The Training Effects Of Lower-Body Wearable Resistance In A Small-Sided Game Approach On Strength, Speed and Change Of Direction Performance In Semi-Elite Soccer Players And How It Can Help Alleviate Hip And Groin Injuries

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Abstract

Soccer is the most played sport in the world. Because of this, it has more professional clubs and more professional athletes compared to any other sport. However, it also comes with a high injury risk, rate, and a congested in-season schedule. One of the biggest and most discussed issues is determining how to train efficiently. Finding the optimal way to train not just from a physical performance stance but also from a soccer specific and a time constraint stance is imperative. Wearable resistance aims to bridge the gap between physical and technical training simultaneously as a training modality. Wearable resistance training is a form of strength training where a fixed load is placed on the body in some manner. It uses the concept of moving micro-loads at high velocities through both accelerating and decelerating forces to load the muscles effectively. However, very limited research has looked at the practical effects of wearable resistance in soccer, with even less looking at the overall training effects it may have. This thesis will determine the incidence for hip and groin injuries in elite soccer by completing a narrative review. This review will also determine the best preventative and pre-habilitative strategies related to hip and groin injuries in soccer. A reliability study will also be presented on a novel groin squeeze device for measuring reliable maximal groin adduction strength. This study was completed following the results found in the narrative review to find a suitable and cost-effective tool to measure maximal groin adduction strength as it was determined as being a key injury risk factor identified in the narrative review. This study was administered in completion on sixteen semi-elite male soccer players across three separate testing days ranging from one to sixty days between sessions. The study was completed to determine the intra- and inter-reliability of the device, which was then used as a testing tool for the training study. Finally, the training study examined the effects of lower-body wearable resistance in a small-sided game approach as a training modality to maintain and improve strength, speed, and change of direction performance in soccer athletes. This study used thirty-seven male elite soccer players,

of which nineteen completed the full study, across two Wellington Phoenix Football Club Academy teams. The participants were split into either a control group or intervention group, with the intervention group wearing wearable resistance. They were put through a battery of physical measures pre-testing and then underwent a sixteen-session intervention. Each intervention session included the same strength, speed and change of direction program as well as a small-sided game as part of their regular soccer trainings. Following all sixteen intervention sessions a post-test was conducted on the small physical measures.

The main findings from this thesis were that: 1) the wearable resistance training effects on groin squeeze peak force were large and statistically significant; 2) the changes in isokinetic knee flexor and extensor strength for the most part was trivial to small and non-significant; 3) the wearable resistance training effects on 20 m sprint were large and statistically significant; 4) the effect wearable resistance training has on change of direction is trivial outside of the velocity changes seen in linear testing; 5) the combination of several preventative and pre-habilitative strategies for hip and groin injuries are more effective; and 6) the novel groin squeeze device demonstrated comprehensive intra- and inter-session reliability for maximal groin adduction strength.

These findings suggest that implementing several preventative and pre-habilitative strategies for hip and groin injuries are the most effective way to reduce the risk of hip and groin injuries in soccer. Furthermore, they suggest that implementing lower-body wearable resistance into a soccer training session are likely to elicit meaningful improvements in sprinting and isometric strength performance. Including lower-body wearable resistance in soccer, or other sports where sprinting and isometric strength are important performance measures, should be considered. However, more research is needed to better understand the full training effect lower-body wearable resistance might provide.

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Attestation of Authorship

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements and/or is otherwise referenced), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institutions of higher learning.”

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Kieran James McMinn

Co-Authored Works

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Matthew Brown	Michael Rumpf	Mathieu Lacome

Ethics Approval

Ethical approval for the thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC) on the 9th of December 2020 and the 12th of February 2021 respectively for a period of three years.

AUTEC – 20/358 – Assessment of kinetic variables in hip abduction (groin squeeze) using load cell technology in a healthy population: reliability.

AUTEC: 20/411 – The effect of lower-body wearable resistance training on measures of physical performance and injury resistance in elite male soccer athletes.

Chapter 1: Introduction

Rationale

Soccer is a highly demanding sport where athletes are constantly on the move. The sport requires both gross and discrete motor skills including various types of ball strikes, jumps and explosive changes in direction and velocity [1]. These demands require individuals to possess advanced lower-body strength [2-4]. The importance of strength in soccer has been widely investigated [2, 5-7], finding that strength training is a reliable indicator for power, agility, and speed, which are all critical for soccer performance. However, due to the typically congested playing schedules in elite soccer, outcomes like strength training can become compromised. The time constraints within a training week make it difficult to optimize the physical performance needs of athletes. As a result, physical qualities can decay, and the risk of injury can increase throughout a season [8-11]. Therefore, establishing time-efficient training interventions that maintain or improve physical performance are imperative.

To be time-efficient it is important to train as sport specific as possible. For soccer, training methods that closer resemble the biomechanical movement and actions that occur within a match can lead to not only positive adaptations but allow for the crossover of both the physical and the technical elements of the game [11-12]. Finding the best training method that is time efficient and encompasses as many elements of soccer as possible can be difficult, however, lower-body wearable resistance is a training modality that can potentially elevate this issue. Wearable resistance training is a form of strength training where a fixed load is placed on the body in some manner. It uses the concept of moving micro-loads at high velocities through both accelerating and decelerating forces to load the muscles effectively. In recent years, wearable resistance has become increasingly popular in sport training. One possible reason for this is its time efficient nature. In a congested week, time practicing often takes priority over resistance and strength trainings, however, wearable resistance attempts to solve this issue. In soccer,

wearable resistance can provide rotational overload to athletes while playing, alleviating the need for some types of additional resistance training.

Moreover, physical, and technical skill development can be gained simultaneously as players are able to continue training whilst getting the additional benefits. Essentially, wearable resistance in soccer is trying to be used as a training modality to get not only on field exposure but also try to avoid the decay in other physical measures to be more time efficient. Research has begun to look at the effects of wearable resistance on physical performance, with meaningful improvements shown in speed and acceleration [3, 13-22], but none of these have been training studies However, one important component of fitness not yet investigated using wearable resistance is groin strength.

In soccer, hip and groin injuries are a frequent occurrence. Approximately 12-16% of all elite soccer injuries are hip and groin related, with the majority being adductor strains [23]. Due to the high-speed changes of direction and the frequent kicking nature of soccer, the load placed on the hip and groin is large, leaving it a high-risk site for injury, re-injury and/or overuse [24]. Low strength in hip adduction and abduction as well as hip flexion and extension have been identified as one of the key risk factors for hip and groin injury [25-27]. These weaknesses are often addressed via various strengthening exercises and programs with several suggesting that they lower the risk of hip and groin injuries in multidirectional sports like soccer [28-30]. However, due to the congested in-season schedules, finding time to fit in all the suggested exercises that focus on hip and trunk muscular development as well as hip adduction and abduction exercises on top of all the other necessary resistance training can be difficult. Therefore, finding not only a time efficient way to train in elite soccer remains a priority but also a way to encompass various injury prevention elements, specifically hip and groin injuries, remains just as important. Wearable resistance could be the answer, however, a lack of

research completed leaves scepticism of its true application in place of a more traditional strength training approach.

Very few studies have investigated the effects of wearable resistance for determining overall strength measures [13-14, 31-32], with no acute training studies been completed. The majority of these have also used upper-body wearable resistance loading via vests or arm sleeves [14, 31-32] as opposed to lower-body wearable resistance where the bulk of the stress on the body is placed during soccer. These studies begin to show that wearable resistance is a suitable tool for movement specific overload strength and power training in movements like jumping. When divulging into other physical measures, the usage of wearable resistance on speed and sprint performance has been investigated more in-depth, with several studies using lower-body wearable resistance [3, 13-22]. These found that wearable resistance elicited meaningful improvements in top speed and accelerated sprinting performance. However, the effects of wearable resistance on change of direction performance have similarly been investigated to the extent of strength performance, with most studies looking at upper-body wearable resistance through central mass loading via vests [4, 33-34]. These showed mixed results with some studies evoking meaningful improvements while others showing trivial to no changes. Only one study looked at wearable resistance within a soccer setting [13], using lower-body wearable resistance as part of a warm-up protocol. This study found promising results for specific strength training in soccer, however, it lacked the use of wearable resistance from an on-the-ball technical soccer training approach. This leaves a gap in the research for the possible effects lower-body wearable resistance could have during a training where a soccer match is replicated more accurately.

While research has begun to show the positive effects of lower-body wearable resistance within sport, further training effect research needs to be completed. There is a gap into understanding the practicality wearable resistance training has on physical performance measures, as well as

understanding how it may be used as a tool to help reduce injury risk. Furthermore, the effect of wearable resistance training in soccer has scarcely been investigated. Accordingly, there is a need to investigate the use of wearable resistance in soccer training to determine its effect on physical performance. There is also a need to investigate it as a potential training modality to reduce injury risk, specifically to the hip and groin, whilst still engaging the technical demands of the sport.

Purpose

This thesis examines the effects of wearing lower-body wearable resistance during small-sided game training on strength, speed, and change of direction performance in soccer athletes. There was a focus placed on not only improving groin adductor strength but also on the prevalence of hip and groin injuries in elite soccer as well as a novel device used to measure groin adductor peak strength. The aims of this thesis were:

1. Review the literature on hip and groin injuries in elite soccer.
2. Review the optimal preventative and pre-habilitative strategies for hip and groin injuries in elite soccer.
3. Determine the intra and inter reliability of a novel groin adductor strength device.
4. Investigate the effects of lower-body wearable resistance worn during small-sided game soccer training on strength, speed, and change of direction performance.

Significance of Thesis

Soccer is the most played sport worldwide and continues to gain popularity [35]. At the elite level, and even flowing down into semi-professional and amateur soccer environments, players, coaches, and staff are all looking for an edge to compete and perform to a higher calibre. Because of this, many players end up overtraining to see improvements [36]. This leads to more

time loss due to injuries which at the highest level has been shown to correlate to worse results [37]. Research behind how to train more efficiently and as soccer specific as possible is an area of interest due to how it could potentially result in more time on the field without hindering injury risk or physical capabilities. This thesis will aim to investigate not only the effects of wearable resistance as a training modality, but also to investigate the optimal preventative and pre-habilitative strategies to reduce the risk of hip and groin injuries in soccer. This thesis could have influence on practitioners working within the soccer setting by providing insight and evidence into the training effects lower-body wearable resistance can have, and how it can be implemented into a training setting. Furthermore, this thesis will present a new novel groin squeeze device that could be a useful tool for practitioners seeking an effective and reliable way to measure hip adduction strength. Potentially this device could be used as an effective screening method alongside the aforementioned preventative and pre-habilitative strategies to significantly lower the risk of hip and groin injuries in soccer.

Thesis Structure

This thesis is comprised of five chapters with three main sections. The first section is a review that examines the prevalence of hip and groin injuries in elite soccer athletes as well as the best preventative and pre-habilitative strategies to mitigate these injuries (chapter 2). The second section is a technical report that examines the intra and inter day reliability of a new novel device used for measuring groin adductor peak strength (chapter 3). The third section is a training study that looks at using lower-body wearable resistance, in a small-sided game approach, as a training modality to maintain and improve strength, speed, and change of direction performance in soccer athletes. All three of these sections were written in the format to the respective journals they have or will be submitted to. There may be some repetition between thesis chapters due to the publication pathway.

Chapter 2: Prevalence of hip and groin injuries among elite soccer athletes and specific prevention and pre-habilitative strategies: A narrative review

Introduction

Hip and groin injuries (HAGI) are a common injury in soccer, with approximately 12-16% of all soccer injuries being HAGI [23]. This is largely due to the load placed on that region from the constant high-speed changes of direction and kicking mechanics that are crucial in the sport [24]. This stress requires soccer athletes to possess high levels of strength and power in their lower limbs [25-26] with muscular deficiencies, specifically around the hip, drastically increasing the risk of injury [27]. Reducing the amount of time spent injured is critical for elite level soccer athletes with injuries impacting not only individual performance long-term but also short-term team success [37-39]. Within elite soccer, HAGI account for a significant amount of time loss for training and games. One study completed over seven consecutive seasons among elite European soccer athletes found that HAGI accounted for 1.1/1000 hours training and/or games missed [23].

HAGI definition, prevention and pre-habilitative have been extensively investigated with new strategies being set in place for how to diagnose and prevent injuries in elite athletes. A key example of this was the Doha agreement meeting in 2014 [24], where experts defined the different types of hip and groin pains and began discussions on treatment and prevention. However, due to the complexity of the hip joint, injury incidence remains high in elite soccer athletes. Finding an optimal combination of prevention and pre-habilitative strategies for soccer specific movements remains important.

Therefore, the aim of this review is to analyse the previous literature on HAGI in elite soccer athletes, highlighting the injury frequency, type, and severity to help gain a greater

understanding of the optimal injury prevention and pre-habilitative strategies that can be used to reduce HAGI in elite soccer.

Methodology

Relevant studies were identified by searching the following electronic databases, Google Scholar, Microsoft Academic, and PubMed. The following search terms were used in combination for these searches: “soccer”, “football”, “elite”, “professional”, “injur*”, “adductor”, “groin”, “hip”, “incidence rate”, “risk factors”, “prevention”, “prehabilitative”, “prehabilitation”, “rehabilitative” and “rehabilitation”. Further sources were also identified from the references of relevant publications. All literature was screened through the following steps: the title, the abstract and the full text. Firstly, the title and then abstract of all potential studies were read and reviewed based on a determined inclusion criterion. If this was met, full texts were read in-depth and reviewed and only included if they met all inclusion criteria. Previous literature was included in this review if it met the following criteria: (1) were in English, (2) used elite soccer athletes, and (3) reported some form of hip and groin injury frequency, either incidence rate and/or percentage. Only publications involving elite soccer athletes were used. An elite athlete is determined by three components: standard/competitiveness of performance, success, and experience at the highest level [40-41]. Although there are multiple publications using ‘elite youth athletes’, the lack of high-level experience for players under 18 means that there are limited cases where an individual under 18 would be deemed elite under the above criteria. Therefore, for this review only athletes over 18 were included who were competing at a professional or at an international level.

Discussion

The main findings from this review were: 1) there are a significant amount of HAGI in elite soccer; 2) adductor strains are the most common type of HAGI; 3) re-injury and overuse of HAGI remains an unresolved problem in elite soccer; and 4) HAGI result in long periods of time-loss from trainings and games.

Injury Frequency

Across the fourteen studies that were analysed for this review, HAGI accounted for approximately 13% of all soccer injuries. This ranked as one of the highest injury sites for all soccer related injuries. Multiple studies used incidence rate per 1000 hours of exposure, revealing an incidence rate between 0.77-4.3 injuries per 1000 hours of exposure [23, 42-44]. However, of these studies only two used a large population across multiple years, both finding an incidence rate of 1.1 injuries per 1000 hours of exposure [23, 44]. Unsurprisingly, the injury rate during games was significantly higher than training, with several studies investigating this issue [42, 45-50]. The frequency of HAGI also appears to be higher in club-seasons as opposed to international tournaments [51].

Injury Type

Adductor injuries were the most common HAGI in the studies that identified location and injury type. Adductor strains accounted for approximately 65% of all HAGI [23, 44]. Hernia, hip flexor, psoas, groin pain, and fractures were other, and significantly less frequent HAGI also stated. One re-occurring message across multiple studies was the frequency of re-injury and overuse in HAGI [23, 27, 45, 47-49]. Re-injury was common due to the loss of flexibility and weakness of muscles post initial injury, with one study stating that re-injuries within two months accounted for 15% of all HAGI [23]. This is likely due to the considerable amount of exposure from a congested in-season schedule demand. This increase in exposure with less recovery time

accelerates not only the likelihood of re-injuries but also the overuse of muscles, specifically the adductors, leading to more muscular strains [27, 49]. Furthermore, several studies suggested the impact that dominant kicking leg may have on HAGI. These stated that adductor injuries were more common in the dominant kicking leg [27, 52]. This is probably caused by the greater volume of shots and passes on the dominant leg, leading to more exposure and a higher risk of injury.

Injury Severity

Injury severity was discussed in five of the analysed studies. Each injury was placed into a category to define the severity of the injury based on the number of days missed from trainings and/or games. The categories were as follows: minimal (1-3 days); mild (4-7 days); moderate (8-28 days); or severe injuries (over 28 days). The studies suggest that HAGI result in long periods of time-loss from trainings and games with over 53% of the injuries leading to 8 or more days of absences [23, 27, 47, 49, 53]. Of that, over 11% are classified as severe injuries. One interesting observation on injury severity was that HAGI from international tournaments tended to have a higher amount of time-loss [51]. However, this is likely due to the greater number of overuse and re-injuries that occur throughout a club-season as opposed to the more acute injuries that are seen in international tournaments [51].

Prevention and Pre-Habilitative Strategies

With the high frequency and severity of HAGI in soccer, a significant focus needs to be placed on prevention and pre-habilitative strategies. The Doha agreement placed a greater attention on how to properly diagnose HAGI [24]. However, there has been limited success in a practical setting on how to reduce HAGI with the current literature being limited and unspecific. Current best practice for prevention strategies appears to be based upon screenings and load management [54-55], while pre-habilitative focuses on strengthening and improving range of

motion around the hip joint [54-56]. Determining the optimal way to reduce both the prevalence and risk of HAGI specifically to elite soccer remains inconclusive.

There are various risk factors related to HAGI that will always be prevalent and uncontrollable, such as, age, injury history, and anatomy [54-56]. However, range of motion and strength around the hip joint are two factors that are largely discussed as a key risk factor associated for HAGI [54-56]. Screening is a commonly used practice among elite soccer teams on a weekly, if not daily basis to determine the risk of injury [57]. Both the groin squeeze and FADIR (flexion adduction internal rotation) tests are used to indicate this risk by combining both strength and range of motion. These tests aim to identify issues with internal rotation, flexion, abduction, and adduction of the hips. Although these screening tests are valuable, they relate more to pain and overuse, acting more prognostically for athletes with current injuries or mobility and strengthening concerns [54].

Low strength in hip adduction and abduction as well as hip flexion and extension have been identified as risk factors for injury [54-56]. These weaknesses are often addressed via strengthening exercises such as Copenhagen adductions, lateral lunges and various sport-specific compound movement training in speed, strength, and agility [28, 30, 54]. Several strengthening exercises and programs have suggested that they may lower the risk of HAGI in multidirectional sports, with the majority of these focused on hip and trunk muscular development [28-30]. One study suggests the usage of the widely investigated FIFA 11+ warm up program. This study confirmed that the FIFA 11+ was successful at reducing the risk of HAGI, however, found that there was a lack of hip adduction in the program which could be elevated by the addition of Copenhagen adductions. They theorized that this could further increase its preventive effect on HAGI [28].

The conjunction of various programs alike the FIFA 11+ that relate specifically to soccer, need to be highlighted and fine-tuned to help alleviate HAGI. Although the importance of individual

risk factors for HAGI should not be diminished. We believe that a broader perspective should be placed across a variety of factors (screening tests, load management, strengthening exercises and mobility improvements) looking at a multidirectional approach to mitigate HAGI.

Conclusion

Consistent with most other previous investigators, we identified that HAGI account for a significant amount of all soccer related injuries. The severity of these injuries is also higher than first perceived, with HAGI accounting for significant time-loss from trainings and games. Interestingly, although screening tests, load management, strengthening exercises and mobility improvements have been used to combat HAGI, the use of them together has not been reported across a reliable elite soccer population to date. Future research should investigate a more multidirectional approach to solving this issue and to determine the effectiveness of these strategies in conjunction to reduce HAGI in elite soccer.

Chapter 3: Inter- and intra-session variability of a compression strain gauge for the adductor groin squeeze test on soccer athletes: A reliability study

Prelude

It was established in the literature review that groin injuries account for a significant amount of soccer related injuries, leading to prolonged absences from training and games. From this review it was concluded that the groin adductors in particular are relatively weak and under-trained for a large portion of soccer athletes, the training of which providing the focus of many groin injury prevention programs. A groin squeeze assessment is typically used to measure peak adductor force, to determine the injury risk for groin injuries in soccer and monitor the efficacy of any injury prevention programs. However, the frequently used testing devices such as the Groinbar, handheld dynamometers, and sphygmomanometers, commonly used for groin squeeze assessment, each have their own issues regarding to either reliability, utility and or pricing. A new portable compression strain gauge device has recently been designed and has the potential to fill this gap and alleviate these issues as an alternative tool for gathering quick and accurate data. However, no evidence exists with respect to the reliability and normative data as collected with the device. Therefore, the aim of this study was to determine and the intra- and inter-session reliability of the new compression strain gauge device.

Introduction

The importance of hip adductor strength for sport performance is well established [58-71], especially within sports requiring high-speed changes of direction such as soccer, rugby, and hockey [58-60, 63, 67-69, 71-72]. Researchers have also shown a relationship between maximal hip adductor strength and injury [59-60, 63, 65, 67, 69]. For example, peak maximal isometric adductor strength lower than 465 N increased the probability of soccer athletes

suffering a groin injury by 72% [67]. Given that groin injuries account for a substantial percentage (12-16%) of all soccer injuries per season [23], it would seem important to measure, monitor, and manage changes in hip adductor strength in soccer athletes to understand potential risks for groin injuries. For this to happen, easy to use, reliable, and affordable technology is needed.

The groin squeeze test is a reliable indicator of overall hip adductor strength [58-69, 73]. This test requires athletes to lie in a supine position, with their hips flexed at either 45 or 90 degrees, and thereafter maximally squeeze their thighs together. Typically, maximal groin strength has been measured using handheld dynamometers (HHD) [59, 63, 65, 68, 74] and sphygmomanometers (SPH) [61-62, 64, 66, 69, 75]. However, these devices can only measure one limb at a time. To assess total maximal groin strength, the ability to assess both limbs simultaneously are more time efficient [76-77].

The Groinbar is a relatively new device that can assess both unilateral and bilateral hip adductor strength and has shown acceptable reliability [76-78]. However, only intra-session reliability has been quantified with this device [76-78]. Therefore, quantifying the inter-session variability of hip adductor strength is needed to gain a better understanding of the utility and reliability of this device. Furthermore, the affordability of the Groinbar is outside the budgets of many potential users.

Given this information, a newly in-house developed, easily transportable compression strain gauge device was designed. The device overcomes the standardization, tester influence, and unilateral measurement issues observed in the HHDs and SPHs. Also, the device used in this study collects data at a higher sampling rate (1000 Hz) as compared to the Groinbar (400 Hz), meaning the device can identify changes in force more accurately. The new technology, therefore, has many advantages over existing technology in the market, however, the reliability of the device has not yet been established. Therefore, the purpose of this study was to evaluate

both intra- and inter-session reliability of a custom-designed compression strain gauge device for measuring peak hip adductor force on a groin squeeze test in soccer athletes.

Methods

Experimental Approach

A repeated-measures experimental design that quantified the variability of a custom-designed compression strain gauge device over three testing occasions in soccer players was implemented. Peak hip adductor force from a groin squeeze was the variable of interest, the variability of which was quantified via coefficients of variation (CV) and intraclass correlation coefficients (ICC).

Participants

Twenty-four semi-professional male soccer players (age 20.4 ± 5.02 years, height 177 ± 14.8 cm, weight 78.1 ± 6.66 kg) from the same team were recruited for this study. Sixteen completed the entire study, due to some participants gaining injuries or failing to complete all three testing sessions. The study was voluntary, and each participant completed and signed either a written or an electronic consent form. Ethics was approved through the Auckland University of Technology Ethics Committee (20/358).

Procedures

Before each testing session, participants completed a ten-minute soccer-specific standardized dynamic warm-up, with a focus placed on hip mobility to ensure the hip-groin area was adequately warmed up and stretched before the groin squeeze test. Participants were then asked to adopt the correct set-up position (see Figure 1). Participants were instructed to remove their shoes and lie with their back, buttocks, and head on the floor, arms parallel to their torso, legs hip-width apart and knees bent with feet on the floor. They were then asked not to move

from this position during the testing session. If the participant moved, the testing administrator re-measured the hip angle and ensured they were placed back into the correct position. Participants had their hip flexion angle measured using a goniometer and set at 45 degrees [58-59, 62, 65]. The compression strain gauge device was then placed between the adductor tubercle of the femurs with the device facing upwards.

Figure 3.1: Schematic of hip adductor strength testing.

Participants completed three trials during each testing session, with a warm-up trial before the first trial. For the warm-up trial, participants were instructed to squeeze the compression strain gauge device for 2 seconds at approximately 50-80% of their maximum effort. This was followed by three trials performed at maximal effort. For each of these trials, participants were instructed to squeeze the compression strain gauge device for five seconds “as hard as possible”. After each trial, one minute of recovery was given. The same testing procedures were replicated for all subsequent testing sessions.

Participants were tested on three occasions with the minimum time between a session being one day and the maximum being sixty days. The time between testing was not standardized, as

such random variation was introduced into the testing, due to several participants failing to turn up to testing days.

Instrumentation

Force data were collected at 1000 Hz via a custom-designed (SPRINZ Laboratories, Auckland University of Technology) compression strain gauge device (see Figure 2), interfaced with custom-designed data acquisition software (MidThighPull.V19). For each trial, the participant was asked to hold a pre-tension of approximately 20-50 N prior to any contraction to keep the device held between their thighs.

Figure 3.2: In-house strain gauge device for assessing hip adductor strength.

Data Analyses

All data were imported into MATLAB ((MathWorks, Natick, MA) for analysis. Using a custom algorithm, each trial was trimmed to length to include a steady pre-tension period of at least 0.5 seconds, force onset, an isometric contraction for at least 2-s, and a force offset. The onset of

force was determined using expert manual selection [79]. Peak force was calculated as the absolute maximum force recorded during the entirety of the 2-second contraction (see Figure 3).

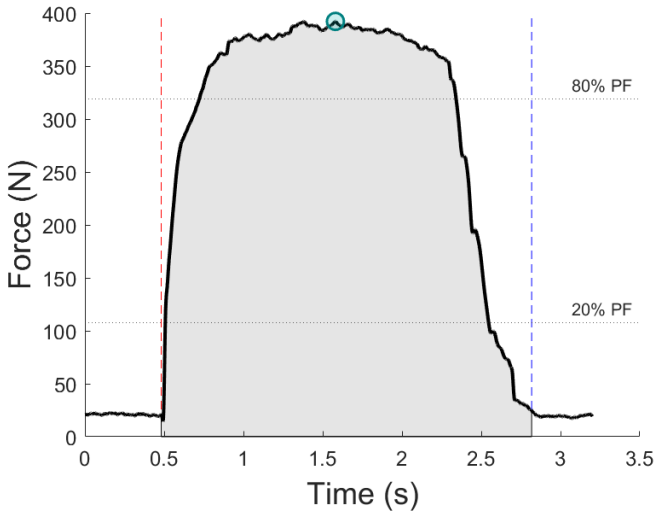

Figure 3.3: Example of a 2-second trimmed contraction.

Statistical Analyses

All statistical analysis was conducted using RStudio IDE (Version 1.4.869, 2009 – 2020 RStudio, PBS) to examine the reliability of peak force within and across three sessions (S1, S2, and S3). Group mean and standard deviations were calculated for intra- and inter-session peak force to describe the centrality and spread of data. Intra-session reliability was assessed using a minimum of 2 trials during the participant's first testing session. Inter-session reliability of peak force was analysed using the average of a minimum of two trials per session. Normality was visually assessed using Q-Q Plots and confirmed using the Shapiro Wilks test ($p > 0.05$). The change in mean, within-subject CV, and ICC - two-way mixed effects, single, absolute agreement were used to analyse systematic change, absolute, and relative consistency, respectively. Confidence intervals of 95% were reported.

Results

The intra-session and inter-session variability of peak force can be observed in Table 1. In terms of systematic change, the change in peak force ranged from 385 N to 410 N with the greatest change observed in intersession variability, between sessions 2 -3 (12.1 N). With regards to absolute consistency, greater variability was associated with intersession (~ 9.2%) compared to intrasession (~ 5.0%) consistency. This trend of greater variability was also associated with the relative consistency measures, the ICCs less for between-session (~ 0.85) compared to within (0.94) session measures.

Table 3.1: Intra- and Inter-session reliability of peak force.

Intrasession									
Intra-Session	**Mean ± SD**			**Change in Mean**		**CV [95% CI]**		**ICC [95% CI]**	
	S1	**S2**	**S3**	**S1-S2**	**S2-S3**	**S1-S2**	**S2-S3**	**S1-S2**	**S2-S3**
Peak Force (N)	385 ± 78.1	395 ± 76.4	392 ± 76.7	9.82	-3.29	5.47 [1.51, 7.59]	4.47 [3.28, 5.40]	0.93 [0.82, 0.97]	0.95 [0.88, 0.98]
Intersession									
Peak Force (N)	409 ± 86.9	398 ± 96.1	410 ± 80.3	-11.1	12.1	9.48 [5.58, 12.1]	8.94 [4.03, 11.9]	0.83 [0.59, 0.93]	0.86 [0.66, 0.94]

Discussion

The purpose of this study was to investigate the intra- and intersession variability of a custom-designed compression strain gauge device for measuring hip adduction peak force in semi-professional soccer players. The main findings were: 1) low systematic change (< 12.1 N) was observed between sessions and within trials; 2) absolute consistency for all measures was less than 10%; and 3) relative consistency was high with all the ICC values being greater than 0.80.

For a full appreciation of the variability of measurements it has been recommended that a systematic change in the mean, as well as measures of absolute and relative consistency (i.e., within-subject variation and retest correlations respectively), should be reported [80]. When looking at the mean data and the change in the mean, it is apparent that there is very little change between testing occasions (<3%). This is noteworthy, especially in terms of between-session variability as retesting was as long as sixty days apart from the first tests. The intra-session systematic change compares favourably with other devices such as a HHD ~ 6.6-19.5% (8); SPH ~ <7% [58, 61, 66]; and Groinbar ~ <4% [76-78]. In this study, the learning effect appears minimal, and players can be tested reliably with as little as one familiarization session before the first testing session.

Although there is no pre-set standard for acceptable CV values, many researchers set a goal of <10% for “good” reliability [81]**.** The greatest variability was associated with the inter-session testing; however, all CVs were less than 10%. Other researchers have reported absolute consistency for: SPH = ~9% [65]; HHD = 11.3% [58]; and Groinbar = 4.9-9.0% [78]. It appears that the absolute consistency of the technology used in this study is comparable to other devices used to measure groin strength.

With regards to relative or rank order consistency, all ICCs were greater than 0.80, with greater variability associated to inter-session testing. Correlations greater than 0.80 are thought high and sufficiently reliable [81]. Other researchers quantifying relative consistency have reported values of: HHD = 0.40-0.97 [59, 73-74, 82]; SPH = 0.61-0.96 [61, 66, 73, 75, 82]; and Groinbar intra-session reliability = 0.81-0.94 [76-78]. Again, the results of the device used in this study are comparable to other devices.

One limitation of this study is that only one variable; peak force, was investigated. Other variables such as time to peak force, impulse, or rate of force development (RFD) could provide greater insight into future investigations with different focus, such as risk of groin injuries among

this population. One of the advantages of the new device is its higher sampling rate and hence it could be postulated that more accurate measures of time-limited data such as RFD could be quantified with the custom-designed compression strain gauge device. Such a contention, however, needs to be investigated. Another limitation for this study was the introduction of non-standardised time between testing days. This was introduced as there was little control to be had over when participants would show up to testing sessions. Although the randomness of the design demonstrated the intra-session reliability it potentially hindered the inter-session reliability. For testing inter-session reliability ideally all testing conditions would be the same for all the participants. This change between participants may have altered the performance in the tests as a significant number of factors could have changed between one day and sixty days.

Conclusion

To our knowledge, this was the first study to use a custom designed-compression strain gauge as a device to measure groin adduction strength and provide comprehensive intra- and inter-session reliability statistics. It appeared that the technology and the methodology were highly reliable and provide an alternative to previously used technology. Due to the information gained through a custom-designed compression strain gauge device, the higher sampling frequency utilized, portability, and the relative affordability, this device offers an effective alternative for measuring maximal strength for hip adduction.

Chapter 4: The training effects of lower-body wearable resistance in a small-sided game approach on strength, speed and change of direction performance in semi-elite soccer players: A training study

Prelude

In the previous chapter the inter- and intra-session reliability and normative data of peak force using a new portable compression strain gauge device during a groin squeeze assessment was established. The new device was found to be reliable as all intraclass correlations were greater than 0.8 and coefficients of variations less than 10%. Knowing that we can reliably measure changes in groin strength, the natural next step is to determine if we can train to help reduce injury-risk and maintain or improve fitness. In many soccer environments that have multiple trainings and/or congested schedules, there may be little time to address both injury prevention and fitness training or maintenance. Lower-body wearable resistance is a training modality that can potentially address both these areas, as you can affix loads to the body and use whilst you are training i.e., the strength training is not separate but a part of training. To the authors knowledge, however, no research has been completed on the longitudinal effect that lower-body wearable resistance can have on the strength of muscles important in soccer injury prevention, and performance. Given this information, the purpose of this study was to examine the training effects of lower-body wearable resistance used in a small-sided game approach on strength, speed and change of direction performance in soccer athletes.

Introduction

Soccer is a highly demanding intermittent sport that involves the ability of both gross and discrete motor skills, such as the variations of ball strikes, jumps and fast changes in direction and velocity [1]. This stress requires individuals to possess advanced lower-body strength, for

speed, and change of direction (COD) performance [2-4]. Groin adductor strength is especially important due to the frequency of HAGI in elite soccer; however, hamstring strength also plays a pivotal role in speed and COD performance. The performance of these physical measures is further crucial in relation to the technical components performed in the sport, such as passing, dribbling, heading, and shooting [6, 83]. Due to the highly congested in-season schedule that soccer athletes have; strength and conditioning coaches spend a considerable amount of time finding the most optimal time efficient training methods to help reduce injury-risk and maintain or improve fitness qualities. This is achieved by training as sport specific as possible, as training methods that closer resemble the biomechanical movement and actions that occur in soccer can lead to not only positive adaptations [11-12] but allow for the crossover of both the physical and the technical elements of soccer. Finding the best training method that is time efficient and encompasses as many elements of soccer as possible can be difficult, however, lower-body wearable resistance (WR) is a training modality that can potentially elevate this issue. It bridges resistance training to sport specific training by providing specific rotational overload to athletes while they perform their sports movements, allowing for not only physical development but also technical skill improvements on the ball. However, to the authors knowledge, no research has been completed on the longitudinal training effect WR can have.

The importance strength has on overall soccer performance has been widely investigated [2, 5-7], finding that strength training is a reliable indicator for power, agility, and speed performance. These physical measures also all play a crucial role in determining how effective a player can be as well. However, the majority of these are completed outside of the specific sport(s) training and may lack the optimal transfer to sport specific performance. Sprint performance is commonly used as a performance indicator for soccer performance [84], especially at elite level. Therefore, improving sprint and acceleration performance is a critical part within soccer. Limited research has been conducted into the usage of WR on strength measures [13-14, 31-32]. Of

these, no acute training studies have been completed with the majority using upper body WR by loading via vests or arm sleeves [14, 31-32]. These found that upper-body WR appeared to be a suitable tool for movement specific overload strength and power training in movements like jumping. Only one study has looked at WR within a soccer setting [13], using it as part of a warm-up. This study lacked the use of WR in a full on-the-ball soccer training setting but still found promising results for specific strength training in soccer.

The usage of WR on speed and sprint performance has been investigated more in-depth than other physical measures, with several studies using lower-body WR [4, 13-22]. These found that WR elicited meaningful improvements in top speed and accelerated sprinting performance.

The effects of WR on COD performance have similarly been investigated to the extent of strength performance, with most studies looking at upper-body WR through central mass loading via vests [4, 33-34]. However, alike the previous physical measures, no study has used WR in a training setting with no acute studies having been completed. The completed studies displayed no clarity around the effect WR has on COD performance, with Istvan et al. finding that WR has a positive effect on COD performance [33] with other studies finding trivial results.

While research has begun to show the positive effects of lower-body WR with athletes, further training effect research needs to be completed so that we can fully understand the practicality wearable resistance training (WRT) has on strength, speed, and COD performance, as well as understanding how it may be a tool to help reduce injury risk. Furthermore, the effect of WRT in soccer has scarcely been investigated and could potentially be a training modality to alleviate the issues of over training during congested schedules.

Therefore, the purpose of this study was to determine the training effects of lower-body wearable resistance in a small-sided game (SSG) approach on strength, speed, and COD performance in semi-elite soccer players.

Methods

Experimental Approach to the Problem

The effects of a 16-session WR intervention training program on strength, speed and COD performance measures were analysed using a randomized two group pre-post-test design. Pre-post-testing were conducted to evaluate the effectiveness of the WR program on isometric strength, isokinetic strength, sprint, and COD performance. Semi-elite male U19 soccer players were randomly divided into a WRT group (*n* = 9) and a control (CON) group (*n* = 10). The WRT and CON groups participated in the same intervention training sessions that included two-twelve minutes of SSG and an on-the-field strength, speed, and COD training program for twelve minutes. The only difference between the groups was that the WRT group wore compression sleeves with 200-600 g distributed to the posterior shank of each leg. Pre-training performances were established before the first week of intervention sessions and post-training performance was measured two-weeks following the interventions conclusion. Quantitative analysis was used to test pre-post-testing scores, while inferential statistics were used to rationalize any observed changes.

Participants

Thirty-nine semi-elite level male soccer players (age: 16.9 ± 0.7 years old; body mass: 70 ± 8 kg; height: 180 ± 6.9 cm) volunteered. The cohort consisted of two teams from the Wellington Phoenix Football Club Academy (WPXA). Sixteen players were removed from the study due to failure to sign and return informed consent forms or finish pre-testing prior to the start of the intervention training sessions. A further four players were removed due to injuries that occurred during the intervention: the injuries unrelated to the study. Of the remaining nineteen that competed the full study, they consisted of a variety of out-fielder positions (central defenders (3), wide defenders (4), central midfielders (8) and forwards (4)). The criteria for inclusion in the

study were to be playing at a semi-elite level in soccer, to be injury and illness free for one month prior to the start of pre-testing and to be actively participating in training and games throughout the season during the intervention. Participants were excluded from this study if they missed three consecutive intervention sessions (injury, absence, illness) or if they failed to adhere to the training program with above 80% participation. Each participant had the procedures of the study, as well as the potential risks and benefits explained to them both verbally and in written form. Prior to any inclusion, each participant had to sign an informed consent. The Auckland University of Technology Ethics Committee approved all procedures undertaken in this study (20/411).

Procedures

Testing. Pre-training performance was completed during the two-week lead up to the intervention and post-testing was completed after a two-week taper period following the final intervention session. Prior to any testing, participants were instructed to refrain from any unusual, unnecessary, or overly vigorous physical activity for twenty-four hours. During this period, participants were continuing to complete regular soccer field trainings to control any sudden changes in physical activity. The subjects wore the same clothing (WPXA training shirts, shorts, and socks), footwear (soccer boots) and completed the respective tests on the same surfaces for both pre- and post-testing. Prior to any testing, participants completed a familiarization session where each test procedure was explained, demonstrated and participants had the chance to practice. Participants were also given a warm-up attempt for each test prior to any maximal testing in both the pre- and post-testing at approximately 50% maximal output. Participants completed a standardized soccer warm-up that varied on the different testing days prior to any testing. For the strength testing, participants were run through their usual pre-habilitative exercises by the team's sport scientist and given a soccer specific dynamic warm-up. For speed and agility testing, subjects were run through a standardized dynamic soccer

warm-up that encompassed light jogging, skipping, bounding, accelerations, decelerations, and COD movements. For the dynamometer testing, subjects completed foam rolling of the hamstring and quadriceps as well as a minimum of five minutes of submaximal cycling on an upright stationary exercise bike. A minimum of twenty-four hours rest was then provided between each separate testing day with at least forty-eight hours rest provided before dynamometer testing. This structure was used to not only fit to the cohorts' tight schedule but also to ensure the appropriate recovery between the various tests were given to avoid influencing the reliability or performance of the testing.

Anthropometrics. Standing body height and weight were measured by the team's sport scientist using a stadiometer and an electronic scale.

Physical Testing: For both the pre- and post-testing sessions for the isometric strength, sprint and COD tests, participants completed four trials. The first trial was a warm-up of approximately 50% maximum effort. This was followed by three trials performed at maximal effort. For each of these maximal effort trials, participants were instructed to perform the test to their best ability. After each maximal trial, a one-minute recovery was given. For the isokinetic dynamometer pre- and post-testing, four trials per leg were completed. The first and third trial was a warm-up of approximately 50% effort. The second and fourth trial was a maximal effort trial, where participants were instructed to perform the test to their best ability. After each trial, a 30-second recovery was given prior to the next warm-up trial starting automatically through the dynamometer protocol.

Isometric Midthigh Pull. The isometric midthigh pull (IMTP) assessment was completed following the anthropometrics. This was completed using a 1000 Hz custom designed portable load cell prototype interfaced with custom software (SPRINZ Laboratories, Auckland University of Technology). All participant data was recorded using a custom designed MATLAB program

for strain gauges (MidThighPull.V19). For each trial, the pre-tension threshold was set to 200 N of force. Prior to any testing the device was zeroed.

For the set-up, participants were instructed to remove their shoes and stand on the baseplate with their feet hip-width apart over the chain and bar. They were then instructed to pick up the bar with their knees partially bent. The chain was then altered for each participant so there was no slack on the chain and that the bar was held, with the chain under tension, halfway between their lateral condyle of the femur and the top of the anterior superior iliac spine of their hip. Participants were instructed to have their knees slightly flexed (between a 130–140-degree knee angle) with an upright torso and their shoulders over the bar. The participants were instructed to hold the bar in overhand grip with the chain held under tension with the bar placed against their thigh.

Groin Squeeze. The groin squeeze (GS) assessment was completed following the IMTP. This was completed using a 1000 Hz custom designed portable load cell prototype interfaced with custom software (SPRINZ Laboratories, Auckland University of Technology). All participant data was recorded using a custom-designed MATLAB program for strain gauges (MidThighPull.V19) that had been adapted to measure compression. For each trial, the pre-tension threshold was set to 50 N of force. Prior to any testing the device was zeroed.

For the set-up, participants were instructed to remove their shoes and lie with their back, buttocks and head on the floor, arms parallel to their torso on the floor, legs hips-width apart and knees bent with their feet on the floor. Their hip angle was then measured using a goniometer and set at 45 degrees. The compression strain gauge was then placed between their adductor tubercle of the femurs, with the device facing upwards.

Isokinetic Dynamometer Assessment. The isokinetic dynamometer assessment was completed on a separate day after the 20 m sprint and COD testing, with at least forty-eight hours given

between the different testing sessions. This was completed using a Biodex System 4 dynamometer (Biodex System 4 Quickset, Biodex Medical Systems, Inc. Shirley, New York, USA). All participant data was recorded through the Biodex 4 Advantage Software package. Prior to testing, profiles were created for all participants that included their name, date of birth, height, weight, and dominant leg. A new isometric concentric/concentric knee flexion and extension at 60 degrees per second program was also created prior to testing. Participants were given a chance to complete a warm-up before each trial as well as a thirty second rest period in-between repetitions. The maximal effort test protocol had five knee extensions and five knee flexions.

For the set-up, participants were instructed to sit in the dynamometer chair. The chair was then adjusted to fit their height. For this, the popliteal fossa of their knees was placed against the end of the chair, and the back of the chair was adjusted so that it was pressed against their lower back. Following this they were strapped in via belts across both shoulders, their waist and whichever leg was being tested. The configuring dynamometer control was then adjusted for the knee joint via the position colour coded label on the device. The chair was then pushed forward and rotated so that the knee lined up with the dynamometer shaft. The tested leg was then attached and strapped tightly into the Biodex leg attachment. The protocol would then start where the participant would have to set their range of motion for their maximum knee extension and flexion, as well as finding the middle angle and weighing the leg. The testing protocol would then begin. This procedure was then replicated following the protocol for the other leg.

20 m Sprint Assessment. The 20 m sprint assessment was completed on a separate day to the groin squeeze and isometric mid-thigh pull testing, with at least twenty-four hours given between the different testing sessions. This was completed using a Stalker Radar ATS II Gun (Stalker ATS Pro II, Texas, USA). All participant data was recorded through the Stalker Radar Gun

program. Prior to any testing sessions the gun was calibrated and set to the standard speed settings for km/h outbound testing.

For the set-up, participants were instructed to wear their soccer boots. The testing for both the pre- and post-testing was completed in the same indoor turf space to ensure the environment was consistent. The radar gun was placed in one corner of the field at approximately naval height (120 cm), with starting cones placed 8 m in front of the gun. Cones were also placed at the 10 m, 20 m, and 30 m splits. The 30 m cones were placed to ensure participants kept sprinting past the 20 m cones to avoid slowing down.

Modified (Flying) 5-0-5 Assessment. The modified (flying) 5-0-5 COD assessment was completed after the 20 m sprint testing. This was completed using a Stalker Radar ATS II Gun. All participant data was recorded through the Stalker Radar Gun program. Prior to any testing sessions the gun was calibrated and set to the standard speed settings for km/h outbound/inbound testing.

For the set-up, participants were instructed to wear their soccer boots. The testing for both the pre- and post-testing was completed in the same indoor turf space to ensure the environment was consistent. The radar gun was placed on the goal line of the field at approximately naval height (120 cm), with starting cones placed 10 m in front of the gun. Cones were placed 5 m in front of the starting cones, these were the finishing cones. Cones were also placed 10 m in front of the starting cones (5 m ahead of the finishing cones), these were the turning point cones.

Intervention Training Program. Participants were randomly assigned to either the CON or WRT group using a random number generator on Microsoft Excel. The CON and WRT group performed the exact same training, the only difference being was that the WRT group were shank loaded with LILA EXOGEN wearable resistance. The intervention consisted of 16-training sessions where the participants would complete approximately thirty-six minutes of training with

the weights. These sessions were run throughout the team's usual weekly training schedule with at least twenty-four hours rest in-between each intervention session or after competitive games were played. The loading position and increments of the weights for the WRT group rotated throughout the intervention (*Table 1*). These parameters were followed to replicate what was completed in a previous study that used wearable resistance as part of a warm-up protocol [13]. For the intervention sessions all participants would complete a standardized warm-up with the sport scientist team that included pre-habilitative exercises, a soccer-specific dynamic warm-up, and an on-ball soccer warm-up for approximately twelve minutes. Following the warm-up, the participants were split into three random groups with even numbers. These groups would take turns rotating through two-repetitions of SSG run by the team's coaches and one-repetition of the strength, speed, and COD training program run by the primary researcher. The SSG were completed in roughly 20 x 20 m spaces as this was typically the appropriate size per player to replicate the estimated physiological match demands and external loading seen in elite soccer players [87]. The constraints and rules of the SSG varied dependent on what the coach wanted to run; however, the intensity was always kept as close as possible. The time was always kept by the primary researcher running the strength, speed, and COD training program, with each rotation taking approximately twelve minutes. During the SSG, the coaches were instructed not to interfere or stop the play at all and would constantly feed in balls, so the game was constantly active. A short break was usually given six minutes through each SSG where the coach would get all the balls back and add/remove constraints of the game. This break never lasted longer than a minute.

The strength, speed, and COD training program implemented by the primary researcher never changed between sessions (*Table 2*). Prior to the first session, the participants were instructed how to complete all the exercises both verbally and given a visual example. During this familiarization participants all had the chance to practice and were given feedback by the

primary researcher. The A-skips, B-skips, forward side shuffles, straight leg shuffles, forward and backward bounding were completed as explosively as possible. The three sprint exercises were completed at maximal effort, attempting to reach top speed but including multiple accelerations and decelerations. The sprint with headers had participants sprinting out and jumping vertically as high as possible, to replicate a soccer header, every 10 m, for 30 m. The forward and backwards sprint had participants sprint 10 m out, then backwards 5 m, forward 10 m, back 5 m and finally forward a final 10 m. The reactive sprints had participants sprinting out ~10 m after a clap, then changing direction (90 degrees) dependent on which way the primary researcher pointed. Following the three rotations during an intervention session, the intervention group would remove the weights, then continue with the remainder of the coach led training session along with all other players. Training sessions lasted between sixty and ninety minutes, inclusive of the intervention. Of that time, roughly forty to seventy minutes the players were actively working (on-the-ball, conditioning, or intervention exercises). The remaining time was either rest periods, drill transitions or coaching instructions.

Table 4.1: Wearable resistance intervention group loading scheme.

Session Number	Loading Weight	Loading Position
1	200 g	Posterior shank – proximal
2	200 g	Posterior shank – proximal
3	200 g	Posterior shank - distal
4	200 g	Posterior shank - distal
5	400 g	Posterior shank – proximal
6	400 g	Posterior shank – proximal
7	400 g	Posterior shank - distal
8	400 g	Posterior shank - distal
9	400 g	Posterior shank – proximal
10	400 g	Posterior shank – proximal
11	600 g	Posterior shank - distal
12	600 g	Posterior shank - distal
13	600 g	Posterior shank – proximal
14	600 g	Posterior shank – proximal
15	600 g	Posterior shank - distal
16	600 g	Posterior shank - distal

Table 4.2: Intervention strength, speed, change of direction training program.

Exercise	Repetitions	Distance
A-skips	2	20 m
B-skips	2	20 m
Forward 45° side shuffle	3	20 m
Straight leg shuffle	3	20 m
Forward bounding	2	30 m
Backward bounding	2	30 m
Sprint with headers	2	30 m
Forward 10 m, backwards 5 m sprints	2	20 m
Reactive change of direction sprints	3	~10 m

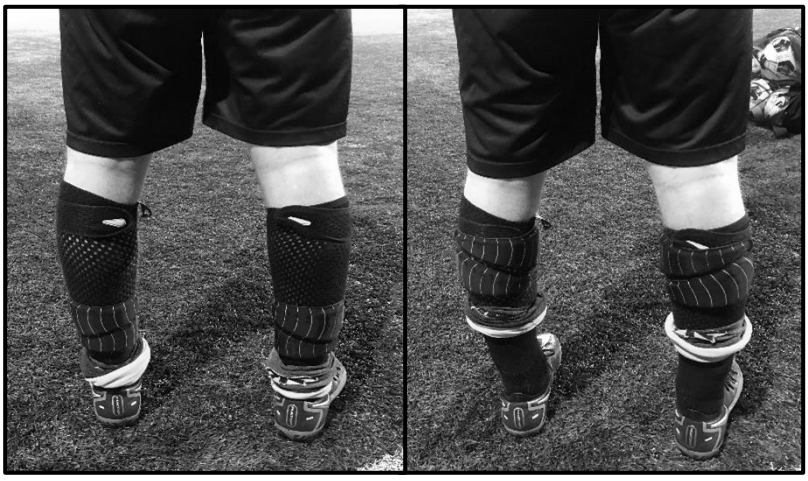

Figure 4.1: Wearable resistance posterior loading: distal (left) and proximal (right).

Data Analysis

Groin Squeeze and Isometric Midthigh Pull Assessment. Raw unfiltered force-time data was exported for subsequent analysis in CSV format. The data was then imported and analysed in MATLAB (MathWorks, Natick, MA), using a custom algorithm. Each trial was trimmed to length to include a pretension period of at least 0.5 seconds, force onset, isometric contraction for at least 2 seconds, and a force offset. Peak force was determined as the absolute maximum force recorded during the entirety of the 2+ second contraction. Each participant had pre- and post-testing trials analysed with outliers removed (n = 9 trials) if the peak force was unstable and/or if

the trial was not held long enough (2 seconds). The best trial for both pre- and post-testing of each participant were taken based off-peak force.

Isokinetic Dynamometer Assessment. Data was processed through the Biodex System 4 Advantage Software that provided a comprehensive report for each participant with a variety of numerical and graphical variable results. The variables used to describe knee flexor and extensor strength output for both legs were extension peak torque (ext. PT), flexion peak torque (flex PT) and antagonist/agonist ratio (agon/ant ratio). The comprehensive report was configured and exported for subsequent analysis in CSV format. Each trial for both pre- and post-testing was then individually reviewed. Trials where there were errors in the range of motion, insignificant torque, or failure to complete the full protocol were removed (n = 2 trials). The best trial for both pre- and post-testing of each participant were taken based off right leg flex PT as it was the dominant leg for most of the participants (89.5%).

20 m Sprint Assessment. Each trial for both pre- and post-testing was individually reviewed through the Stalker Radar II Gun program. Any clear outlying data points that were significantly outside the clear trendline were removed. The raw unfiltered velocity-time (V-T) data, at a sampling rate of ~47 Hz was collected and exported for subsequent analysis in CSV format. The data was then imported and analysed in MATLAB Script, using a custom algorithm. Each trial was analysed from the start of movement. Movement onset was determined using a 10-sampling rolling average and then a 0.8 m/s threshold. From onset of movement, raw V-T data was fit with a mono-exponential function to model the change of mass velocity of the participant [85]. Outlier samples in the raw V-T data were identified by a residual functional removing ± 2 S.D of the residual. The mono-exponential function was then fit again to the remaining data to obtain final modelled V-T data [85]. Final mono-exponential modelling of the V-T data fit to raw data with an average $r^2 = 0.99$. The variables used to describe sprint performance were theoretical maximum horizontal force (F0), peak power (Pmax), maximal velocity (Vmax), slope

of the force-velocity profile (Sfv) and the sprint split times (5, 10 and 20 m). The best trial for both pre- and post-testing of each participant were taken based off Pmax, as it highly correlated to overall sprint performance [85].

Modified (Flying) 5-0-5 Assessment. Each trial for both pre- and post-testing was individually reviewed through the Stalker Radar II Gun program. Any clear outlying data points that were significantly outside the clear trendline were removed. Then the raw unfiltered V-T data, at a sampling rate of ~47 Hz was collected and exported for subsequent analysis in CSV format. The data was then imported and analysed in MATLAB Script, using a custom algorithm. Each trial was trimmed from the start of movement. Onset of movement was manually identified along with COD point by locating the minimum peak in the velocity data. Any speed data below speed at onset was forced to 0 m/s. Each participant had pre-and post-testing trials analysed with outliers removed (n = 13 trials) if the velocity was above 1 m/s at the starting point or if the COD point was significantly wrong (> 1m). The start of the 5-0-5 was determined as 5 m from the onset of movement using integrated speed data. The variables used to describe COD performance were maximal 5-0-5 velocity (Vmax), average 5-0-5 velocity (avgV) and time to complete the test (s). The best trial for both pre- and post-testing of each participant were taken based off time.

Statistical Analysis

All statistical analysis was conducted using RStudio IDE (Version 1.4.1717). Means ($\bar{x}$) and standard deviations (SD) were calculated to represent centrality and spread of the dependent variables. A two-way mixed measures ANOVA test was completed for the between factor, the intervention training groups, and the within factor, the pre-post-testing times. The data was assessed using a boxplot method for outliers and distribution estimation, with no outliers being observed in the data. Normality of distribution for all dependent variables were assessed using Shapiro-Wilk's test for each cell design ($p > 0.05$). Homogeneity of variance was assessed

using the Levene's test for each cell design ($p > 0.05$) and the homogeneity of covariance was assessed using a box's M test ($p > 0.05$). If a significant two-way interaction was observed the simple main effects from a one-way ANOVA were checked, if that was significant, simple pairwise comparisons were calculated. If no significant two-way integration was observed, the two factors (group and time) for the main effects of variables were analysed. These were followed with pairwise comparisons adjusted using the Bonferroni multiple testing correction method. When any interaction or main effect for time was observed, the Bonferroni post hoc test was performed in each group. The absence of statistically significant differences between each group before the intervention was confirmed by performing an independent t-test. Hedges g effect sizes (ES) were calculated to quantify the differences in the CON and WRT groups with an alpha level of 0.05 and confidence intervals of 95%. The ES were categorized as small effect (0.2), medium effect (0.5) and large effect (0.8). Individual training responses were identified as a change in intervention training by using a smallest worthwhile change (SWC) threshold. This was calculated by multiplying the smallest effect size (0.2) by the between group SD. Any individual change above this threshold was considered to have had a practical worthwhile change.

Results

Isometric Midthigh Pull. The within and between group isometric strength comparisons can be observed in *Table 4. 3*. The CON within group changes ranged from ~7.5-11.3%, with the training showing a small to moderate effect size, however, the changes in the GS over the intervention were non-significant with 60% of the participants not exceeding the SWC. Training with WRT on both isometric measures resulted in statistically significant increases (~20%), with particularly large changes (ES = 1.03) in GS strength, with only one subject failing to exceed the

SWC. Trivial non-significant changes were observed between groups for both IMTP and GS tests. Individual comparisons relative to percent change are displayed in *Figure 4.2a*.

Table 4.3: Isometric midthigh pull (IMTP) and isometric groin squeeze (GS) test pre-post intervention results.

	Within CON Group			Between Group	Within WRT Group		
	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]	ES (p-value)	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]
IMTP Peak Force (N)	1396 ± 224	1543 ± 220	11.3 ± 9.66 (0.006) ES = 0.61 [0.22, 1.0]	ES = 0.17, p = 0.08	1418 ± 254	1702 ± 371	19.7 ± 13.1 (0.002) ES = 0.65 [0.32, 1.0]
GS Peak Force (N)	404 ± 60.5	430 ± 54.2	7.53 ± 14.7 (0.19) ES = 0.40 [-0.22, 1.03]	ES = 0.11, p = 0.17	380 ± 46.3	454 ± 79	21.1 ± 24.9 (0.04) ES = 1.03 [-0.03, 2.08]

Groin Squeeze. The within and between group isokinetic strength comparisons can be observed in *Table 4.4*. The CON within group changes ranged from ~3.2-16%, the training effects trivial to moderate effect, however, the changes in strength over the intervention were non-significant with many participants not exceeding the SWC for extension (60%) and flexion (30%) peak torque. Training with WRT resulted in mostly trivial changes (ES = ~0-0.31) with changes varying from ~-1-16%, and slightly less participants not exceeding the SWC for extension (44%) and flexion (33%) peak torque. Trivial non-significant changes were observed between groups for both extensors and flexors and most within-group changes were non-significant also.

Table 4.4: Isokinetic extension and flexion peak torque test pre-post intervention results.

	Within CON Group				Between Group	Within WRT Group		
	Leg Tested	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]	ES (p-value)	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]
Ext PT (N*kg)	Right	190 ± 36.9	*194 ± 27.7	3.16 ± 8.78 (0.46) ES = 0.09 [-0.15, 0.33]	ES = 0.02, p = 0.55	181 ± 29.6	192 ± 33	7.51 ± 18.8 (0.36) ES = 0.31[-0.38, 1.01]
	Left	185 ± 40	196 ± 31.2	8.04 ± 15.2 (0.15) ES = 0.25 [-0.09, 0.59]	ES = 0.10, p = 0.20	187 ± 36.4	*184 ± 43.1	-1.51 ± 12.4 (0.69) ES = -0.07 [-0.46, 0.31]
Flex PT (N*kg)	Right	*114 ± 32.3	124 ± 18.5	11.5 ± 14.6 (0.17) ES = 0.25 [-0.11, 0.61]	ES = 0.04, p = 0.41	103 ± 20.2	120 ± 29.4	16.9 ± 17.5 (0.03) ES = 0.56 [0.08, 1.03]
	Left	99.2 ± 20.3	113 ± 17.3	15.8 ± 14.6 (0.007) ES = 0.65 [0.22, 1.09]	ES = 0.13, p = 0.13	110 ± 35.3	109 ± 22.3	3.36 ± 16.4 (0.91) ES = -0.03 [-0.54, 0.49]
Agon/Ant Ratio (%)	Right	60.7 ± 14.4	64.1 ± 8.63	8.88 ± 16.6 (0.38) ES = 0.25 [-0.32, 0.82]	ES = 0.005, p = 0.77	57.4 ± 8.83	59.2 ± 13.9	3.92 ± 21.4 (0.7) ES = 0.13 [-0.57, 0.84]
	Left	54.6 ± 10	58.4 ± 9	7.9 ± 11.4 (0.08) ES = 0.36 [-0.03, 0.76]	ES = 0.009, p = 0.69	58.3 ± 13.2	60.3 ± 11.6	1.64 ± 17.1 (0.62) ES = 0.15 [-0.48, 0.77]
**Failed normality check*								

20 m Sprint Assessment. The within and between group 20 m sprint comparisons can be observed in *Table 4.5*. In terms of the CON within group comparison only the 20 m split pre-post results were found to be statistically significant. Sprint changes ranged from ~3-10% with small to large effect sizes, with only one trivial finding (Sfv), however, 22% of participants failed to exceed the SWC for 5, 10 and 20 m sprint times. Training with WRT resulted in statistically significant improvements in all but one of the radar measures (Vmax), with 4-19% change and very large changes (ES = ~-1.5 to -2.3) in sprint time across 5, 10 and 20 m splits with only one subject failing to exceed the SWC. Trivial non-significant changes were observed between groups for all sprint variables. Individual comparisons relative to percent change for sprint times are displayed in *Figure 4.2b*.

Table 4.5: Radar 20 m sprint test pre-post intervention results.

	Within CON Group			Between Group	Within WRT Group		
	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]	ES (p-value)	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]
F0 (N)	537 ± 113	572 ± 158	6.4 ± 18 (0.31) ES = 0.21 [-0.21, 0.63]	ES = 0.09, p = 0.24	476 ± 65.6	559 ± 88	17.9 ± 14.1 (0.004) ES = 0.91 [0.33, 1.5]
Vmax (m/s)	7.94 ± 0.27	8.22 ± 0.17	3.61 ± 4.55 (0.06) ES = 1.12 [-0.24, 2.48]	ES = 0.07, p = 0.29	8.03 ± 0.3	8.14 ± 0.33	1.47 ± 2.88 (0.19) ES = 0.33 [-0.17, 0.83]
Pmax (W)	1139 ± 228	1258 ± 301	10.3 ± 13.8 (0.06) ES = 0.37 [0, 0.74]	ES = 0.05, p = 0.38	1050 ± 170	1227 ± 216	17 ± 9.44 (0.0006) ES = 0.73 [0.41, 1.05]
***Sfv (%)**	-63.1 ± 14.4	-64.8 ± 20.5	3.04 ± 23.7 (0.73) ES = -0.08 [-0.58, 0.41]	ES = 0.10, p = 0.21	-53.7 ± 6.75	-63.4 ± 9.77	19.3 ± 20.2 (0.02) ES = -1.03 [-1.98, -0.07]
5m Split (s)	1.3 ± 0.06	1.26 ± 0.09	-2.67 ± 6.43 (0.27) ES = -0.41 [-1.16, 0.35]	ES = 0.13, p = 0.14	1.35 ± 0.03	1.26 ± 0.04	-6.62 ± 3.81 (0.002) ES = -2.31 [-4.29, -0.33]
10m Split (s)	2.07 ± 0.07	2.01 ± 0.11	-2.83 ± 4.41 (0.11) ES = -0.57 [-1.28, 0.14]	ES = 0.14, p = 0.13	2.13 ± 0.04	2.01 ± 0.06	-5.64 ± 2.75 (0.0005) ES = -2.15 [-3.61, -0.69]
20m Split (s)	3.39 ± 0.09	3.29 ± 0.12	-2.98 ± 3.05 (0.03) ES = -0.86 [-1.63, -0.09]	ES = 0.06, p = 0.35	3.45 ± 0.09	3.31 ± 0.09	-4.17 ± 1.96 (0.0003) ES = -1.46 [-2.2, -0.71]
**Failed box's M normality test*							

Modified (Flying) 5-0-5 Assessment. The within and between group modified 5-0-5 COD comparisons can be observed in *Table 4.6*. The CON within group changes ranged from ~1.6-9.5%, the changes in the velocity were statistically significant (ES = ~1.0 to 1.6), however, the overall change in total COD time was found to be non-significant and trivial with 50% of participants failing to exceed the SWC. With regards to the WRT, the changes in avgV were found to be statistically significant with changes ranging from ~-3.0 to 6.2%. The changes in the velocity measures were moderate to large, whereas the change in COD time was small but showed only 22% of participants failing to exceed the SWC. Trivial non-significant changes were observed between groups for all modified 5-0-5 COD variables. Individual comparisons of Vmax and avgV can be seen in *Figure 4.2c*.

Table 4.6: Radar modified (flying) 5-0-5 COD test pre-post intervention results.

	Within CON Group			Between Group	Within WRT Group		
	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]	ES (p-value)	Pre ($\bar{x}$ ± SD)	Post ($\bar{x}$ ± SD)	% Change ± SD (p-value) ES [95% CL]
Vmax (m/s)	5.82 ± 0.28	6.2 ± 0.36	6.74 ± 6.55 (0.03) ES = 1.05 [0.03, 2.07]	ES = 0.04, p = 0.43	5.86 ± 0.21	6.08 ± 0.26	3.97 ± 7.19 (0.17) ES = 0.84 [-0.52, 2.21]
avgV (m/s)	3.67 ± 0.21	4.0 ± 0.16	9.53 ± 9.09 (0.02) ES = 1.62 [-0.16, 3.4]	ES = 0.03, p = 0.50	3.73 ± 0.11	3.96 ± 0.25	6.2 ± 7.57 (0.05) ES = 1.11 [-0.17, 2.39]
Time (s)	2.36 ± 0.19	2.38 ± 0.12	1.64 ± 9.02 (0.75) ES = 0.14 [-0.76, 1.04]	ES = 0.06, p = 0.33	2.48 ± 0.19	2.4 ± 0.12	-2.71 ± 8.77 (0.31) ES = -0.46 [-1.4, 0.48]

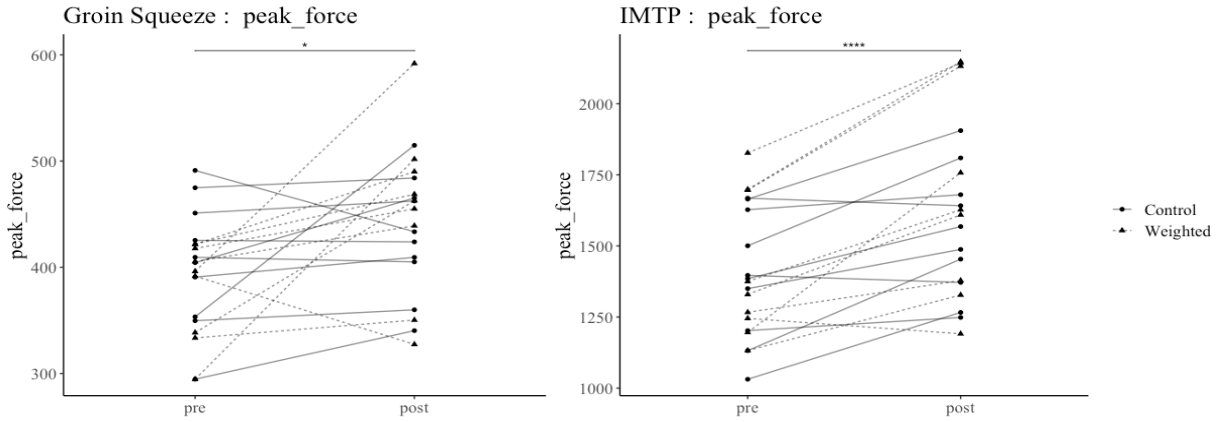

Figure 4.3a: Individual isometric peak force strength test changes.

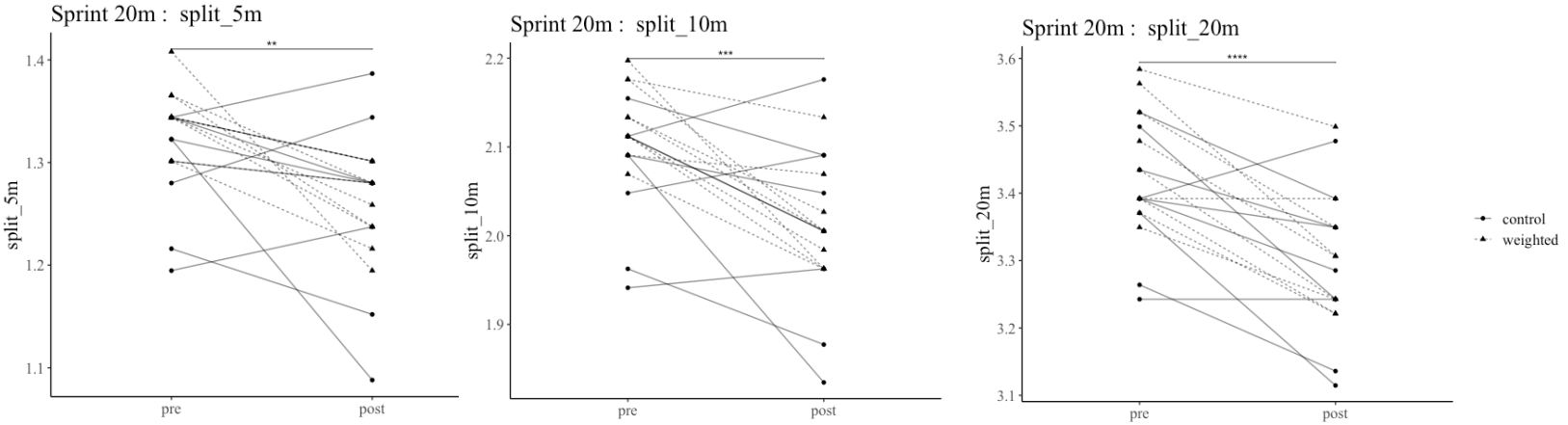

Figure 4.3b: Individual sprint time (5, 10, 20 m split) test changes.

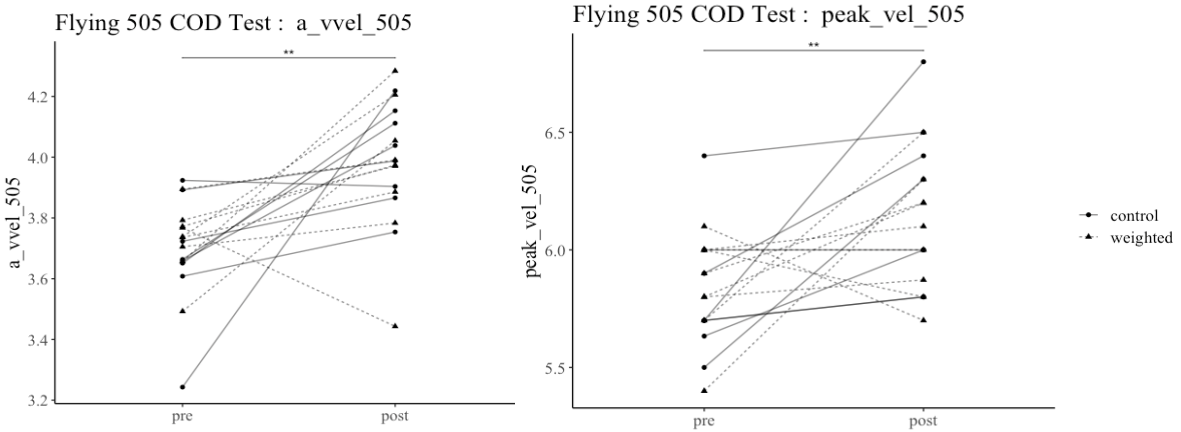

Figure 4.3c: Individual avgV and Vmax modified 5-0-5 COD test changes.

Discussion

Understanding the effects of WR implementation in a SSG approach to training with an on-the-field strength, speed, and COD training program, was the focus of this research. Though there were no statistically significant differences between the WRT and CON groups from the intervention, there were some greater gains in strength seen in the WRT group as well as within-group findings that were of statistical and practical significance, which are discussed going forward.

In terms of the strength outcomes, it appears that both the SSG training and the on-the-field training program improved IMTP peak force (CON; ES = 0.61, WRT; ES = 0.65) irrespective of whether players were shank loaded or not. Previous researchers have shown the benefit strength performance improvement can have on soccer performance [7-6], however, limited research has looked at training effect in an SSG setting, with no research having used WR. A further focus of this study was to determine if an on-the-field training program could increase the strength of the groin musculature. It seems that the addition of WR provided enough overload, to elicit noticeable ($p < 0.05$) increases in groin strength. This may have been due to the high-intensity lateral movement requirements in the on-the-field training program, from the SSG training and from the type of passing that frequently occurred in a SSG with pitch dimensions of this study i.e., side-foot passing (hip external rotation with ankle eversion and dorsiflexion). This is a novel and important finding as the increase in groin strength from WRT may be an effective injury prevention modality, especially considering the amount of groin injuries prevalent in soccer [23, 67, 72].

It was thought that the training program might also increase knee flexor and extensor torque, however, the results for both training groups were for the most part trivial and non-significant. This was expected in terms of the WR not having a significant effect due to the lack of sustained high velocity movements occurring in the SSG training. Furthermore, the size of the SSG pitch

may have impacted this, as the confined space may not have allowed for any significant sustained high velocity movements. Greater pitch size may have not only elicited greater knee flexor and extensor workload but also included more longer passes and shots i.e., laced-passing/shots (hip flexion/extension with ankle plantarflexion), that require more activation of the knee flexor and extensors [86-87]. To the knowledge of the authors, very few researchers have investigated the influence of SSG on knee flexor and extensors [86]. Finding that larger SSG spaces elicited greater internal and external loads resulting in more accelerations but decrements in hamstring force [86]. Notwithstanding these results, no research group has investigated the effect of SSG with WR on knee flexor and extensor torque, and it is proposed that larger SSG pitch sizes could improve knee flexor and extensor strength, however, such a contention needs verifying.

With regards to the sprint measures, the main between group observations were that the changes in the WR were statistically significant (except Vmax) and the training effects on average were larger than the unloaded condition (CON; ES = ~0-1.1, WRT; ES = ~0.3-2.3). The efficacy of WR as a speed training tool has been documented previously via multiple studies [13, 15, 17-18, 20], however, this is the first study to document changes using a SSG approach. The only other study to use WR as part of a soccer training session, was Bustos et al [13]. However, they used the WR as part of a warm-up and although they found significant increases in 10 and 20 m sprint times (ES; 10 m = -0.5, 20 m = -0.3), it was significantly less than the effect seen from the SSG approach. It appears from the effect sizes that the use of shank loaded WR provided a movement-specific training stimulus that improved sprint ability greater than the unloaded group. Once more with larger pitch sizes and higher velocity movement (greater kinetic energy and therefore muscular work), it would be expected that the WRT would result in greater improvements in sprint performance measures.

The COD results are difficult to understand in that the velocity for the CON were significantly greater but the time to complete the test was slower, whereas WRT resulted in smaller velocity improvements, but their COD times were faster. Once more it is difficult to compare these results to other literature as most literature in this area is acute [33] in design. WR has been used previously for improving COD performance, however, the majority of that has been completed using upper-body WR [34, 88-89]. This has been shown to have little to no impact on COD performance outside of peak velocity as it does not seem to influence horizontal force production due to the location of the WR in relation to the centre of mass loading. More research is needed on lower-body WR for COD performance to determine the true training effects it may have.

Using WR on the posterior shank during SSG and a strength, speed, and COD training program within soccer may be an effective measure to improve sprint and isometric strength performance, however, several limitations to this study have been identified. First, the small sample size for this study may have influenced the statistical significance, or lack of, between groups. Second, even though the reliability of these measures has been established previously, the variability associated with some measures was large making it problematic for results to be deemed statistically significant. In truth, this is most likely the reality of training, as averaging results may have masked the individual responses to different types of training. Third, by using 20 x 20 m pitches it limited the participants ability to perform sustained high velocity actions. This was especially seen when more players were involved in the training session as it no longer mimicked the typically external loads and estimated physiological match demands in elite soccer [87]. Although this had little influence on lateral movement, as seen in the significant GS adaptations, it may have influenced the effect WR had on knee flexor and extensor torque and net improvement in the sprint measures. Finally, rather than using slow velocity isokinetic

dynamometry (60 deg/sec) to assess high velocity strength changes from training, it might have been better to measure these changes more specific to the speeds at which they trained at.

Practical Applications

It needs to be recognized that lack of statistical significance does not preclude findings being of practical significance, thus the use of statistics such as ES and SWC are valuable. The following is a summary of the more important observations from this study. Soccer like many sports, are interested in time-efficient strategies to condition the athletes for injury prevention and performance purposes. This is especially so in those teams that have congested schedules, where fitness qualities such as strength, speed, and COD can detrain because of the absence of adequate training stimuli. Therefore, smart training options are needed to maintain these fitness qualities, particularly in-season. It appears that with the SSG and the on-the-field training program approach used in this study, that the strength and speed measures can be improved in-season. Furthermore, it seems that the addition of WR can enhance these improvements even further, especially in relation to the GS and sprint performance. Also, it is quite likely that these adaptations can be modified with the changing of pitch sizes. That is, with larger pitch sizes relative to the number of players per the area size, the WR would provide a larger mechanical and therefore muscular overload, given work-energy theorem. The dose-response relationship to using WR with different field dimensions, however, needs further investigation.

Chapter 5: Discussion and Conclusion

The overall purpose of this thesis was to provide more insight into the benefits and implications of lower-body wearable resistance in a training approach to soccer. To achieve this, it was necessary to first highlight and determine the incidence frequency, type, and severity of hip and groin injuries in elite soccer, as well as provide discussion on optimal preventative and pre-habilitative strategies (chapter 2). In addition, a reliability study was completed to test a novel groin squeeze device for adductor strength (chapter 3), and subsequently used in the training study to measure peak adductor force.

A review of literature showed that hip and groin injuries account for a significant amount of all elite soccer related injuries, resulting in significant time-loss from training and games. Furthermore, the review found that although screening tests, load management, strengthening exercises and mobility improvements have been used to combat hip and groin injuries, their combined use has not been reported across a reliable elite soccer population.

Given the information from the review of literature, chapter 3 focused on a novel groin squeeze device. To the authors knowledge, this was the first study to use a custom designed-compression strain gauge as a device to measure groin adduction strength and provide comprehensive intra- and inter-session reliability statistics. The findings showed that the novel technology had not only a higher sampling frequency than other commonly used devices but was portable and had good utilisation. The device was shown to be highly reliable and provided an alternative to previously used instrumentations for maximal strength hip adduction testing. Additionally, in conjunction with the findings from chapter 2, this device could be used effectively as a quick and easy groin squeeze screening device to reduce the risk of hip and groin injuries.

Chapter 4 investigated the training effects of a lower-body wearable resistance study via a small-sided game approach on strength, speed and change of direction performance in semi-

elite soccer players. Although the results showed a lack of statistical significance it does not preclude the findings of practical significance. Soccer is like other sports in that there is an interest in finding the most time-efficient strategies to aid in injury prevention and performance. The study found that the small-sided game approach was effective in improving strength and speed measures in-season. Furthermore, it seems the addition of lower-body wearable resistance enhanced these improvements further, especially in relation to groin squeeze strength and sprint performance. However, due to the small-sided game pitch sizes the players weren't exposure to large mechanical and therefore muscular overload which may have led to the trivial changes seen in the isokinetic testing.

The key findings from this thesis have been highlighted in figure 5.1. They suggest that the implementation of lower-body wearable resistance training has several beneficial physical adaptations. The training study showed that groin squeeze peak force changes were large and statistically significant. When relating this back to chapters 2 and 3, it shows how this finding could play an important role in reducing hip and groin injuries. The study also showed large and statistically significant changes on 20 m sprint speed. However, the changes to both isokinetic knee flexor and extensor strength, as well as change of direction performance were trivial to small, outside of the velocity changes seen in the linear 20 m speed testing. This thesis also suggested that combining several preventative and pre-habilitative strategies could be an effective way to reduce hip and groin injuries. Fine tuning an already researched strategy like the FIFA 11+ and adding in the missing hip adduction exercises, like Copenhagen adductions, alongside screening and proper load management could further increase the preventive effect. The final findings from this thesis showed that the new novel groin squeeze device demonstrated comprehensive intra- and inter-session reliability for maximal groin adduction strength.

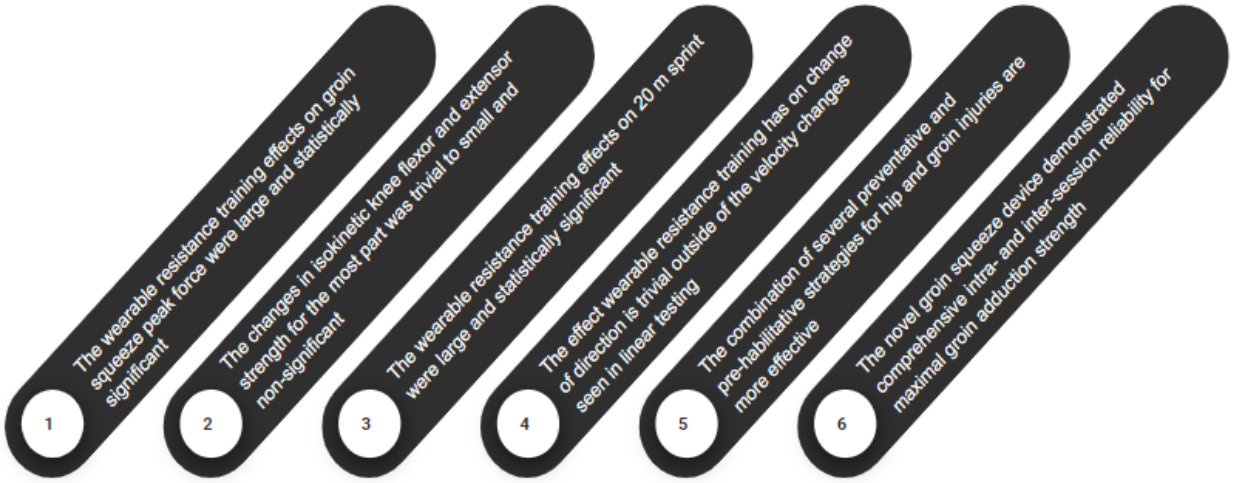

Figure 5.1: Key findings from thesis.

Practical Applications

Based on the findings from this thesis, the following practical applications have been put forward to assist any soccer coach, sport scientist, physiotherapist, researcher and/or relevant practitioners. These applications will help when looking to implement both, wearable resistance into a training session, as well as the usage of a novel strain gauge groin squeeze device for testing:

1. Prescribing a multidirectional approach to hip and groin injury prevention by incorporating various training strategies, including strengthening, screening, mobility, and load management.
2. The use of the novel strain gauge device as a baseline adductor maximal strength test, a performance test and as a pre-training or game screening device. This could be used as a way of monitoring the strength and soreness of groin adductors to reduce the risk of overuse injuries and adductor strains, two of the most common hip and groin injuries in soccer.

3. The use of a small-sided game approach to soccer training as an effective in-season tool to maintain and even increase strength and speed measures.
4. The use of a periodized in-season lower-body wearable resistance training protocol to enhance or maintain in-season physical performance measures. This would aim to avoid the commonly seen decay that leads to a greater risk of injuries.

Limitations

There were several limitations of this thesis due to: 1) the nature of working with a professional soccer club/academy; and 2) the effects of COVID during data collection. These limitations have been outlined below:

1. Due to the heavily congested training schedule of the participants for both the reliability study and the training study, the optimal time to complete data collection days was altered. This massively altered the initial suggested methodology and ultimately the results.
2. Multiple participants in the training study had to be removed due to the inability to continue with the data collection. This was due to failure to train through a variety of ways such as injury, illness, COVID and/or promotion to a higher team or removal from the academy. This led to significantly smaller control and experimental groups.
3. With the addition of weights to the experimental group it was obvious which individuals were in the control group versus the experimental group. This could have led to some of the variety in the testing results due to each individuals perceived change in performance over the course of the intervention.
4. As the weights began to get heavier throughout the training study it was frequent for some of the experimental group participants to have their compression socks slip down to their ankles. At times they would also have the weights either fly off or break during the small-sided games. As they are in a professional academy, the players were more

focused on the training session than the study, and therefore would often have the weights in the incorrect position for large periods of the intervention. This could be a key factor in some of the experimental group participants not having statistically significant changes in the pre- to post-testing.

5. Following the end of the intervention for the training study there was supposed to be a two-week detraining period followed by another set of post-testing. This would have shown whether the experimental group had any prolonged positive adaptational effects post the intervention versus the control group. However, due to COVID this second post-testing was not able to take place and therefore a large picture of the data was missing.
6. Players would constantly train up and/or down with the group the intervention was based around. This meant that the SSG would become more condensed due to there often being more players in the 20 x 20 m area than expected. This could have impacted the external loading and estimated physiological match demands that SSG are frequently based around.
7. Altering the location and weight of the load constantly throughout the intervention period could have clouded what was the most effective for positive adaptations.

Future Recommendations

The limitations presented as well as findings from the thesis can help inform future research in this area on how to: 1) approach hip and groin preventative and pre-habilitative strategies; 2) implement the usage a strain gauge groin squeeze device; and 3) implement wearable resistance into a training session. These future recommendations have been outlined below:

1. Investigate a more multidirectional approach to preventative and pre-habilitative strategies to aid in solving the issue of hip and groin injuries. This approach could determine the effectiveness of these strategies in conjunction.

2. The use of larger pitch sizes relative to the number of players for the small-sided games as this could have led to greater mechanical and therefore muscular overload, specifically on the hamstrings, which could have impacted the results of the isokinetic testing.
3. Use of a consistent loading pattern for the experimental group instead of switching from proximal to distal loading. Also, the use of a consistent weight instead of slowly increasing the weight. This would help fine tune the optimal loading and weight pattern to either maintain or increase physical performance measures in-season.
4. Testing the rate of force development for the novel groin squeeze device instead of just the peak maximal force.
5. Incorporating a mid-intervention testing window to see how early the positive adaptations occur due to the wearable resistance.
6. Incorporating a two-week detraining period followed by another set of post-testing. This would have shown whether the experimental group had any prolonged positive adaptational effects post the intervention.
7. Sticking to a constant weight and location of the load may have given a clearer indication for the greater changes in strength on the WRT, instead of following the loading patterns seen in previous research [13]. Following a more ridged loading pattern may have further elicited positive adaptations. Based off rotational inertia, keeping the weight distal from the axis of rotation of the knee would have increased the substantial effect and therefore muscular work required. Keeping the weight at 400g and distal, as opposed to building up the load and changing from proximal to distance, could have achieved not only a clearer answer but also may have shown greater changes in strength and speed.

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Appendices

Appendix I. Parent/Guardian Information Sheet

The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes

Information Sheet

Project title: The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes.

Project Supervisor:	Dr Craig Harrison
Researcher:	Kieran McMinn
Date:	24 November 2020

An Invitation

Hello, my name is Kieran McMinn, and I am currently a student at Auckland University of Technology completing my Master of Philosophy. I would like to invite your son to participate in my upcoming research study. This study will be completed at their club, Wellington Phoenix, and will be mostly based around their current training schedule. Participation in the research is voluntary and your son is able to withdraw from participation at any time. Regardless of if your son participates or not it will have no impact on their standing at the club or their relationship with their coaches or staff. This research is looking at wearable resistance and the impact it has on physical performance measures within elite level soccer athletes. I would like your son's involvement through participation, will you help?

What is the purpose of this research?

Due to congested training schedules, training efficiency in elite level soccer athletes is critical. This research aims to find strategic ways of introducing wearable resistance into current football training sessions. The purpose of the research is to investigate the effect of lower-body wearable resistance has on physical performance measures in elite level male athletes. The information gained from this research will be presented in a way so that your son's name and contact details will remain confidential. The information from this research will be confidential when presented in any publications.

How was your son identified and being invited to participate in this research?

Your son was identified as a potential participant for this research as he fits into the following categories:

- He is a player on the Wellington Phoenix Under 23's team.
- He is between 16 and 23 years of age.
- He is injury and illness free and is fully participating in training and competition.

How does he agree to participate in this research?
Your son will receive this document with an attached Assent and Consent Form. If your son would like to participate in this study, he will need to complete and sign the consent form. If he is under 16 years of age you will need to complete and sign the consent form instead, he will also need to complete and sign the assent form. Once this has been signed, and returned to the primary researcher, Kieran McMinn, your son will be able to participate in the research study.

His participation in this research is voluntary (it is his choice) and whether he chooses to participate will neither advantage nor disadvantage him. Your son can withdraw from the study at any time. If they choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to him removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible. Failure to participant in either the pre- or post-testing or failure to participate in 80% of the intervention sessions may result in your son's data and information being withdrawn from the study.

Where will this research take place?
Pre-Testing Session 1 (*time TBC*): Wellington Phoenix training facilities: Ricoh Sports Centre

Pre-Testing Session 2 (*time TBC*): New Zealand Defence Force: Messines Avenue, Trentham

Post-Testing Session 1 (*time TBC*): Wellington Phoenix training facilities: Ricoh Sports Centre

Post-Testing Session 2 (*time TBC*): New Zealand Defence Force: Messines Avenue, Trentham

When and for how long will this research take place?
This research will take place during preseason for the Wellington Phoenix Under 23's team. The intervention will occur over 8-weeks, with 2 training sessions per week. The intervention will occur during their normal training hours. Each training session will begin with two 15-minute small-sided games with their normal coaches and 15-minutes of dynamic movements. Pre-testing will run the week before the intervention, with the post-testing occurring the week after the intervention. The pre- and post-testing will take place in week 1 and 10 of the intervention and be split over two separate days for both pre- and post-testing. The breakdown for the pre- and post-testing sessions are below:

Pre/Post Testing 1, at Wellington Phoenix training facilities: Ricoh Sports Centre

Anthropometrics: ~5-10 minutes

30m Sprint: ~10-15 minutes

Flying 5-0-5 Agility: ~5-10 minutes

Isometric Mid-Thigh Pull: ~10-15 minutes

Adductor Groin Squeeze: ~5-10 minutes

Total: ~1 hour

Pre/Post Testing 2 at New Zealand Defence Force: Messines Avenue, Trentham

Isokinetic Dynamometer:

Set: Up: ~15-20 minutes

Testing: ~20-40 minutes

Total: ~1 hour

Who will be involved in this research?

Players from the Wellington Phoenix Under 23's team will be involved in this research. The participants will be split into either the intervention or the control group. Involvement in the study is completely voluntary and will have no effect on their standing within the team or with their coaches or peers. This will be the same if they chose not to participate, or if they withdraw from the study. Failure to participant in either the pre- or post-testing or failure to participate in 80% of the intervention sessions may result in your son's data and information being withdrawn from the study.

What will happen in this research?
The study will be an 8-week long training intervention that follows a two-group pre-test-post-test design. The testing will take place the week prior to and following the intervention. Pre- and post-testing will include a battery of specific performance tests investigating power, speed, strength and change of direction measures. The groups will be randomly assigned but based off position (attackers and defenders) to ensure that a variety of positions are both in the intervention and the control group.

The 8-week intervention will include 2 training sessions per week. The training session interventions will consist of a small-sided intense game mixed with intervals of explosive movements for 45 minutes at the beginning of the session. If your son is assigned to the intervention group, he will be loaded with wearable resistance on his calves weighing between 200g-600g per leg. This load will change as will the location of the weight throughout the intervention. If your son is assigned to the control group, he will still complete the training session intervention, but will not have his calves loaded. During each session both the intervention and control groups will be wearing a GPS monitor and a heart rate unit to track the intensity of the whole session. Following the session, both groups will also be asked what their perceived rate of exertion was using an RPE scale. Each intervention session will consist of small-sided games that are intermixed with explosive movements like sprints, bounds and jumps.

At the beginning of each session your son will be given and instructed to wear heartrate monitors and GPS units, those in the intervention group will also be given weights to wear based each respective session. Your son will then be randomly split into three equal groups. The groups will each spend 15 minutes going through the explosive movements and 2x15 minutes playing small-sided games. The small-sided game is a match between the two groups that aren't doing the explosive movements for that 15-minute period. This will be on a 15-10m pitch (subject to change based on numbers). The groups will keep rotating every 15 minutes until everyone has completed the explosive movement section and played 2 rounds of small-sided games. Afterwards the participants in the intervention group will take off the weights for the remainder of that training session. The Wellington Phoenix FC coaches will then take over and run a usual session that is estimated to be two hours long in total. Following the training players will turn off and hand back in their heart rate monitors and GPS units and asked what the RPE (rate of perceived exertion) was for that whole training session on a scale of 1-10 (10 being high). This training procedure will be repeated twice a week over the eight-week intervention study. If you, or your son, does not consent to participating in this research he will not be wearing a GPS monitor or a heart rate unit and will not be asked to complete an RPE scale. He will still train for the first 45 minutes of each session but will not complete the explosive movement intervention. However, he will still train and remain in the small-sided games led by the coach, like how a normal training session would run.

Breakdown of Groups:

The intervention group (those with weights) will wear the weights for the first 45 minutes of practice for the small-sided games as well as the explosive movement intervention section. They will wear a GPS monitor and a heart rate unit throughout the whole training session and then complete an RPE form at the end of training.

The control group (those participating in the study but without weights) will participate in both the small-sided games and the explosive movement intervention section alike the intervention group but won't have any weights on. They too will wear a GPS monitor and a heart rate unit throughout the whole training session and then complete an RPE form at the end of training.

The non-consent group (those not participating in the study) will participate in the small-sided games led by the coach for the full 45 minutes and will not come over for the explosive movement intervention. They will not complete an RPE form at the end of training.

Figure AI.1: Lila EXOGEN Compression Garment Calf Sleeves.

Figure AI.2: VXSport Example (GPS).

Types of Performance Assessments

These performance tests will be completed pre and post the 8-week intervention. These tests will not be overly exerting and have a lower risk of any injury. Prior to any maximal testing familiarization tests will be completed to ensure the assessments are completed at as high a standard as possible.

1. Anthropometrics

We will measure their standing height using a stadiometer, bodyweight using a scale and tibial lever length using a tape measure.

2. 30m sprint

This test measures their acceleration and maximum speed. They will run in a straight 30m distance as fast as possible. This starts from a stationary, standing position with a radar gun set

up 10m behind them that will measure their speed and acceleration. They will perform at least 3 trials during both pre- and post-testing.

3. Flying 505 agility-test

The flying 505 agility test measures their ability to change direction whilst running at high speed. A radar gun is set up 10m behind the starting point and will measure their speed and acceleration. Two markers are set at 0m (starting/finishing marker) and 10m (turning marker). They will first run to the 10m turning marker, 10 meters away, turn around and run through the starting/finishing marker. They will perform at least 3 trials during both pre- and post-testing.

4. Isokinetic Dynamometer

Four protocols will be recorded on the isokinetic dynamometer: concentric, eccentric, flexion, and extension of the knee. This will measure hamstring and quadricep isokinetic strength and strength ratio. They will be placed in an isokinetic dynamometer in a seated position and firmly stabilized by straps to ensure that only the knee to be tested is movable. The machines speed will be set at 60-degrees per second. They will go through the four protocols that require them to either push against or resist against the machine for a total of 5 times per protocol.

5. Isometric Mid-Thigh Pull

This test will assess their maximum lower body strength and power. They will step onto the base plate and have their thighs touch the barbell. They will then wrap their hands around the barbell and position themselves correctly so that their shoulders are back, arms are fully extended, and chest is faced upwards and looking straight ahead. They will then pull the bar upwards as hard as they can for 5 seconds. They will perform at least 3 trials during both pre- and post-testing.

6. Adductor Groin Squeeze

This test will assess their adductor strength. They will lie on their back with their head down and arms flat by their side. A goniometer will then be used to have their hips at a 45-degree angle. They will then have a strain gauge placed between their knees and will be asked to squeeze the device as hard as they can for 5 seconds. They will perform at least 3 trials during both pre- and post- testing.

Questionnaires

If they chose to consent, they will be asked to complete a quick perceived rate of exertion questionnaire following each intervention training session. Details of the questionnaire are below:

Session RPE

Following each intervention session, they will be asked to give a rating of your perceived rate of exertion (how hard the session was) from a score of 1-10 (1 being low, 10 being high). This RPE will be completed orally and should take less than one minute. This answer will remain confidential except to the primary researcher, Kieran McMinn.

Who will see your son perform?

Only your son and the primary researcher will see how they perform during the pre-and post-testing. Group data will be provided to their coach if you consent, therefore he nor anyone other than the primary researchers will know how your son performs. If you would like to allow your son's coach to see his individual results, these will be provided to you upon request.

What are the discomforts and risks for your son?

It is not anticipated that your son will experience discomfort that would be greater than that occurring during their normal football training sessions. The tests have been chosen as they are test's your son has likely performed before as an elite level soccer athlete. They have also been specifically designed and tested for your son's safety. There is also a small risk of discomfort in the compression garments, which may be alleviated by correct sizing. It is highly unlikely that your son will require counselling because of participation in this research.

How will these discomforts and risks be alleviated?

Risk will be reduced as much as possible by implementing a suitable warm-up and cool-down before and after each testing session, abstaining from high intensity training in the 24 hours prior to each testing occasion, and arriving to each testing session well hydrated and having eaten at least 90 minutes prior to the start. Your son will also be sufficiently familiarized with all physical movements and tests. In addition, the intervention will occur during and as a part of your son's normal football training. No additional time or physical requirements will be asked of you or your son if you chose to take part in this study.

What are the benefits?

The benefits of your son being a part of this study include:

- Being made aware of their performance measures during pre-season training
- Being made aware of your son's ability to accelerate, sprint, jump, run, and his strength and power.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury because of your son's participation in this study, rehabilitation, and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will your son's privacy be protected?
All the data from this study will be de-identified. That means that you and your son's name and contact information will not be available outside of the research database. The data from this research will be stored in a secure location at AUT SPRINZ, including consent forms.

- Only the primary researcher will have access to any identifiable data.
- Only the primary researcher will know who have chosen to participate in the research. The head coach will not know who has NOT chosen to participate.
- De-identified group performance data will be made available to the head coach, if you and your son explicitly consent to this.
- Individual performance data will be made available if you request this. This data will NOT be made available to the head coach or other staff.
- De-identified, group performance data will be made available in the form of a publications.

What are the costs of participating in this research?
There are no costs associated with this research; all equipment will be supplied. In addition, since this research will be taking place during your normal football training hours, there will be no additional time needed. However, some data collection may take place at an alternative location during the pre- and post-testing. This time has been broken down above but will equate to roughly 4- one-hour testing sessions.

What opportunity do I have to consider this invitation?
Please take the necessary time you need, up to four weeks, to consider the invitation to participate in this research.

It is reiterated that your son's participation in this research is completely voluntary. If you require further information about the research topic, please feel free to contact Kieran McMinn (details are at the bottom of this information sheet).

Will my son receive feedback on the results of this research?
Your son will receive feedback and a summary of their individual and group results at the end of the data collection if requested. This would be his own individual results of whichever intervention group he was in (intervention or control). He would also receive a de-identifiable group results summary. If they would like any additional information, please contact the primary researcher, Kieran McMinn (see contact details below)

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Craig Harrison (See Supervisor contact details below).

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC:

Email:	ethics@aut.ac.nz
Mobile:	+64 (9) 921 9999 ext. 6038

Whom do I contact for further information about this research?

Please keep this information sheet and a copy of the Consent and Assent forms for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Primary Researcher: Kieran McMinn, BSc

Email: Kezza9Mc@gmail.com

Mobile: +64 (0)21 074 4794

Project Supervisor Contact Details:

Project Supervisor: Dr Craig Harrison

Email: craig@athletedevelopmentproject.com

Mobile: +64 (0)27 226 5181

Appendix I. Participant Information Sheet

The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes

Information Sheet

Project title: The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes.

Project Supervisor: Dr Craig Harrison

Researcher: Kieran McMinn

Date: 24 November 2020

An Invitation

Hello, my name is Kieran McMinn, and I am currently a student at Auckland University of Technology completing my Master of Philosophy. I would like to invite you to participate in my upcoming research study. This study will be completed at your club, Wellington Phoenix, and will be mostly based around your current training schedule. Participation in the research is voluntary and you can withdraw from participation at any time. Regardless of if you participate or not it will have no impact on your standing at the club or your relationship with your coaches or staff. This research is looking at wearable resistance and the impact it has on physical performance measures within elite level soccer athletes. I would like your involvement through participation, will you help?

What is the purpose of this research?

Due to congested training schedules, training efficiency in elite level soccer athletes is critical. This research aims to find strategic ways of introducing wearable resistance into current football training sessions. The purpose of the research is to investigate the effect of lower-body wearable resistance has on physical performance measures in elite level male athletes. The information gained from this research will be presented in a way so that your name and contact details will remain confidential. The information from this research will be confidential when presented in any publications.

How were you identified to be invited to participate in this research?
You were identified as a potential participant for this research as you fit into the following categories:

- You are a player on the Wellington Phoenix Under 23's team.

- You are between 16 and 23 years of age.
- You are injury and illness free and are fully participating in training and competition.

How do I agree to participate in this research?

You will receive this document with an attached Assent and Consent Form. If you would like to participate in this study, you will need to complete and sign the consent form. If you are under 16 years of age you will need to complete and sign the assent form instead, as well as your parents/legal guardians signing a consent from. Once this has been signed, and returned to the primary researcher, Kieran McMinn, you will be able to participate in the research study.

Your participation in this research is voluntary (it is your choice) and whether you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible. Failure to participant in either the pre- or post-testing or failure to participate in 80% of the intervention sessions may result in your data and information being withdrawn from the study.

Where will this research take place?

Pre-Testing Session 1 (*time TBC*): Wellington Phoenix training facilities: Ricoh Sports Centre

Pre-Testing Session 2 (*time TBC*): New Zealand Defence Force: Messines Avenue, Trentham

Post-Testing Session 1 (*time TBC*): Wellington Phoenix training facilities: Ricoh Sports Centre

Post-Testing Session 2 (*time TBC*): New Zealand Defence Force: Messines Avenue Trentham

When and for how long will this research take place?

This research will take place during preseason for the Wellington Phoenix Under 23's team. The intervention will occur over 8-weeks, with 2 training sessions per week. The intervention will occur during your normal training hours. Each training session will begin with two 15-minute small-sided games with your normal coaches and 15-minutes of dynamic movements. Pre-testing will run the week before the intervention, with the post-testing occurring the week after the intervention. The pre- and post-testing will take place in week 1 and 10 of the intervention and be split over two separate days for both pre- and post-testing. The breakdown for the pre- and post-testing sessions are below:

Pre/Post Testing 1, at Wellington Phoenix training facilities: Ricoh Sports Centre

Anthropometrics: ~5-10 minutes

30m Sprint: ~10-15 minutes

Flying 5-0-5 Agility: ~5-10 minutes
Isometric Mid-Thigh Pull: ~10-15 minutes
Adductor Groin Squeeze: ~5-10 minutes
Total: ~1 hour

Pre/Post Testing 2 at New Zealand Defence Force: Messines Avenue, Trentham
Isokinetic Dynamometer:
Set: Up: ~15-20 minutes
Testing: ~20-40 minutes
Total: ~1 hour

Who will be involved in this research?

Players from the Wellington Phoenix Under 23's team will be involved in this research. The participants will be split into either the intervention or the control group. Involvement in the study is completely voluntary and will have no effect on your standing within the team or with your coaches or peers. This will be the same if you chose not to participate, or if you withdraw from the study. Failure to participant in either the pre- or post-testing or failure to participate in 80% of the intervention sessions may result in your data and information being withdrawn from the study.

What will happen in this research?
The study will be an 8-week long training intervention that follows a two-group pre-test-post-test design. The testing will take place the week prior to and following the intervention. Pre- and post-testing will include a battery of specific performance tests investigating power, speed, strength and change of direction measures. The groups will be randomly assigned but based off position (attackers and defenders) to ensure that a variety of positions are both in the intervention and the control group.

The 8-week intervention will include 2 training sessions per week. The training session interventions will consist of a small-sided intense game mixed with intervals of explosive movements for 45 minutes at the beginning of the session. The intervention group will be loaded with wearable resistance on their calves weighing between 200g-600g per leg. This load will change as will the location of the weight throughout the intervention. While the control group will still complete the training session intervention, they will not have their calves loaded. During each session both the intervention and control groups will be wearing a GPS monitor and a heart rate unit to track the intensity of the whole session. Following the session, both groups will also be asked what their perceived rate of exertion was using an RPE scale. Each intervention session will consist of small-sided games that are intermixed with explosive movements like sprints, bounds and jumps.

At the beginning of each session, you will be given and instructed to wear heartrate monitors and GPS units, those in the intervention group will also be given weights to wear based each respective session. You will then be randomly split into three equal groups. The groups will each spend 15 minutes going through the explosive movements and 2x15 minutes playing small-sided games. The small-sided game is a match between the two groups that aren't doing the explosive movements for that 15-minute period. This will be on a 15-10m pitch (subject to change based on numbers). The groups will keep rotating every 15 minutes until everyone has completed the explosive movement section and played 2 rounds of small-sided games.

Afterwards the participants in the intervention group will take off the weights for the remainder of that training session. The Wellington Phoenix FC coaches will then take over and run a usual session that is estimated to be two hours long in total. Following the training players will turn off and hand back in your heart rate monitors and GPS units and asked what the RPE (rate of perceived exertion) was for that whole training session on a scale of 1-10 (10 being high). This training procedure will be repeated twice a week over the eight-week intervention study. If you do not consent to participating in this research, you will not be wearing a GPS monitor or a heart rate unit and you will not be asked to complete an RPE scale. You will still train for the first 45 minutes of each session but will not complete the explosive movement intervention. However, you will still train and remain in the small-sided games led by the coach, like how a normal training session would run.

Breakdown of Groups: The intervention group (those with weights) will wear the weights for the first 45 minutes of practice for the small-sided games as well as the explosive movement intervention section. They will wear a GPS monitor and a heart rate unit throughout the whole training session and then complete an RPE form at the end of training.

The control group (those participating in the study but without weights) will participate in both the small-sided games and the explosive movement intervention section alike the intervention group but won't have any weights on. They too will wear a GPS monitor and a heart rate unit throughout the whole training session and then complete an RPE form at the end of training.

The non-consent group (those not participating in the study) will participate in the small-sided games led by the coach for the full 45 minutes and will not come over for the explosive movement intervention. They will not complete an RPE form at the end of training.

Figure AI.3: Lila EXOGEN Compression Garment Calf Sleeves.

Figure AI.4: VXSport Example (GPS).

Types of Performance Assessments

These performance tests will be completed pre and post the 8-week intervention. These tests will not be overly exerting and have a lower risk of any injury. Prior to any maximal testing familiarization tests will be completed to ensure the assessments are completed at as high a standard as possible.

1. Anthropometrics

We will measure your standing height using a stadiometer, bodyweight using a scale and tibial lever length using a tape measure.

2. 30m sprint

This test measures your acceleration and maximum speed. You will run in a straight 30m distance as fast as possible. This starts from a stationary, standing position with a radar gun set up 10m behind you that will measure your speed and acceleration. You will perform at least 3 trials during both pre- and post-testing.

3. Flying 505 agility-test

The flying 505 agility test measures your ability to change direction whilst running at high speed. A radar gun is set up 10m behind the starting point and will measure your speed and acceleration. Two markers are set at 0m (starting/finishing marker) and 10m (turning marker). You will first run to the 10m turning marker, 10 meters away, turn around and run through the starting/finishing marker. You will perform at least 3 trials during both pre- and post-testing.

4. Isokinetic Dynamometer

Four protocols will be recorded on the isokinetic dynamometer: concentric, eccentric, flexion, and extension of the knee. This will measure hamstring and quadricep isokinetic strength and strength ratio. You will be placed in an isokinetic dynamometer in a seated position and firmly stabilized by straps to ensure that only the knee to be tested is movable. The machines speed

will be set at 60-degrees per second. You will go through the four protocols that require you to either push against or resist against the machine for a total of 5 times per protocol.

5. Isometric Mid-Thigh Pull

This test will assess your maximum lower body strength and power. You will step onto the base plate and have your thighs touch the barbell. You will then wrap his hands around the barbell and position themselves correctly so that your shoulders are back, arms are fully extended, and chest is faced upwards and looking straight ahead. You will then pull the bar upwards as hard as you can for 5 seconds. You will perform at least 3 trials during both pre- and post-testing.

6. Adductor Groin Squeeze

This test will assess your adductor strength. You will lie on your back with you head down and arms flat by your side. A goniometer will then be used to have your hips at a 45-degree angle. You will then have a strain gauge placed between your knees and will be asked to squeeze the device as hard as you can for 5 seconds. You will perform at least 3 trials during both pre- and post- testing.

Questionnaires

If they chose to consent, they will be asked to complete a quick perceived rate of exertion questionnaire following each intervention training session. Details of the questionnaire are below:

Session RPE

Following each intervention session, you will be asked to give a rating of your perceived rate of exertion (how hard the session was) from a score of 1-10 (1 being low, 10 being high). This RPE will be completed orally and should take less than one minute. This answer will remain confidential except to the primary researcher, Kieran McMinn.

Who will see you perform?

Only you and the primary researcher will see how you perform during the pre-and post-testing. Group data will be provided to your coach if you consent, therefore he nor anyone other than the primary researchers will know how you perform. If you would like to allow your coach to see your individual results, these will be provided to you upon request.

What are the discomforts and risks for you?

It is not anticipated that you will experience discomfort that would be greater than that occurring during your normal football training sessions. The tests have been chosen as they are tests you have likely performed before as an elite level soccer athlete. They have also been specifically designed and tested for your safety. There is a small risk of discomfort in the compression garments, which may be alleviated by correct sizing. It is highly unlikely that you will require counselling because of participation in this research.

How will these discomforts and risks be alleviated?

Risk will be reduced as much as possible by implementing a suitable warm-up and cool-down before and after each testing session, abstaining from high intensity training in the 24 hours prior to each testing occasion, and arriving to each testing session well hydrated and having eaten at least 90 minutes prior to the start. You will also be sufficiently familiarized with all physical movements and tests. In addition, the intervention will occur during and as a part of your normal football training. No additional time or physical requirements will be asked of you if you chose to take part in this study.

What are the benefits?

The benefits of you being a part of this study include:

- Being made aware of your performance measures during pre-season training.
- Being made aware of your ability to accelerate, sprint, jump, run, and your strength and power.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury because of your participation in this study, rehabilitation, and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will your privacy be protected?

All the data from this study will be de-identified. That means that your name and contact information will not be available outside of the research database. The data from this research will be stored in a secure location at AUT SPRINZ, including consent forms.

- Only the primary researcher will have access to any identifiable data
- Only the primary researcher will know who have chosen to participate in the research. The head coach will not know who has NOT chosen to participate.
- De-identified group performance data will be made available to your head coach, if you explicitly consent to this.
- Individual performance data will be made available to you if you request this. This data will NOT be made available to the head coach or other staff.
- De-identified, group performance data will be made available in the form of a publications.

What are the costs of participating in this research?

There are no costs associated with this research; all equipment will be supplied. In addition, since this research will be taking place during your normal football training hours, there will be no additional time needed. However, some data collection may take place at an alternative location during the pre- and post-testing. This time has been broken down above but will equate to roughly 4- one-hour testing sessions.

What opportunity do I have to consider this invitation?

Please take the necessary time you need, up to four weeks, to consider the invitation to participate in this research.

It is reiterated that your participation in this research is completely voluntary. If you require further information about the research topic, please feel free to contact Kieran McMinn (details are at the bottom of this information sheet).

Will I receive feedback on the results of this research?

You will receive feedback and a summary of your individual and group results at the end of the data collection if requested. This would be your own individual results of whichever intervention group you are in (intervention or control). You would also receive a de-identifiable group results summary. If you would like any additional information, please contact the primary researcher, Kieran McMinn (see contact details below)

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Craig Harrison (See Supervisor contact details below).

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC:

Email:	ethics@aut.ac.nz
Mobile:	+64 (9) 921 9999 ext. 6038

Whom do I contact for further information about this research?

Please keep this information sheet and a copy of the Consent and Assent forms for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Primary Researcher:	Kieran McMinn, BSc
Email:	Kezza9Mc@gmail.com
Mobile:	+64 (0)21 074 4794

Project Supervisor Contact Details:

Project Supervisor:	Dr Craig Harrison
Email:	craig@athletedevelopmentproject.com
Mobile:	+64 (0)27 226 5181

Appendix II. Parent/Guardian Consent Form

Parent/Legal Guardian Consent Form

Project title: The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes.

Project Supervisor: Dr Craig Harrison

Researcher: Kieran McMinn

Date: 24 November 2020

- I have read and understood the information provided about this research project in the Information Sheet dated 24 November 2020.
- I have had an opportunity to ask questions and to have them answered.
- I understand that if I chose to consent, my son's head coach may know he is participating and if he is allocated to the intervention group.
- I understand my son's data will be stored securely for a period of 6 years.
- I understand that if my son fails to participate in 80% of the training program it may result in his withdrawal from the study.
- I understand that my son is taking part in this study voluntary and that he may withdraw himself from the study at any time without being disadvantaged in any way.
- I understand that if he withdraws from the study then he will be offered the choice between having any data that is identifiable as belonging to himself removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.
- If my son withdraws, I understand that all relevant information will be destroyed.
- I agree to my son taking part in this research (please tick one): Yes◯ No◯
- I wish for my son to receive a summary of the research findings (please tick one): Yes◯ No◯
- I agree to sharing a summary of the research findings with coaching staff (please tick one): Yes◯ No◯

Parent/Legal Guardian Signature: .....

Parent/Legal Guardian Name: .....

Parent/Legal Guardian Contact Details (if appropriate): .....

Date: .....

Appendix II. Participant Assent Form

Assent Form

Project title: The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes.

Project Supervisor: Dr Craig Harrison

Researcher: Kieran McMinn

Date: 24 November 2020

- I have read and understood the information provided about this research project in the Information Sheet dated 24 November 2020.
- I have had an opportunity to ask questions and to have them answered.
- I understand that if I chose to assent, my head coach may know I am participating and if I am allocated to the intervention group.
- I understand my data will be stored securely for a period of 6 years.
- I understand that failing to participate in 80% of the training program may results in my withdrawal from the study.
- I understand that taking part in this study is voluntary and that I may withdraw myself from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw myself from the study then I will be offered the choice between having any data that is identifiable as belonging to myself removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.
- If I withdraw myself, I understand that all relevant information will be destroyed.
- I agree to take part in this research (please tick one): Yes◯ No◯
- I wish to receive a summary of the research findings (please tick one): Yes◯ No◯
- I agree to sharing a summary of the research findings with coaching staff (please tick one): Yes◯ No◯

Participant Signature: .....

Participant Name: .....

Participant Contact Details (if appropriate): .....

Date: .....

Appendix II. Participant Consent Form

Consent Form

Project title: The effect of lower-body wearable resistance training on measures of physical performance in elite male soccer athletes.

Project Supervisor: Dr Craig Harrison

Researcher: Kieran McMinn

Date: 24 November 2020

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- I have had an opportunity to ask questions and to have them answered.
- I understand that if I chose to consent, my head coach may know I am participating and if I am allocated to the intervention group.
- I understand my data will be stored securely for a period of 6 years.
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- I understand that taking part in this study is voluntary and that I may withdraw myself from the study at any time without being disadvantaged in any way.
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- If I withdraw myself, I understand that all relevant information will be destroyed.
- I agree to take part in this research (please tick one): Yes◯ No◯
- I wish to receive a summary of the research findings (please tick one): Yes No◯
- I agree to sharing a summary of the research findings with coaching staff (please tick one): Yes◯ No◯

Participant Signature: .....

Participant Name: .....

Participant Contact Details (if appropriate): .....

Date: .....