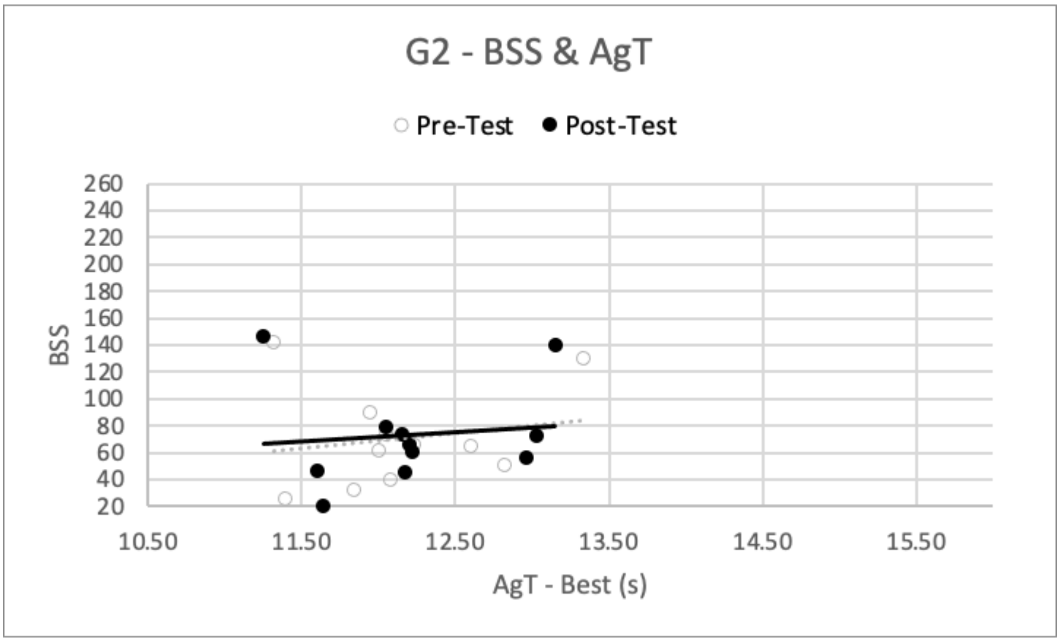


Figure 33 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Bulgarian Split Squat and Agility Time Score for Group 2

4.5.3 Leg Strength-Body Weight Ratio and Agility

Figures 34 and 35 plot pre- versus post-data for LSBWR against AgT for each group. Figure 34 shows a general trend in pre- and post-data for AgT times to decrease as LSBWR increases for G1. There is an increased steepness of the trendline for the post-intervention plot, as compared to the larger spread in the pre-test plot (similar to BSS in Figure 32) and clustering towards faster times for AgT, with the number of results falling below 11.50s also increasing.

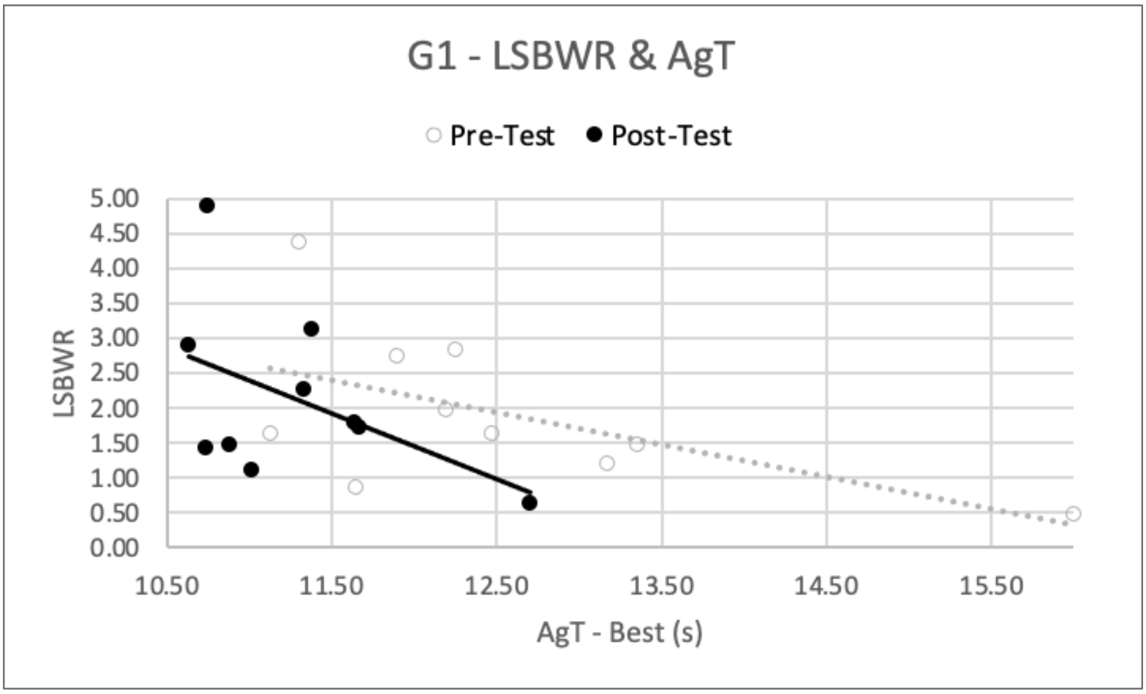


Figure 34 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Leg Strength – Bodyweight Ratio and Agility Time Score for Group 1

Figure 35 shows a similar trendline in the pre-test plot for G2 but shows a decrease in the steepness of the trendline in the post-test plot, with more results falling above 11.50s in the post-test than in the pre-test.

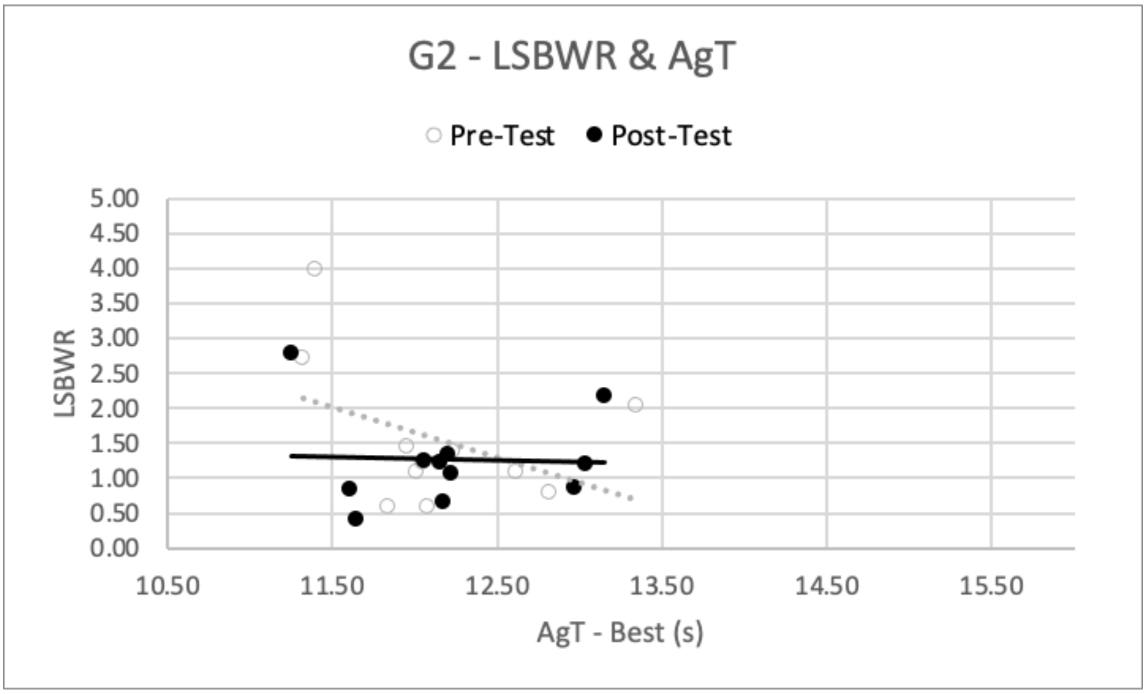


Figure 35 - Scatterplot Illustrating the Pre versus Post Intervention Relationship of Leg Strength – Bodyweight Ratio and Agility Time Score for Group 2

CHAPTER 5: DISCUSSION

5.1 Weight, Height, and BMI

The athletes in the study fell around the 75th percentile for weight, between the 75th and 90th percentile for height, and around the 60th percentile for BMI (InsideOutInstitute, 2022). Since G1 were indicated as the better players, it is perhaps not surprising to see that they were slightly taller and heavier than G2, given the advantages of physical height in the sport of Australian football. However, this difference between groups did not reach statistical significance. For the purposes of this study, it is interesting to note that BMI—which measures relative height to weight—was similar between the two groups, lending value to the discussion around RQ1 and the selection of a relative, versus absolute, leg strength protocol in the methodology, particularly with reference to the Collings et al. (2021) research demonstrating BMI as a risk factor for injury.. With respect to this even though there was, on average, a net increase in weight of 1.11kg more in G1 than G2, there was only a net increase of 1cm in height of G1 over G2, resulting an *increase* in BMI for G1 of 0.19 and a *decrease* in BMI for G2 of -0.17, resulting in a net change of 0.36. These data were not statistically significant but contribute to the greater body of data available for future research.

In summary, there was little change between, pre- and post-measures in either group, which is expected when considering both the short timeframe and the design of the intervention program, for strength (as opposed to hypertrophy—which is associated with increases in lean mass and therefore often weight) gains.

5.2 Bulgarian Split Squat

G1 performed better in the BSS aggregate score pre-test by an average of 21 repetitions, with the gap increasing to 32 repetitions in the post-test. This demonstrates a positive change for G1 and indicates that the intervention may have had some influence. Reviewing each leg separately, one can also see there is a larger change in left leg scores compared to right leg scores in both groups, but a bigger change in G1 (19.17% v 7.4%). Leg (or foot) dominance was not recorded, and thus it is not possible to draw meaningful conclusions, but since most people are right-footed, there may be an indication that the intervention had a greater influence on the traditionally less dominant side. Considering the findings of Cameron et al. (2003) whereby an imbalance in leg strength is predictive of hamstring injury, the relative closing of the gap in strength results between left and right legs points to a potential benefit. Equally, the increased risk of injury associated with an adductor/adductor imbalance as indicated in Tyler et al. (2001) is likely to benefit from unilateral leg strength improvements in the BSS.

With respect to RQ2, the results suggest that, although a statistically significant change was not observed, a field-based intervention program may produce a positive, albeit small, change in leg strength when compared to a comparison group.

It is perhaps also not surprising to observe the initial distributions or subsequent changes. A change in G1 further away from normal distribution lends itself to the notion the intervention had an influence, whereas for G2, even though there was positive skew and leptokurtic distribution initially, the changes were much smaller, reflecting only nominal change in data distribution.

The *t*-test showed some statistical significance in G2 for the left leg ($p < 0.05$), which may reflect the initial lower numbers recorded, but also potentially relates to leg or foot dominance as previously mentioned.

ANOVA analysis did not reveal any statistical significance between the change scores of the groups and ANCOVA analyses to control for pre-test differences in anthropometric data, also elicited no statistical change.

A 10% increase in strength performance over six weeks (in the field of strength and conditioning) would be considered a meaningful result by many S&C trainers. Therefore a 14% increase represents an important return for the work and time invested. Such a conclusion is relevant, particularly considering the intervention program did not make use of traditional resistance equipment.

There are myriad factors contributing to change, but also considerable challenges including no control over recovery, nutrition, sleep, rest or other activities or stresses. While less experienced athletes would tend to respond more quickly and more acutely than seasoned professionals, reflecting on the participants and the strength and conditioning culture for this demographic, the improvements do warrant notice. Further research can only serve to potentially benefit the athletes if the increase demonstrated in strength translates to improvements in performance (as shown by (Brorsson et al., 2010a)) and/or injury prevention.

5.3 Leg Strength-Body Weight Ratio

One of the key elements of investigation in this work-based project, LSBWR, showed improvement in both groups. G1 recorded higher absolute scores. In fact, the pre-test data for G1 are stronger than the post-test data for G2 (G1 – 107.4 pre-test vs G2 - 90.73 post-test). A 10% improvement in G1 against a 4% improvement in G2 failed to demonstrate significance either within groups using the student's *t*-test, or between groups, using the ANOVA. ANCOVA analyses to control for pre-test BSS, height and weight also failed to register statistically significant changes. While not showing significant differences, the research does tend to show that a better LSBWR (using whichever application of strength) is likely to be associated with improved sprint and CODS performance (Arin et al., 2012; Brorsson et al., 2010a) and the a lower LSBWR may increase susceptibility to injury (Case et al., 2020).

The already unusual distribution reflects the demographic undertaking the research, and again, it is perhaps not surprising to see high correlations. Considering the raw data as well as the statistical analyses, it is clear that there has been a change and the distribution denotes a change away from normal distribution, which represents positive results from the intervention, albeit not reaching a statistically significant level.

5.4 Agility T-Test

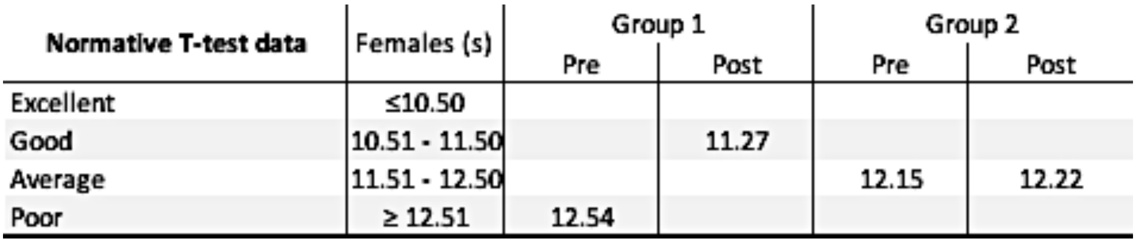
The AgT is interesting because of the various components contributing to the performance result. Looking at BSS and then the combination of LSBWR, G1 outperformed G2 in numerical terms for both datasets. However, when looking at the AgT data, G2 perform better in the pre-tests than G1. The physical testing measures (weight, BSS, LSBWR), would initially suggest, then, that there is no advantage to having a greater LSBWR when compared to AgT performance. However, following the strength program intervention, there was a decrease in time for G1 (-1.27s / -10.13%) and a slight increase for G2 (+0.07s /

+0.58%). In this setting, a decrease in time represents an improvement in performance.

The *t*-test returned statistical significance in all AgT trials for G1 and ANOVA analyses showed statistical significance between the changes values for both groups. Furthermore, correlational data return a high correlation for LSBWR and AgT in both pre- (p = 0.06) and post-test ($p < 0.05$) results.

When comparing these findings against normative data reported for AgT, (Hoffman, 2006, pp. 112-114), G1 moved from the border of 'poor/average' to 'good' and G2 started and remained in the 'average' rating.

Table 16 - Normative Agility T-Test Data for Females



Normative T-test data	Females (s)	Group 1		Group 2	
		Pre	Post	Pre	Post
Excellent	≤10.50				
Good	10.51 - 11.50		11.27		
Average	11.51 - 12.50			12.15	12.22
Poor	≥ 12.51	12.54			

This adds some support for RQ1 and the argument that this could be an important consideration for coaches and athletes.

It is possible that the intervention program, which addressed the elements of joint stability, movement in multiple planes of motion, acceleration, deceleration, and core stability could all have contributed to improvement in the AgT scores even though the primary goal was to improve BSS. This aligns with the comments from Young and Farrow (2006) on the difficulty in isolating a single element of agility responsible for improvement and the notion that many strength and conditioning coaches adopt a broad approach to their training programs to facilitate an optimal training response.

5.5 Correlations

Figure 29 shows a clear change in correlations with agility between the pre- and post-intervention data. The significant ($p < 0.05$) pre-intervention correlations for agility are with weight and BMI, neither of which show significant correlations in the post-intervention data. Conversely, the BSS and LSBWR show no significant correlation with AgT in the pre-intervention data, but both show significant correlation ($p < 0.05$) at post-intervention. Whilst it is important not to confuse causation with correlation, it is interesting to observe that there was an improvement in BSS score, which affects LSBWR score and that this showed correlation with AgT after the intervention. Since the changes in weight and BMI were nominal, it is reasonable to view the change in leg strength as a potentially contributing factor.

Looking at these correlations, specifically for G1, RQ1 can be addressed and it can be observed that there do appear to be relationships in isolated physical variables that can be trained and used in combination to aid improvements in performance tasks. This reflects patterns in much of the research which correlate leg strength and relative leg strength to improved performance in linear sprint, plyometric and CODS performance tasks (Baker & Newton, 2008; Bogdanis et al., 2019; Spiteri et al., 2014).

5.6 Conclusions

These data do not show an optimal LSBWR that directly speaks to a better AgT performance. Rather, there seems to be a trend indicating that a greater LSBWR increases the likelihood of a better AgT performance. The numerical data supports a similar trend for BSS and correlational data supports this showing a correlation that matches that of LSBWR with AgT. Since other research has shown an improvement in absolute strength, these results support the inference that regardless of bodyweight, to some degree a greater BSS returns a greater AgT.

Although not indicated, it also seems likely that there will be a point at which a larger data population may reveal a point of diminishing returns, where the correlational benefit of body weight and leg strength becomes outweighed by the physics of controlling the mass involved, particularly with respect to COD and AgT as opposed to linear speed, where the stress on the joints is less varied, more predictable, and uniplanar. A review of agility indicated:

> The available research provides little support that leg muscle strength, power, and reactive strength are major contributors to agility performance. However, a rationale was made to suggest that plyometric training that involves single-leg lateral movements could potentially be beneficial to COD speed development (Young & Farrow, 2006, p. 28)

Similarly, a 2012 study on first division basketballers found no significance between isokinetic strength and T-Test performances (Alemdaroğlu, 2012), but also noted that "One possible reason for the lack of correlation between tests performance may be the different energy systems that each measure needs" (p. 105). This speaks not only to the importance of testing validity, but also to the complexity involved in separating basic human movement, force production and energy delivery systems from sports performance more broadly. A review has shown benefits from heavy-load (70-90% 1RM) strength training for linear sprint speed and COD and agility, but this also recognises that not all research reflects similar results, positing that variations in methodology may contribute to this phenomena (Hammami et al., 2018).

With enough data, it may be possible to observe an optimal LSBWR or LSBWR range which would be more easily identifiable to coaches in the field and more applicable to the workplace environment. Speaking to RQ2, the performance results (BSS and AgT), and associated trendlines and correlations suggest that there is a positive response to the intervention program. Observing the data holistically, it is important to recognise that the group size and selection mean all statistical conclusions should be considered accordingly. The standard deviations are broad in some instances and in a larger study this would likely be different, and it might be possible to factor out the outliers with different statistical analyses. As it is, the outliers in this case remain factorial and as such, their influence remains significant.

Despite this, changes have been observed both within and between the groups. Numerical data identifies greater changes between pre- and post-testing data for G1 than G2 across all measurable variables that could have been affected by the intervention – BSS, LSBWR and AgT – with statistically significant improvements in dynamic performance test of AgT ($p < 0.01$). Being able to stimulate an observable training response of this type, without requiring access to a specific training facility has broad implications for application in the field and could provide the basis for some relatively simple modifications at club level for many competitive athletes. Adolescent female athletes in particular, because of bio-mechanical differences associated with both sexes and height associated with Australian football, would benefit from greater LSBWR in terms of AgT performance. It is possible that a field-based physical training intervention might help to overcome some of the psycho-social barriers associated with S&C in this demographic.

To address RQ3, the broader research would suggest that better leg strength and agility places an athlete in better control of their joints.

A more robust and responsive musculo-skeletal system will, subsequently, be more resistant to non-contact injury. There also seem to be no negative results from any research on the subject. Which is to say that while the current research is somewhat contradictory about the degree and type of changes a physical intervention program might have on anatomy, physiology, and athletic performance, they all report varying degrees of positive change – from no recorded benefit, right through to statistically significant beneficial changes. For the purpose of this study, no research reported negative results that caused harm or were detrimental to the performance of participants. In the context of this study, set in a real-world workplace, addressing not just physical training, but psycho-social elements of implementing S&C programs for adolescent female athletes, this observation is critically important. It means that, as long as a program is appropriately designed, following the fundamental principles of S&C, there can only be varying degrees of benefit. In the context of addressing the challenges of developing and delivering a program to a squad of adolescent female athletes in Australian football, this could be an important factor for both the athletes and their parents. To be able to champion S&C programming that is safe, potentially effective, deliverable in the field in a group environment without specialist equipment that can be intimidating, can only serve to help change the perceptions and the culture at this level of the sport.

CHAPTER 6: CONCLUSIONS

6.1 Introduction

The purpose of this research project was to address the well-documented increase in lower limb injuries in adolescent female athletes playing competitive Australian football in Queensland. More specifically, using the training field as the workplace, the project aimed to investigate the effects of a leg strength intervention program on the performance variable of agility and to observe whether there was an optimal LSBWR associated with increased agility performance. By locating the program in this environment – a familiar, and social surrounding – and without using intimidating equipment, it was hoped that it might be possible to overcome some of the barriers commonly reported by this demographic for adopting a reluctant stance towards engagement in strength and conditioning programs. Furthermore, if an intervention of this type could elicit positive results, the implications for future practise extend further into the potential mitigation the ACL injuries commonly seen in this demographic in this sport. In the context of the Professional Studies program, it challenged the researcher to address the problem through the lens of experience and work-based learning, where the challenges of the real-world workplace could be addressed, problem solved and implemented in a way that could benefit the individual, the organisation and the profession.

Chapter 1.1 introduced some context to the discussion, highlighting current real-world information that demonstrates the phenomenon of increasing female participation in competitive sport and notes the associated rise of lower limb injuries. This was expanded in section 1.2, which shows the direction and purpose of the project and why it is important, relevant, and original in the academic space and context of the workplace. Section 1.3 detailed the specific research questions addressed in this project while 1.4 illustrated how, professionally, the researcher is well placed to both ask the questions and undertake the task of designing and implementing a project that can serve to address them from an educated and experienced perspective, placing them into the context of work-based learning.

Chapter 2 sought to identify and investigate the research surrounding the key elements of importance with respect to the research questions. Section 2.1 started with injury risk and 2.1.1 introducing the framework for what constitutes an injury is built before 2.1.2 sought to identify and explain the anatomical, neurological, and biological mechanisms that contribute to the problem, and which are relevant to the research. In 2.1.3 the factors which contribute to greater exposure to injury with respect to definition and mechanism were explored and placed in relative context.

Section 2.2 introduced leg strength and bodyweight, beginning with 2.2.1 which again reviewed the importance of defining terms and providing context for the research questions. Section 2.2.2 reviewed the literature surrounding these relationships and definitions so that the reader may understand more clearly the objective of the project and the approach used in the methodology.

Section 2.3 addressed the female versus male literature. Section 2.3.1 highlighted the reported differences in type and volume of injuries sustained by female versus male athletes, providing further evidence of the anatomical factors which may contribute. Section 2.3.2 identified the biological evidence found surrounding menstrual cycles and how this may be a consideration for female athletes who could be at an even higher risk of injury based on the hormonal influences on physiology. This is carried forward into section 2.3.3 which explores the social and cultural influences that may present barriers to commencement and/or adherence to strength training interventions – factors which carry particular importance in a workplace environment.

Section 2.4 pulls the research into the even narrower channel of adolescents. The integration of growth rates, hormonal changes, and social and cultural factors, specifically for female adolescents involved in the activities exposing them to greater risk of lower limb injuries, combine to present powerful motives for careful consideration when introducing strength and conditioning practises. These highlight some of the practical difficulties faced in the workplace by coaches who have regular and considerable influence on the demographic in question.

In 2.5 the variable of agility is introduced, reviewing what is meant by the term and how it exists as an important performance variable in Australian football, before exploring its relevance in context for lower limb injury. Research highlights the difficulty in isolating a single element that contributes to the multi-faceted performance variable of agility. It identifies that agility can mean many different (yet equally valid) things in different contexts and be applied in many different manners. Section 2.6 explores interventions designed to enhance one or more of these elements to uncover relationships that may improve performance or affect injury risk. It reveals that the complexity and system interdependence found in the human body means that many of the training protocols used will train multiple elements even if the intention is to target only one specifically. All the elements related to the project are concluded in section 2.7.

Chapter 3 details the methodology introduced in 3.1 with paradigm, method and research design explained in section 3.2. The workplace research setting explained in 3.3 is integral to the project bringing a real-world perspective to the research problem. The study population and criteria detailed in 3.4 related directly back to the research problem and questions and the physical data collected in 3.5 from the intervention programs detailed in 3.6 provide the appropriate data for collection and analysis detailed in 3.7 and 3.8.

Chapters 4 and 5 present, explore and discuss the results of the project, explaining the relevance of the data and how it serves to address the research questions. Reflecting on previous research, the data are shown to be aligned with many previous studies on leg strength, improved performance and human movement.

6.2 Achievement of Learning Objectives

The way the workplace operates is constantly evolving and the inclusion of human participants adds myriad possibilities and adjustments to a project of this nature. The learning objectives identified as most beneficial were from the fields of systemised information gathering, objective judgement, work methods and process logic, as well as technology adoption. While all of these are already a feature in the workplace, the application of these in a systemised and coherent structure to search for clear and concise information has been a challenge on many levels. The consistent drive to apply these elements in the context of the triple dividend of benefits to the researcher, organisation and profession has shaped the implementation and reflective practise associated with each.

6.2.1 Systemised Information Gathering and Objective Judgement

The researcher has found that level of experience and anecdotal observation can lead to a somewhat subjective view of the workplace. Beliefs about what is true and accurate have been challenged in this work-based project and the process of reviewing literature and placing it in context against a set of specific research questions has allowed the researcher to view the workplace and workplace dynamics through a more objective lens. Some beliefs have been challenged and others reinforced, largely because of stepping back from application of skills and practise that are familiar, and using information gathered from credible resources to better inform decisions in the workplace.

6.2.2 Work Methods, Process Logic, and Technology Adoption

The objective judgment initiated during the systemised information gathering process has created a more fluid work method which has been shaped by the clearer process-logic applied. Technology is fundamental to the strength and conditioning community, allowing coaches and practitioners to measure a wider range of variables with greater specificity and more accuracy. This leads to a note of caution to assess which of the technologies is most suited to measuring which variable. In this project, simple technology was used since it was deemed the most appropriate for the task at hand and less likely to present faults or misreads for the researcher. In the context of human subjects, the technology also needs to be obvious and easy to administer and use since repeated trials of physical activity due to inconsistent technology could compromise performance and therefore results. The research also reflects the increasing use of technology. Using machinery to replicate consistent landing pattern across knee joints and computer software to monitor and interpret the data (Lipps et al., 2013; Wojtys et al., 2016) is something that would not have been available to researchers from previous generations. In the context of human movement and performance however, the researcher has found that sheer volume of contributing factors (which can now be researched due to advances in technology), in conjunction with the variation in methodology, subject recruitment and context, might prevent a specific topic being researched thoroughly. With respect to this project and the application in the workplace, much of this will not be accessible or useable in a practical sense and so even as the volume and quality of research increases, the divide between pure research in controlled conditions and practical application in the workplace seems to grow larger.

6.3 The Triple Dividend

The triple dividend provides the foundation for this project. The way in which the project was approached was framed by the reflective practise designed to shine a light on personal experience and strength and to then apply a process to better the areas where improvements can be made in a way that benefits not just the individual, but by extension the organisation within which the individual sits, and the broader profession in which the workplace resides. (Fergusson, van der Laan, et al., 2019)

6.3.1 Benefits to the Researcher

Viewing the project holistically, the researcher has benefitted significantly from its implementation and completion. Shifting the lens to become more objective, as previously mentioned, has allowed for reflection on current practise and generated consideration for better practise moving forwards. The researcher is far better informed on a subject and demographic that has current importance and significance in the industry and has learned a great deal about how to communicate and collaborate in that space. The opportunity to share this professional knowledge in context and to potentially influence future practise is something that is exciting and important.

6.3.2 Benefits to the Organisation

The workplace environment is now better placed to serve a hitherto less understood demographic. The wider community of the workplace will benefit from the advances made by the researcher through this project. The broader context in which the findings of the project and the research associated with it can now be placed means that adolescent female athletes that come into the workplace environment have a greater chance of receiving safe and effective strength and conditioning programs. The programs might improve performance and perhaps mitigate ACL injury risk as indicated in some of the research in the literature review.

6.3.3 Benefits to the Profession

The profession benefits from a contribution to the greater body of knowledge, helping future practitioners and researchers to make informed choices about their strength and conditioning programming. The intervention program can provide coaches of female athletes with a framework on which to approach ways to implement a physical training programming safely and successfully in a workplace, with no specialist equipment, which will help to overcome some common barriers in the project demographic.

6.4 Conclusions, Implications for Future Practise and Directions for Future Research

There is wealth of research documenting the anatomical and physiological differences between male and female athletic populations, which place female athletes at a higher risk of specific injuries.

Adolescents too, have many factors which could contribute to increased risk of injury. In this project anthropometric data and static leg strength performance were used in combination to investigate a relationship with agility performance. The underlying drive to investigate these relationships was the increasing and disproportionate ACL injury rate in adolescent female athletes playing AFLW in Queensland as opposed to their male counterparts (AFLW, 2019). A physical intervention demonstrated an improved leg strength-bodyweight ratio that correlated with improved agility performance. A review of the research suggests that improved agility may be a contributing factor in mitigating ACL injury risk.

The information provided by this project may help to inform future practise in the workplace. It indicates that female adolescent athletes require different considerations to their male counterparts in both physical and psycho-social departments. It suggests that a leg strength intervention, delivered in the workplace, in a group environment and without specialised strength equipment can have a positive effect on agility performance and contributes to the preservation of athlete wellness.

The work-based project did not reveal an optimal leg strength-bodyweight ratio, and future research with larger cohort numbers and a randomised allocation of subjects might help to further inform in this topic. Although the intention of the project was to record injury rates across the season and compare the intervention and comparison group, it was not possible due to COVID-19 challenges to project timelines, but future research would benefit from collecting this data to add to the greater body of knowledge, and to better inform future practise and future research.

It is reasonable to assume that if females have only been recently engaged in these competitive sports at the highest level, then the research and data surrounding that participation must also be relatively new and emerging. This is one reason this research topic is so relevant; the industry is only now beginning to interact with a generation of emerging female athletes who have a limited number of female role-models in professional sport. The cultural landscape is being formed now; it is flexible and unpredictable and being informed by research and the application of research being conducted in the recent past and the present. It is hoped these findings have made a contribution to this field of research.

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