

An 8 week neuromuscular training programme reduces the
risk of ACL injury and increases athletic performance
variables in female court sport athletes

By Ryan Morrow

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Abstract

Court sport athletes repetitively perform movements which require physical attributes such as agility, acceleration, muscular power, muscular strength and balance. Unfortunately, some of the movements performed by court sport athletes such as changing direction quickly, decelerating and landing from a jump put athletes at an increased risk of injury their anterior cruciate ligament. Females in particular are at an increased risk of injuring this ligament in comparison to their male counterparts. The purpose of this study was to investigate if a neuromuscular training protocol increased athletic performance variables and reduced the risk of ACL injuries in female court sport athletes. Twenty female court sport athletes took part in this study (stature: 169 ± 7 cm, mass: 61.3 ± 8.3 kg, age: 22.3 ± 2.0 years, competitive playing experience: 5.4 ± 1.6 years). Participants were split evenly through random allocation, comprising of ten in the control group and ten in the intervention group.

Both the control and intervention groups pre-tests involved a 20 m sprint, counter-movement jump (CMJ), Illinois agility test and the Qualitative Analysis of a Single Leg Squat (QASLS), which is an assessment used to profile a participant's risk of an ACL injury. After the pre-tests the intervention group engaged in a modified version of the Fifa 11+ neuromuscular training programme twice a week over an eight week period. During this eight week period both groups were instructed to continue with their habitual training regimes as delivered to them by their sport coaches. After eight weeks both the control and intervention group participants were recalled to repeat the pre-test protocols.

A 2 (Control vs. Intervention) x 2 (Pre vs. Post – within subjects) mixed ANOVA demonstrated significant improvements for the intervention group's CMJ (9.7% improvement) and QASLS (117% improvement on left leg and 65% on the right) in comparison to the control group following the training intervention. No significant differences between the two groups were found for the Illinois agility test and 20 m sprint. However, there was a within-group improvement in 20 m sprint for the intervention group post training (2.2% decrease). The results demonstrate a modified Fifa 11+ protocol can be considered an effective neuromuscular training programme for reducing the risk of ACL injuries and improving athletic performance variables in female court sport athletes.

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1.0 INTRODUCTION

Athletes who take part in court sports such as badminton, squash, futsal, netball, basketball and volleyball are required to display a range of similar physical qualities whilst competing in their respective sport (Kant et al., 2012; Phomsoupha et al., 2015). Agility, acceleration, muscular power, muscular strength, balance and aerobic endurance are desirable attributes for the athletes who take part in any one of the previously mentioned court sports (Chandler et al., 2014; Cosmin et al., 2016; Fort-Vanmeerhaeghe et al., 2016; Junior et al., 2017). Players, coaches, sports scientists, and strength and conditioning practitioners recognise these physical qualities are to some extent modifiable and can be improved through certain training methods (Bizzini et al., 2015; Steffen et al., 2008).

One training method in particular which has demonstrated promise for improving performance indicators is neuromuscular training (Owoeye et al., 2014; Pensini et al., 2002). Neuromuscular training programmes include plyometric, balance, perturbation and strength exercises. These forms of training induce specific neural adaptations within the descending corticospinal tracts, motor units, neuromuscular junctions as well as improving the reflex potential of the muscle spindles (Akbari et al., 2017; Benis et al., 2016; Gjinovci et al., 2017). The previously mentioned neural adaptations improve an individual's ability to recruit targeted muscle groups quickly and efficiently in order to execute dynamic movements whilst maintaining proper alignment of the joints (Haff and Triplett, 2015). Past research has suggested neural adaptations particularly benefit sprint performance, agility, speed, muscular power and muscular strength (Palazon et al., 2016). Court sport athletes are required to repetitively perform movements patterns such as jumping, landing and changing direction quickly whilst competing (Cosmin et al., 2016; James et al., 2014; Junior et al., 2017). All of these movement patterns require a simultaneous contribution of all of the previously mentioned physical attributes.

Another factor to consider as a player or a person responsible for the training and welfare of athletes, is injury prevention. Irrespective of gender the movement patterns performed by court sport athletes inherently present a risk of injury if performed with compromised technique and body mechanics (Hewett et al., 2010). For example, repetitive quick changes in direction can cause anterior translation of the tibia relative to femur which then places a significant amount of strain on the anterior cruciate ligament (ACL). This excessive strain exerted on the ACL can cause this ligament to rupture (Hirschmann et al., 2015). Females are at an additional risk of injuring their ACL, they are reported to be up to eight times more likely to injure their ACL in

comparison to males (Elliot et al., 2010; Mall et al., 2014). The speculated reasons why females are at an increased risk of injuring their ACL include hormonal and anatomical differences in comparison to males (Shults, 2015; Charlton et al., 2001). Although the secretion of certain hormones affect the rigidity of the ACL it may be unethical to recommend the methods which can inhibit the secretion of particular hormones (Van Lunen et al., 2003). Equally, the anatomical differences exhibited by females which increases their risk of an ACL injury cannot be modified (Silver, 2009). Females often demonstrate neuromuscular deficiencies in comparison to males (Hewett et al., 2010; Hewett et al., 1996; Huston and Wojtys, 1996). Electromyography (EMG) research has demonstrated females appear to have a lower ability to recruit the muscle groups needed to protect the integrity of the ACL (Hughes and Dally, 2015; Decker et al., 2002). Unlike the previously mentioned risk factors which are difficult to modify, it has been demonstrated through EMG measurements that if females engage in an effective neuromuscular training programme it can increase their ability to recruit muscles groups needed to protect the ACL (Zebis et al., 2008; Cosmin et al., 2016).

One neuromuscular training programme that has demonstrated significant promise for decreasing the risk of injury and improving performance variables is the FIFA 11+ (Owoeye et al., 2014; Soligard et al., 2008). This programme was initially developed in 2006 by both the Santa Monica Sports Medicine Foundation and the Oslo Trauma and Research Centre, with the intention to reduce the risk of common injuries in football players i.e. knee, ankle, groin and hamstring. Soligard et al. (2008) were the first to report the benefits the FIFA 11+ training programme had for reducing injury rates. Soligard et al. (2008) had participants perform the FIFA 11+ protocol over an eight-month period. Significant reductions in minor ($P = 0.041$) and severe injury ($P = 0.005$) were found in the intervention group when compared to the control group. Subsequently interest in the FIFA 11+ programme developed, which led to the publication of several papers concluding that the FIFA 11+ programme had beneficial effects in reducing injuries (Silvers-Granellie et al., 2015; Reis et al., 2013; Zebis et al., 2008). In addition, Bizzini et al. (2013) showed the FIFA 11+ protocol can acutely improve performance indicators in 20 male football players by having them perform the FIFA 11+ programme as a warm up. Significant improvements were found straight after performing the FIFA 11+ training programme in comparison to the baseline (P values ranging from <0.015 to <0.001) for certain performance variables such as Star excursion balance test, squat jump, counter-movement jump (CMJ), agility and 20 m sprint, while no changes occurred for rate of force development and maximal voluntary contraction of the quadriceps muscles.

The implementation of the Fifa 11+ protocol has demonstrated to reduce the risk of injuries and increase performance indicators in mostly football players (Owoeye et al., 2014; Soligard et al., 2008). Other than football there is noticeable lack of research on how the Fifa 11+ protocol benefits those in different sporting disciplines. Considering a female's increased risk of an ACL injury and the additional risk of injuring this ligament through participating in a court sport (López González et al., 2017; Bahr and Reeser, 2003), it seems more than appropriate to design a study assessing if a modified Fifa 11+ programme can reduce the risk of an ACL injury and improve a person's physical capabilities.

This study intends to investigate if an adapted version of the Fifa 11+ training programme decreases a female court sport athletes risk of an ACL injury as well as simultaneously improving athletic performance variables such as sprint performance, lower body power and agility. To the author's knowledge no previous research has assessed whether implementation of the Fifa 11+ programme reduces the risk of ACL injuries and improves performance indicators within court sport athletes.

2.0 LITERATURE REVIEW

The physical demands of court sports are well documented within the literature (Chandler et al., 2014; Fort-Vanmeerhaeghe et al., 2016; Kant et al., 2012). Participants are required to perform movements such as jumping, landing and changing direction as quickly as possible in order to gain an advantage over their opposition (Cosmin et al., 2016; Junior et al., 2017). These physical demands place a significant amount of stress upon the body which increases the risk of injury (Agel et al., 2005; Langeveld et al., 2012). A ligament located within the knee known as the anterior cruciate ligament (ACL) is often injured by female court sport athletes. Recently published research into the prevalence of ACL injuries has discovered females are up to eight times more likely to injure this ligament (Elliot et al., 2010; Mall et al., 2014) in comparison to males. The previously mentioned physical demands of court-based sports and certain gender specific predispositions such as neuromuscular deficiencies can significantly increase a female's risk of damaging their ACL during training and competition (Hewett et al., 2016; Zazulak et al., 2007).

The knee joint is the largest and most complex joint within the human body (Hirschmann et al., 2015) it consists of the medial tibiofemoral, the lateral tibiofemoral, the patellofemoral and the proximal tibiofibular joint. The knee allows for a large range of motion for flexion/extension and internal/external rotation and has also been optimally adapted to withstand loads and forces acting upon it (Hirschmann et al., 2015). Several ligaments within the knee (refer to figure 1) are responsible for stabilising the knee during the aforementioned motions, these ligaments are known as the medial collateral ligament (MCL), lateral collateral ligament (LCL), posterior cruciate ligament (PCL) and ACL (Silvers, 2009).

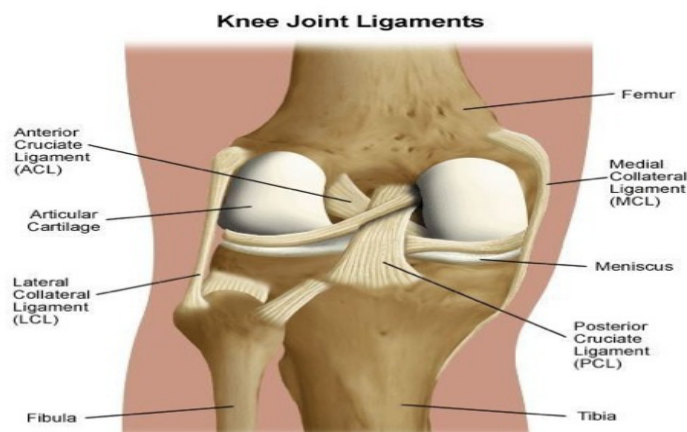


FIGURE 1. ANATOMY OF THE KNEE (STANFORD HEALTH CARE, 2019)

The anterior cruciate ligament (ACL) is one of the four ligaments within the knee, classified as the major stabilising intracapsular ligament in the knee joint (Tsukada et al., 2008). This ligament prevents anterior tibial subluxation as well as reducing internal rotation of the tibia (Silvers, 2009). Although there is speculation whether the ACL ligament is formed by one, two or 6-10 fibrous bundles (Hirschmann and Müller, 2015) it is commonly accepted that it is in fact two bundles that make the ACL (Siebold et al., 2008; Tsukada et al., 2008). Current research has supported the assertion that the ACL comprises of two separate fibrous bundles known as the anteromedial (AM) and posterolateral (PL), the names of these two bundles specify their insertion points to the tibia (Kopf et al., 2009). The AM bundle is longer than the PL however, the full ACL ranges between 22-44 mm (average 32 mm) in length (Amis and Dawkin, 1991).

Published studies have documented that the full ACL connects lateral and anterior to the medial intercondylar spine of the tibia and to the medial point of the lateral femoral condyle (Dienst et al., 2002; Kopf et al., 2009). The two separate bundles are situated differently to one another; Ellsion and Berg (1985) recorded that the AM emerges from the superior/posterior section of the femoral attachment and connects to the anteromedial aspect tibial attachment which is posterolateral to the PL. The PL which is the larger bundle of two, originates from the inferior/anterior point of femoral attachment aspect of the posterolateral point of the tibial attachment just behind the AM. The AM bundle begins to tighten when the knee is flexed at a 60° angle, unlike the PL bundle which is lax during flexion but tight when the leg is extended (Mall et al., 2013).

As previously mentioned the ACL is responsible for preventing excessive movement of the knee in different directions (Silvers, 2009), it is thought that both bundles contribute evenly to preventing anterior translation of the tibia relative to femur, however the PL bundle contributes the most in controlling rotational stability (valgus and varus) (Gabriel et al., 2004; Sakane et al., 1997). Due to the repetitive loads and forces the ACL is responsible for absorbing it is often damaged (Granán et al., 2008; Lal and Hoch, 2007), multidirectional kinematics are frequently observed in sports that require a participant to move dynamically which in turn increases the likelihood of an ACL injury (Hootman et al., 2007).

2.1 PREVALENCE OF ACL INJURIES

Anterior cruciate ligament injuries are highly prevalent worldwide in both males and females (Shultz, 2015; Silvers, 2009), in the United States alone it is estimated that it costs 7.6 billion US dollars per year to treat, rehabilitate and manage the injury (Mather et al., 2013). The prevalence of ACL injuries can be estimated through observing data such as the number of ACL reconstructions performed nationally (Renstrom et al., 2008) however, it is important to note this underestimates the true number of ACL injuries as many are unrecorded (Renstrom et al., 2008). Data collected from 57 Norwegian hospitals in 2004 recorded a total of 2793 ACL reconstruction operations over an 18 month period (Granán et al., 2008), this equated to an annual population incidence of ACL reconstructions of 34 per 100,000 citizens. This study also estimated that 85 Norwegian citizens per 100,000 were between the age of 16-39 (a higher risk age group) and would require an ACL reconstruction. Granán et al. (2008) stated 57% of the ACL reconstructions were performed on males, the remaining 43% of ACL reconstructions belonged to females. Mall et al. (2014) conducted a similar piece of research and analysed the ACL reconstructions (ACLR) recorded from 1994 to 2006 by the United States National Hospital Discharge Survey and the National survey of Ambulatory Survey. Mall et al. (2014) found a significant increase in ACLR's from 1994 to 2006 ($P = 0.015$), in 1994 the number of ACLR's completed was recorded at 86,687 (32.9 per 100,000 citizens), this increased to 129,836 in 2006 (43.5 per 100,000 citizens). This study also found the number of ACLR's increased significantly quicker in females when compared to males ($P = 0.0003$). It was hypothesised the significant increase in ACLR's was due to the increasing number of females taking part in sport; in 1972 female participation in high school sport was estimated at 3.7% and by 1998 had grown to 33% (Giugliano and Solomon, 2007), participation was then reassessed in 2006 and female's participating in high school sports was estimated to be at three million which represents more than a 1000% increase since 1972 (Lal and Hoch, 2007). Although a higher number of ACL sports injuries are recorded for males due to the higher number who participate compared to females (Gianotti et al., 2009), it is consistently reported that females are more likely to suffer an ACL injury during a non-contact sport (Mall et al., 2014). A study supporting this was conducted by Hootman et al. (2007) who analysed the collated data of injuries using the Wald statistics from a negative binomial model. Injury data was collected over a 16-year period from 15% of the National Collegiate Athletic Association institutes. Over 16 academic years 5000 ACL injuries were reported, averaging 313 per year

and the highest incident rate of ACL injuries was found in females (0.33 per 1000 athlete's exposure to a game or practice).

2.2 ACL INJURY RISK IN FEMALES

As previously mentioned, females are at a higher risk of suffering an ACL injury in comparison to males. In fact several studies have stipulated that they are eight times more likely to injure this ligament (Elliot et al., 2010; Mall et al., 2014). Due to this phenomenon researchers have strived to understand the aetiology as to why females are at an increased risk, yet at present it is still to be fully understood (Shultz, 2015). However, many studies have been published attempting to rationalise why a female is at an increased risk of injuring their ACL (Hewett et al., 2016; Ylimaz et al., 2017; Zazulak et al., 2007). The common risk factors recorded which determine the probability of an ACL injury in a female include unfavourable anatomy, certain hormone secretion, biomechanical and neuromuscular deficiencies (Stanley et al., 2016) which will now be discussed in more detail.

2.2.1 ANATOMY

Several anatomical differences exist between genders which may put females at an increased risk of injuring their ACL (Hewett et al., 2016; Silvers, 2009). Anatomical factors such as increased femoral anteversion, an increased Q angle, excessive tibial torsion, and excessive subtalar pronation is more commonly observed in females compared to males (Leppanen et al., 2016; Shultz, 2015). The size of the intercondylar notch of the femur and the diameter of the ACL are two common anatomical differences between genders (Shelbourne et al., 1998). Previous research has demonstrated both the intercondylar notch and ACL to be smaller on average in females in comparison to males (Jacobsen, 1976; Kennedy et al., 1974). Due to a smaller intercondylar notch within the female knee it has been suggested, obstructions and impingements of the ACL may take place which could increase the probability of an ACL injury (Levins et al., 2017). On average men tend to have a wider intercondylar notch which is in a U-shape, adversely women often demonstrate a marginally smaller notch which is the shape of a cresting-wave (A-shape) (Nisell, 1985; Silvers 2009). A study conducted by Shelbourne et al. (1998) observed the ACL injury rates in both female and males, the researchers also studied the size of the intercondylar notch in all participants. This studied concluded on average females who were the same height as males had a smaller sized

intercondylar notch, however, there was no significant difference between gender and the rate of ACL injuries.

As previously mentioned the size of females ACL has been recorded to be smaller than that of males (Hutchinson and Ireland, 1995), which may affect a female's ability to resist anterior displacement of the tibia increasing the risk of an ACL injury. Some experts believe a smaller notch size coincided with a smaller, weaker ACL could in fact increase the risk of damaging the ligament further (Houseworth et al., 1987). A study conducted by Levins et al. (2017) measured the geometry of the ACL in 55 females who had suffered an ACL injury, the stature of both the injured and uninjured ACL was measured. This study found the volume (551 mm³ to 1495 mm³) and cross sectional area (0.2 cm² to 0.7 cm²) of the ACL differed between the female participants, but size was not considered a significant (P = 0.88) reason why the participants had injured their ACL, potentially dispelling this anatomical difference why females are at higher risk of injuring their ACL.

Furthermore, another anatomical factor which may put females at a higher risk of injuring their ACL is an increased quadriceps femoral angle (Q angle) which can contribute towards a valgus position (Hewett et al., 2016). The Q angle (refer to figure 2) of an individual is determined by a line drawn from the anterior superior iliac spine to the centre of the patella and one other line drawn from the centre of the patella to the tibial tubercle centre (Kerim et al., 2017). Although there is no empirical evidence proving so, it is demonstrated in literature that females have larger Q angles in comparison to males (Livingston, 1998; Ylimaz et al., 2017). It has been proposed that a Q angle within the limit of 15 to 20 degrees can cause disorders in lower body mechanics (Hewett et al., 2016), which can attribute towards the knee falling into a valgus position in turn causing ACL damage (Cesar et al., 2016; Hewett et al., 2016). It is important to note anatomical risk factors alone do not cause ACL injuries; however, the anatomical factors may play a significant role when the body is dynamically moving (Silver, 2009). Future studies assessing incidence rates in relation to anatomic risk factors and multiplanar dynamic movement patterns are necessary (Rafeuddin et al., 2016; Silver, 2009).

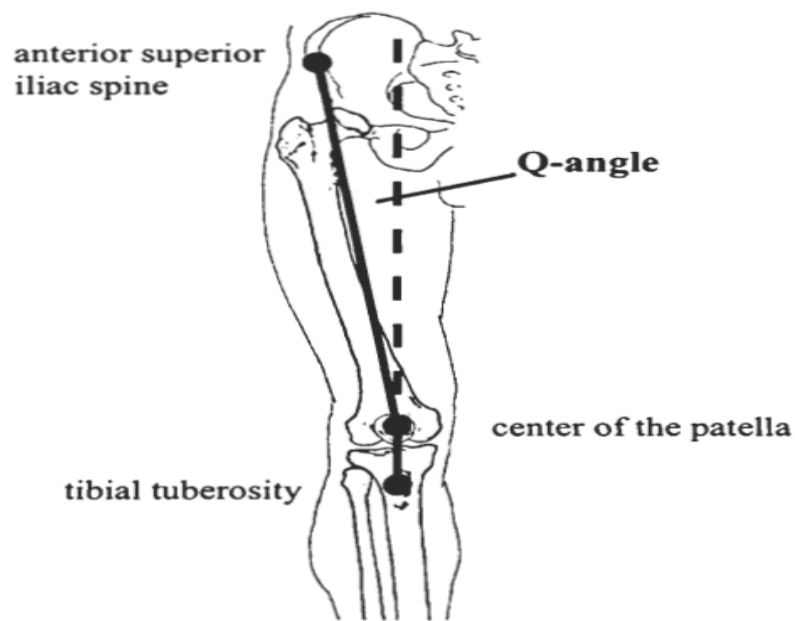


FIGURE 2. VISUAL REPRESENTATION OF THE Q ANGLE (HEWETT ET AL., 2010)

2.2.2 HORMONAL INFLUENCES

Previous research has demonstrated hormones such as estrogen, progesterone and relaxin can compromise collagen metabolism of the ACL in turn affecting its integrity; receptors for these specific hormones have been identified on the human ACL (Karageanes et al., 2000; Van Lunen et al., 2003). Studies have proposed serum increases in the aforementioned hormones can affect the ACL's fibroblast proliferation and procollagen synthesis and subsequently weaken the ACL three to seven days following the provision of these hormones (Charlton et al., 2001). Some research has suggested that females have heightened secretion of these hormones during the luteal phase of their menstrual cycle (Shultz et al., 2004) concomitantly this phase of the menstrual cycle may be a reason as to why females are more prone to ACL injuries. During this phase of the menstrual cycle serum levels of the hormones estrogen, progesterone and relaxin increase and can decrease collagen synthesis which weakens the integrity of the ACL, making the ligament less rigid and lax in turn increasing the risk of damaging the ACL (Hewett et al., 2010).

Contrary to previous studies which suggested females are at higher risk of injuring their ACL during phases of the menstrual cycle (Charlton et al., 2001; Shultz et al., 2004), Pollard et al

(2006) discovered the fluctuations in estrogen throughout the menstrual cycle did not significantly increase ACL laxity. However, this study like others (Karageanes et al., 2000; Van Lunen et al., 2003) discovered on average that females exhibit higher levels of estrogen at any given time in comparison to males. Pollard et al. (2006) also found the females in their study had larger laxity of ACL in comparison to males, the higher levels of serum estrogen may have attributed towards this. A study conducted by Stijak et al. (2015) discovered women with lower concentrations of testosterone and higher concentrations of 17- β estradiol and progesterone are predisposed to ACL ruptures. These hormones were higher in the women that injured their ACL consistently, and not only during phases of their menstrual cycle. Another study conducted by Park et al. (2009) concurred with the Stijak et al. (2015) study and found no significant differences in knee joint laxity between the follicular and luteal phase of the menstrual cycle. However, this study did demonstrate significant knee joint laxity when the knee joint was placed under load ($P = 0.015$) between the ovulation and luteal phase. This study unlike others explains how non-contact injuries may occur under load (i.e. a quick change of direction) during the menstrual cycle due to an increased knee laxity, making it more specific and relevant to sport.

Although the research suggests certain hormones increase a female's risk of injuring their ACL, there is a significant amount of ambiguity as to when the female ACL is at its most lax as demonstrated by the research (Park et al., 2009; Pollard et al., 2006; Stijak et al., 2015). Some academics have stated that the risk of ACL injuries due to the increase secretion of certain hormones could be subject specific (Pollard et al., 2006; Stijak et al., 2015), meaning it would be difficult to predict when a person is at a higher risk of injuring their ACL. Taking this into consideration it would appear to be more viable and logical to implement methods that a person has more control over to attempt to reduce their risk of an ACL injury.

2.2.3 BIOMECHANICAL AND NEUROMUSCULAR

The reasons discussed as to why females are at a higher risk of injuring their ACL are difficult to fully determine due to the complexity of the related factors. However, one difference between the two genders that can be trained and potentially improved is the neuromuscular control of the muscles that Hewett et al. (2016) has suggested can provide protection for the ACL. It is proposed that the females recruit the quadriceps more so than their hamstrings. Putting this into context, if a female athlete who partakes in a court sport was to jump upwards and on their way down over-recruited the quadriceps, their leg would be in a hyper extended

position on landing, this biomechanical disadvantage may cause excessive anterior translation of the tibia and potentially cause the ACL to tear (Hewett et al., 2010; Hewett et al., 1996; Huston and Wojtys, 1996). Bowerman et al. (2006) identified the hamstring to quadriceps (H:Q) strength ratio in 54 male and female students using a Biodex isokinetic dynamometer. The study yielded a significant difference in H:Q ratio between the two genders ($P = 0.0001$), males had considerably stronger hamstrings, quadriceps and a greater H:Q strength ratio in comparison to females. These findings concurred with those previously mentioned (Hewett et al., 2010; Huston and Wojtys, 1996) providing evidence to support that females have a reduced hamstring and quadriceps strength. Another study by Hughes and Dally (2015) observed the EMG of the rectus femoris, biceps femoris and gluteus maximus in 10 males and 10 female basketball, volleyball and netball players whilst they performed movements such as landing from a vertical jump and a rapid change of direction. The study concluded the rectus femoris muscle activity was significantly greater in females ($P = 0.01$) and biceps femoris activity was significantly higher in males ($P = 0.01$). It is well acknowledged that the hamstrings have an important role in the stabilisation of the knee, offering a supporting function to the ACL (Benjaminse et al., 2015).

Another group of muscles that are essential in absorbing ground reaction forces as well as controlling lower limb alignment during an array of different sporting movements (Gupta et al., 2004) are located within the hip region. It has been reported that females lack the ability to recruit these muscle groups as efficiently as males (Hewett et al., 2016). A study by Nguyen et al. (2017) observed the range of motion in female football players hips and found significant asymmetries ($P = 0.001$). Nguyen et al. (2017) found a significant number of the participants had an insufficient ability to adduct and externally rotate the hips into a position that allowed for the recruitment of the aforementioned muscles in order to maintain a safe lower extremity alignment (Hewett et al., 2016). When the correct muscles in the hip region fail to be recruited during a sporting movement such as landing from a jump or a sudden change in direction, it can cause malalignment of the lower body. In turn the ligaments within the knee are relied upon to absorb the ground reaction force and to maintain lower limb alignment (Bolgia et al., 2016; Hewett et al., 2010) which increases the likelihood of an ACL rupture (Leporace et al., 2012; Rafeuddin et al., 2016).

Training programmes which include movement patterns designed to recruit and strengthen the muscles in the hips have shown promise in reducing the risk of ACL injuries due to the

improvement in an individual's ability to maintain lower limb alignment (Nguyen et al., 2017). Omi et al. (2018) demonstrated the chronic benefits of a training programme which included exercises focusing on recruiting and strengthening the muscles within the hips through a 12 year study. Exercises performed by the participants included single leg squats, rebound jumps and balancing exercise on a bosu ball. Before the intervention period Omi et al. (2018) observed the ACL injury rates over a four year period in 757 female basketball players, in total the authors recorded 16 ACL injuries over this time period. The authors then implemented a training programme which included strengthening, jumping and balancing exercises, the authors had the participants complete this programme three times a week whilst in season. Eight years later (12 years total) nine ACL injuries were recorded, this equated to an ACL injury incidence of 0.10/1000 athlete exposure (1 game or 1 practice), whereas the ACL injury incidence within the four year period was much greater at 0.25/1000 athlete exposure (Omi et al., 2018). Compared to the four year observation period the intervention period significantly reduced ACL injury rates ($P = .017$). This study like others provides evidence to support that by incorporating exercises designed to elicit activity in certain neuromuscular pathways, ACL injury incidences can be reduced within female athletes (Leporace et al., 2013; Rafeeuddin et al., 2016).

It has been demonstrated that a significant amount of females have an inability to control the trunk of their body as efficiently as males whilst performing sporting movements due to neuromuscular deficiencies (Hewett et al., 2010; Zazulak et al., 2007). This phenomenon is known as trunk dominance (Hewett et al., 2010). If for example a female was to land from a jump one footed with the trunk of her body tilted (a compromised posture), the ground reaction force would attempt to track towards the athlete's centre of mass. The force would first of all progress through the knee joint which can subsequently move the knee into a valgus position (Hewett et al., 2010) in turn putting the athlete at a high risk of injuring their ACL. Zazulak et al. (2007) observed the injury rates of 277 college athletes over a three year period (140 males and 137 females) and before this observational period tested the core proprioception ability of the athletes using a motorised trunk rotation unit. Eleven females that sustained a knee ligament injury over the three years demonstrated significant deficits in trunk proprioceptive positioning abilities in comparison to the men and uninjured women ($P = 0.05$). Furthermore, Raschner et al. (2012) who measured the flexion and extension strength of the core musculature and incidence of ACL injuries in 175 females and 195 males over a ten-year period. The study identified that both males and females who had more flexion and extension strength in the core

musculature remained uninjured ($P = 0.009$) in comparison to those who had weaker core strength. This study like many others (Pollard et al., 2006; Ylimaz et al., 2017) also found the female to male ACL risk ratio was higher in females (95% CI 1.3 to 4.2).

The evidence suggests neuromuscular deficiencies are more prevalent in females than males and due to these weaknesses females are at an increased risk of sustaining an ACL injury (Benjaminse et al., 2015; Hewett et al., 2010). The evidence provided rationalises the need for the incorporation of a neuromuscular training programme, which includes exercises attempting to address these neuromuscular inadequacies (Benis et al., 2016; Soligard et al., 2018).

2.3 THE PHYSICAL DEMANDS OF COURT-BASED SPORTS

Athletes who participate in court sports such as netball, volleyball, badminton, squash, basketball and futsal are required to demonstrate similar physical qualities such as agility, acceleration, muscular power, muscular strength and aerobic endurance (Chandler et al., 2014; Cosmin et al., 2016; Fort-Vanmeerhaeghe et al., 2016; Junior et al., 2017; Kant et al., 2012; Phomsoupha et al., 2015). Unlike other sports, court sport participants are required to perform quick, repetitive movements such as jumping, landing and changing direction quickly (Cosmin et al., 2016; James et al., 2014; Junior et al., 2017; Langeveld et al., 2012). To perform these movements safely and effectively an athlete must recruit the correct muscle groups (McCann et al., 2011). However, it has been clearly reported within the literature that a significant number of female athletes perform the movements with compromised mechanics or posture in turn increasing risk of ACL injury occurrence (Dedinsky et al., 2017; Hewett et al., 2016). It is repeatedly reported within literature that ACL injuries are often suffered in the absence of contact (Fox et al., 2016; McCann et al., 2011), as damage to the ACL occurs in multiplanar movements at the hip and knee during the previously mentioned manoeuvres (Brown et al., 2014; James et al., 2014; Renstrom et al., 2008). For example, the quadriceps are recruited to stiffen and stabilise the knee joint however, if the quadriceps are over recruited this can place the leg in an extended position which can pull the tibia anterior relative to the femur (Cesar et al., 2016; Hewett et al., 2010). Considering the quadriceps need to be recruited in order to perform the previously mentioned non-contact sporting movements, the tibia can often reach the position which causes strain on the ACL as the ligament tries to hold the tibia posteriorly (Hewett et al., 1996; Malinzak et al., 2001). If too much strain is applied this can result in an ACL injury.

2.4 INJURY PREVALENCE AND RISK IN COURT-BASED SPORTS

López González et al. (2017) observed the injury rates in 289 female and male basketball players over a three month period and found the most commonly injured area of the body in the female participants was the knee (42%), whereas the knee was only the third most injured area in the male participants (17%). This study not only found that females are at a higher risk of injuring their ACL in comparison to males, but also the prevalence of knee injuries within this court sport. Bahr and Reeser (2003) observed the injury rates amongst 178 female professional volleyball players over an eight-week period in five different tournaments, the most commonly injured body region was the knee (30% of all injuries recorded), the knee was also the region of the body that caused most time loss when injured. Shariff et al. (2009) designed a study to investigate the injury patterns amongst 180 female and males badminton players over a two-year period and found the region of the body most commonly injured was the lower limb (63%) and out of six locations of the lower limb, the most frequently injured was the knee (38%). Although these studies emphasise the high prevalence of knee injuries in female court sport athletes, some may question their credibility due to the smaller number of participants recruited in comparison to other pieces of research (Agel et al., 2005; Langeveld et al., 2012).

A study including a large number of participants was conducted by Hespén et al. (2011); data of injury incidences in 1234 male and female soccer and futsal players over a season was gathered. The area of the body found to be the most commonly injured in this study was once again the knee (22% female and 20% male), this study also demonstrated a percentage difference in knee injuries between female and male participants. Another study conducted by Langeveld et al. (2012) used a questionnaire and one year long season to map and monitor injuries in 1280 female netball players. 10 anatomical sites of the body were identified as commonly injured areas, out of the 10 sites the knee was the second most commonly injured (19%) part of the body. Interestingly, this study also unearthed that out of eight, the most frequently injured structure was the ligament (47%). Although a larger participant pool was used within these studies, a shorter surveillance period was implemented in comparison to other pieces of research (Agel et al., 2005) which may cause some to question the methodologies used.

A study conducted by Agel et al. (2005) reviewed the data gathered by the National Collegiate Athletic Association (NCAA) Injury Surveillance System database over a thirteen-year period.

A total of 6176 American schools participated in this study, the data was gathered from athletes who played basketball and soccer. A prevalence of 683 ACL injuries were sustained in basketball (514 women, 168 men) and 586 in football (394 women, 192 men); 67% of all female ACL injuries recorded for both sports were non-contact (woman basketball 76% and woman soccer 58%) and 60% of male ACL injuries were also non-contact in nature (male basketball 70% and male soccer 50%). This study also supported other influential pieces of research (Hewett et al., 2016; Schmitt et al., 2016) in discovering that females, regardless of the sports they play, have significantly higher ACL injury rates in comparison to males (non-contact $P = 0.01$, contact $P = 0.01$). Hootman et al. (2007) observed the injury rates in 15 sports and found the sport which yielded the most ACL injuries in a female sport woman was the court sport basketball (475 in total), whereas the field based sport woman lacrosse recorded only 13. Interesting to note almost three quarters of ACL injuries are non-contact in nature (Boden et al., 2000). The prevalence of ACL injuries in court sport athletes and females is more than apparent as demonstrated by the research; through examining the evidence there is a clear link between neuromuscular deficiencies and the high rates of ACL trauma in females (Agel et al., 2005; Gianotti et al., 2009; Langeveld et al., 2012). It is also clear that court sports athletes require certain physical attributes to perform their sport optimally (Chandler et al., 2014; Fort-Vanmeerhaeghe et al., 2016), taking all this into consideration a neuromuscular training programme designed to reduce the risk of ACL injuries as well as increasing performance is a prerequisite for safe and effective participation in court sports.

2.5 NEUROMUSCULAR TRAINING

Research has demonstrated some participants have an inability to recruit the relevant muscles to the extent required for efficient performance in certain movements (Hewett et al., 2010; Hewett et al., 1996), this can be due to the lack of activity within the primary motor cortex. This lack of activity then effects the signal sent down descending corticospinal tracts which then prevents the motor neuron producing the action potential needed to recruit the muscle fibres to perform a movement safely and effectively (Kuhn et al, 2017). Past research has concluded through performing new movement patterns, central neural adaptations can take place in the motor cortex and along the descending corticospinal tracts (Pensini et al., 2002) in turn eliciting the essential action potential needed to cause the muscle fibres to contract to perform the movement correctly (Owoeye et al., 2014).

Past research has also suggested neural adaptations can take place in the motor unit in response to training (Bizzini et al., 2013; Hewett et al., 2010). The motor unit, consists the motor neuron and the associated muscle fibres stimulated by the motor neuron. Motor units have different firing rates which can affect the recruitment of muscle fibres, it is generally proposed that as force generation increases in magnitude the slow twitch fibres must be recruited before the fast twitch, this is known as the size principle (Haff and Triplett, 2015). The size principle theory is limiting for athletes who need to express a large amount of force as quickly as possible (Junior et al., 2017; Cosmin et al., 2016). For example, if an athlete needed to change direction or decelerate abruptly, they may not possess the ability to recruit the fast twitch muscle fibres quick enough to perform this movement safely and effectively. This is due to the slow twitch muscles having to be recruited before it is possible to recruit the desirable, high force producing, fast twitch fibres (Shepherd, 2003; Gamble, 2013). However, the size principle can be potentially bypassed following the longitudinal practice of certain training methods (Newton et al, 1996). Specifically, plyometric, speed, power and agility training can induce selective recruitment of fast twitch muscle fibres (Gjinovci et al., 2017). Therefore, when performing the previously mentioned movements athletes may acquire the ability to recruit the fast twitch, rapid force developing fibres when needed, instead of having to sequentially recruit the slow twitch fibres upon movement initiation (Zatsiorsky and Kraemer, 2006).

An interesting study conducted by Matin et al. (2014) demonstrated the beneficial effects of a neuromuscular training programme by recruiting 24 male sports participants. Matin and colleagues (2014) then randomly assigned the participants to either a control or intervention group, the intervention group completed a neuromuscular training programme three times a week for 60 minutes at a time, whilst the control group completed regular exercise routines. The neuromuscular training programme included exercises such as bosu ball planks, hurdle jumps, medicine ball lunges and bosu ball hamstring curls. At the end of the four week training period it was discovered that the intervention group demonstrated significantly better scores in the stork stand balance test in comparison to the control group ($P = 0.001$). Although this study demonstrated the beneficial effects of a neuromuscular training programme it also provided evidence how this method of training can require equipment that may be expensive to some such as medicine balls, dumbbells, bosu ball and hurdles. However, such equipment can be deemed as costly and maybe unaffordable for some, taking this into consideration a neuromuscular training programme requiring minimal equipment to perform would make it

easier for athletes to integrate this method of training into their regimes (Bonato et al., 2018; Soligard et al., 2008).

Another study using a relevant cohort was carried out by Bonato et al. (2018) who conducted a randomised control trial to observe the effects of a neuromuscular training programme in female basketball players injury incidences. The neuromuscular training programme implemented by Bonato et al. (2018) was designed with the use of previous research that found a reduction in sporting injuries as well as an increase in performance (Benis et al., 2016; Mandelbaum et al., 2005; Soligard et al., 2008). This study implemented the neuromuscular training programme into the athlete's warm up routine, on average the overall exposure each athlete had performing the neuromuscular routine was 46.8 hours. Types and rates of injuries during a 2015-2016 basketball season were recorded. The experimental group demonstrated a significant injury reduction in comparison to the control group ($P = 0.006$), another promising finding within this study was the reduction in incidences of ACL lesions possibly due to their involvement in the neuromuscular programme ($P = 0.038$). This study not only provides evidence that a neuromuscular training regime can reduce the risk of ACL injuries, it also revealed notable increases in counter-movement jump height ($P = 0.0001$) as well as improvements in the lower quarter Y-Balance test ($P = 0.001$ right limb, $P = 0.003$ left limb).

The neuromuscular training programme within this study comprised of body weight exercise only, which makes it much easier for coaches, strength and conditioners and athletes to implement into their training. A piece of research orchestrated by Benis et al. (2016) discovered similar results to that of the Bonato et al. (2018) study; after female's basketball players performed a body weight neuromuscular training programme twice a week over an 8-week period, significant improvements were recorded in the participant's ability to perform the Y balance test when compared to the control group (left limb $P = 0.001$, right limb $P = 0.0004$).

The discussed pieces of independent research demonstrated the effectiveness of a neuromuscular training programme (Benis et al., 2016; Bonto et al., 2018); Mandelbaum et al., 2005; Soligard et al., 2008) systematic reviews have also approved these findings (Huebscher et al., 2010; Zech et al., 2010). Huebscher et al. (2010) conducted a systematic review of 32 studies and after consideration chose seven with strong methodologies. After thoroughly examining these papers it was concluded neuromuscular training programmes are effective in reducing the risk of lower limb injuries ($P = 0.01$), in particular ankle injuries ($P = 0.01$) and more relevantly, knee injuries ($P = 0.01$).

The neuromuscular regimes discussed have either reduce the risk of injury, increase performance or address both simultaneously (Benis et al., 2015; Huebscher et al., 2010; Zech et al., 2010). However, a neuromuscular routine which has attracted a significant amount of attention due to its practicality and proven effects in reducing injury incidences as well as having a positive impact on performance is known as the Fifa 11+ protocol.

2.6 FIFA 11+ PROTOCOL

As previously discussed, neuromuscular training programmes have shown to reduce the risk of ACL injuries in both females and males (Weltin et al., 2017; Hewett et al., 2016). One neuromuscular training protocol that has demonstrated significant promise when researched is the Fifa 11+ (Owoeye et al., 2014; Soligard et al., 2008). The Fifa 11 was initially developed in 2006 by both the Santa Monica Sports Medicine Foundation and the Oslo Trauma and Research Centre with the intention to reduce the risk of common injuries in football players i.e. knee, ankle, groin and hamstring (Bizzini et al., 2013). The original Fifa 11 protocol comprised of 10 exercises designed to activate core stability, balance, dynamic stabilisers and eccentric hamstring strength (F-MARC, 2005). The new revised Fifa 11+ protocol comprises of 15 exercises and is split into three sections (see table 1). Section one includes running exercises, section two focuses on strength, plyometric and balance exercises and section three incorporates further running exercises. Unlike the Fifa 11 protocol the Fifa 11+ has three different levels of difficulty for each exercise in section two. This was put in place in order to encourage participation.

2.6.1 FIFA 11+ AND INJURY PREVENTION

The first study researching the effects of the Fifa 11 protocol was conducted by Steffen et al. (2008), this was a randomised controlled trial designed to examine whether the protocol reduced the injury rates in female footballers when used as a warm up. In total 2092 females from an under 17s league in Norway participated in the study over a seven-week period. The intervention group yielded no significant reduction in injuries when compared to the control group (intervention group = 3.6 injuries per 1000 hours played, CI 3.2–4.1 and control group 3.7, CI 3.2–4.1; RR 5 1.0, CI 0.8–1.2; P = 0.94). This may have been due to the low compliance rates as only 52% of the participants within the intervention group completed the required number of sessions.

Soligard et al. (2008) also studied the effectiveness of the FIFA 11 programme with a revised version. Due to the amendments made to the programme it was renamed the FIFA 11+ protocol, on this occasion the programme included exercises with variations and progressions so that all participants could participate and challenge themselves (see table 1). The improved protocol also included structured running exercises that increased its specificity as a warm up (Soligard et al., 2008). Overall, 1892 participants were recruited for this study and were required to perform the FIFA 11+ protocol over an eight-month period. To be included in the study participants had to perform the FIFA 11+ as a warm up a minimum two times a week and the coaches reported the player's participation and injuries. Unlike the study conducted by Steffen et al. (2008), 80% of the 65 intervention teams performed 44 sessions, which demonstrates much better compliance rates with the programme. The author suggested the improved compliance rates are more than likely what attributed towards the study yielding a significant reduction in all injury rates that occurred over the season; a significant decrease in all injuries ($P= 0.041$) and severe injuries ($P= 0.005$), was found in the intervention group when compared to the control group.

The Soligard et al. (2008) study sparked interest within the football domain and in several other sports, for example a study by Owøye et al. (2014) decided to research if the FIFA 11+ warm up reduced the risk of injury in male football players aged between 14 and 19. Owøye and colleagues (2014) recruited 414 players for this study who were randomly assigned to a control or an intervention group. The intervention group performed the FIFA 11+ protocol over a six-month period whilst the control group performed their normal warm up routine. Compliance rates showed on average the intervention teams performed the FIFA 11+ programme 30 ± 12 sessions per team (1.6 times per week). After the research period the intervention group exhibited significant decreases in overall injury rates ($P = 0.006$) and lower extremity injuries specifically ($P = 0.004$) in comparison to the control group.

Silvers-Granellie et al. (2015) researched the efficacy the FIFA 11+ protocol had in reducing injury rates in male university football player. 61 teams took part in the study (31 control group = 850 players vs 30 intervention group = 675 players) over a football season. The intervention group performed the FIFA 11+ protocol as their warm up on average 30.5 times over the season, the control group were required to continue with their regular warm up regimes. The injury records were analysed post data collection and it was found the control group suffered 665 injuries in total which corresponds with an incidence rate (IR) of 15.04 injuries per 1000 (hours)

athlete exposure. Interestingly the intervention group sustained only 285 injuries, this represents an IR of 8.90 per 1000 athlete exposure. The Fifa 11+ protocol significantly reduced injury incident rates by 46% (P = 0.0001) and significantly reduced the number of days missed training or competing due to injury (P = 0.007). This study included additional value because authors reported the regions of the body injured; the knee related injuries suffered in the control group was noted a 115 whereas the intervention group recorded only 59 knees injuries. The type of knee injury was also recorded and intriguingly only three ACL injuries were recorded in the intervention group, this was a significant reduction (P = 0.01) in this type of injury in comparison to the control group who recorded a total of 16 ACL injuries.

TABLE 1. ORIGINAL FIFA 11+ PROTOCOL (SOLIGARD ET AL., 2008)

Exercise and section	Sets and repetitions
Section 1 (over a 25 m distance) <ul style="list-style-type: none"> • Straight ahead • Hip out • Hip in • Circle partner • Shoulder contact • Quick forwards and backwards 	All exercises performed 2 x in the allocated area
Section 2 <ul style="list-style-type: none"> • Plank (3 levels of difficulty) • Side plank (3 levels of difficulty) • Nordic curls (3 levels of difficulty) • Test your partners balance (single leg) (with football) • Squats (3 levels of difficulty) • Jumps (3 levels of difficulty) • Bounding (3 different heights) 	1 min rest between each set and exercise <ul style="list-style-type: none"> • 3 x 20-60 seconds • 2 x 20-30 seconds (each side) • 3 x 3-15 repetitions • 2 x 30 seconds (each leg) • 2 x 10 repetitions • 2 x 16 (each leg) • 2 x 6
Section 3 (over a 25 m distance) <ul style="list-style-type: none"> • Across the pitch • Bounding • Plant and cut 	<ul style="list-style-type: none"> • 2 x in allocated area • 2 x in allocated area • 2 x in allocated area

A systematic and meta-analysis was produced by Gomes Neto et al. (2016) to find out if the Fifa 11+ programme was effective in decreasing injury incidences. After considering 329

records eleven articles were deemed eligible due to their superior methodologies. It was found the Fifa 11+ training programme significantly reduced the risk of injuries (risk ratio = 0.69; 95% CI: 0.49–0.98; P = 0.02) and improved dynamic balance (weighted mean difference = 2.68; 95% CI: 0.44–4.92; P = 0.02). The increase in dynamic balance is significant as poor neuromuscular control can lead to poor balance which is a strong precursor for an ACL injury (Hewett et al., 2016; Zazulak et al., 2007). Although the implementation of the Fifa 11+ protocol has reduced the risk of injuries in participants, there is a lack of research stipulating the specific kind of injuries the Fifa 11+ protocol reduces. The study by Silvers-Granellie et al. (2015) was divergent in comparison to others observing the effects of the Fifa 11+ protocol as it specified the types of injuries reduced due to the protocol. More pieces of research such as the Silvers-Granellie et al. (2015) study observing the effects the Fifa 11+ protocol has on reducing specific injuries such as a career threatening ACL injury is needed as it may support the protocol further.

2.6.2 FIFA 11+ AND PERFORMANCE

The Fifa 11+ protocol is an evidence based routine initially designed with the sole purpose of preventing injuries, and has been repetitively served its purpose as an injury reduction tool (Owoeye et al., 2014; Steffen et al., 2008). Although a routine designed to prevent injury in sport is paramount to most, a routine that aids performance is also desirable (Dedinsky et al., 2017). Researchers believe the Fifa 11+ protocol included dynamic exercises that could potentially elicit desirable physiological responses that may improve sporting performance (Bizzini et al., 2013; Impellizzer et al., 2013).

Bizzini et al. (2013) were the first to research whether the Fifa 11+ protocol could improve specific variables; 20 male football players (mean age 25.5) took part in the study and were asked to perform four different sessions to assess if the Fifa 11+ warm up protocol had desirable effects upon post activation potentiation, decrease in stiffness, rise in core temperature and resting oxygen consumption. The study adopted a within subject pre-post method with two baselines to assess the effects of the Fifa 11+ protocol. On each of the four sessions the participants performed the Fifa 11+ warm up, however, the tests performed to assess performance changed each session to ensure that participants did not become fatigued and results were corrupted. Significant improvements were found post Fifa 11+ warm up in comparison to the baseline (P values ranging from 0.015 to <0.001) for all variables measured (Lactate, VO₂, Core temperature, Star excursion balance test, squat jump, counter-movement

jump, stiffness, agility and 20 m sprint) with the exception of rate of force development, maximal voluntary contraction. The study also demonstrated significant enhancements in all aforementioned variables post Fifa 11+ warm up (P values ranging from 0.052 to <0.001) in comparison to the control period (designed to replicate a common warm up) with the exceptions of force development, maximal voluntary contraction.

Although Bizzini et al. (2013) found the Fifa 11+ warm up to specific variables in comparison to the control period, the authors of this paper fail to detail the contents of the control period which devalues the findings. As discussed Bizzini et al. (2013) discovered the Fifa 11+ protocol improved several physical parameters acutely which may encourage sporting participants to adopt this protocol prior to performance. However, Palazon et al. (2016) believed if the Fifa 11+ could elicit long term improvements in performance it may increase the protocols credibility furthermore. With this in mind Palazon et al. (2016) recruited 45 male football players to assess both the acute and chronic effects of the Fifa+ protocol. After completing the procedure three times a week over four weeks no statistical differences ($P > 0.05$) in joint range of motion, dynamic postural control, sprinting and jumping were found when compared to a control group who performed their regular routine. Therefore, the findings in this study indicate the FIFA 11+ may be considered an appropriate protocol for inducing improvements in physical performance when compared with other training regimes used by football players. The already mentioned systematic and meta-analysis produced by Gomes Neto et al. (2016) did not only discover the Fifa 11+ protocol is effective in reducing the risk of injury but it also increased certain performance parameters such as dynamic balance ($P = 0.02$) and agility ($P = 0.04$).

The previously mentioned research suggests that the Fifa 11+ protocol not only improves performance measurements, but also reduces the risk and incident rates of ACL injuries (Palazon et al., 2016; Soligard et al., 2008). The participants used in a significant number of studies demonstrating the benefits of Fifa 11+ protocol are football players (Bizzini et al., 2013; Bizzini et al., 2013; Impellizzer et al., 2013). There is a noticeable lack of research on how the Fifa 11+ protocol benefits those in other sporting disciplines. As previously mentioned court sport athletes require physical qualities such as agility, acceleration, muscular power, muscular strength and aerobic endurance (Chandler et al., 2014; Cosmin et al., 2016). Considering all that has been discussed within the literature review, it seems more than appropriate to design a study assessing if a modified Fifa 11+ programme can reduce the risk of an ACL injury and

improve the physical capabilities in female court sport athletes. The author hypothesised if female court sport athletes were to engage in an evidence based neuromuscular training programme it would elicit chronic improvements in sprint performance, CMJ height, agility performance as well as reducing their risk of an ACL injury.

3.0 METHODS

3.1 PARTICIPANTS

22 female university students were initially recruited for this study, two were removed from the study due to not meeting the eligibility criteria of achieving 87.5% (Ter Stege et al., 2014) attendance as part of the intervention group. The participants were split evenly through random allocation, this comprised of 10 in the control group and 10 in the intervention group (mean \pm standard deviation, age; years, playing experience; (stature: 169 ± 7 cm, mass: 61.3 ± 8.3 kg, age: 22.3 ± 2.0 years, playing experience: 5.4 ± 1.6 years). The participants came from a variety of different sporting backgrounds which included badminton, squash, futsal, netball, basketball and volleyball. The sports were chosen due to the similar movement patterns exhibited in each (Chandler et al., 2014; Cosmin et al., 2016; Fort-Vanmeerhaeghe et al., 2016; Junior et al., 2017; Kant et al., 2012; Phomsoupha et al., 2015). The athletes involved in this study performed in the British University and College Sport (BUCS) leagues for their respective sports. Participants were required to confirm they had no history of knee, thigh, hip or lower back injuries within the past year. If participants claimed to have suffered an ACL tear in their lifetime they were exempt from taking part in the study. An 87.5 percent level of attendance (14 out of 16 sessions) needed to be achieved by the intervention group participants otherwise they were removed from the study. The study received ethical approval from the University of Lincoln School of Sport and Exercise Science institutional ethics committee in line with the Helsinki Declarations for research with human volunteers. In addition, all participants provided informed consent before any participation for both the control and intervention group, the consent forms stipulated procedures and potential risk factors within the study, this information was also communicated verbally.

3.2 RESEARCH INSTRUMENTS AND PROCEDURES

This study was a two group, SPSS generated randomised control trial (Fifa 11+ vs. control group). The participants from both the intervention and control group were evaluated at two points throughout the study; before (pre) and after (post) eight weeks of the intervention programme (refer to figure 2 for schematic representation of study). Prior to collecting the data all participants went through a standardised warm up. This consisted of full body static stretch followed by two laps of the sports hall at Lincoln University (172 m). This was then followed

by a battery of tests which included the following exercises and were performed in the order listed; 20 m sprint, counter-movement jump (CMJ), qualitative analysis of single leg squat (QASLS) and Illinois agility test. The tests were performed two days after training or competition to allow for sufficient recovery and to reduce the risk of inaccurate data. All tests were carried out on basketball court surface.

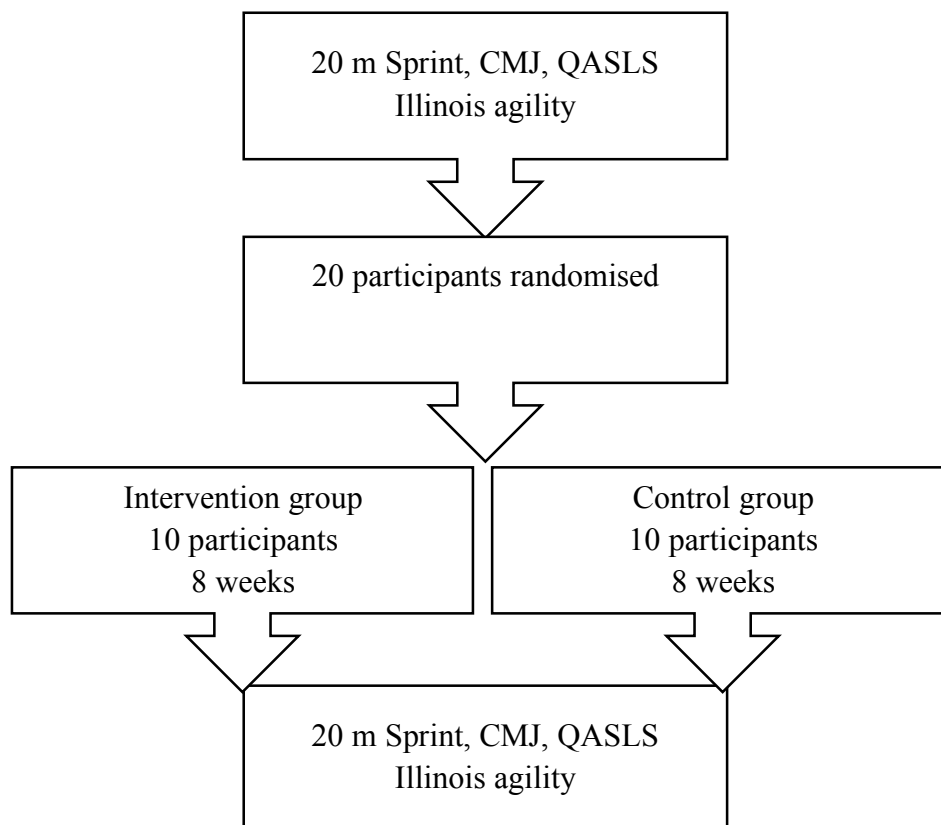


FIGURE 3. SCHEMATIC REPRESENTATION OF THE STUDY DESIGN

3.2.1 20 M SPRINT

The 20 m sprint was chosen due to its relevance as court sport athletes seldom sprint further than 20 m within a game in one given effort (Chandler et al., 2014; Cosmin et al., 2016; Junior et al., 2017). Participants were initially required to run the 20 m distance three times at a jogging pace with one minute rest in-between each trial. After the three trial runs the participants were then asked to complete three 20 m sprints as quickly as possible through the speed gates with one minute rest in-between each sprint to allow for recovery. The quickest

time out of the three-test run was recorded in both the pre and post-tests. All sprints were recorded with the use of Smart Speed (Fusion Sport, Queensland, Australia) electronic timing gates, the start and finish of the 20 m sprints was marked with masking tape. All sprints were from a standing start and the toe of the leading leg was placed behind start line.

3.2.2 COUNTER-MOVEMENT JUMP

A CMJ was chosen to assess the participants lower body power. In all court sports participants are required on occasions to produce vertical power (Cosmin et al., 2016; Junior et al., 2017; Phomsoupha et al., 2015) to perform sport specific movements. The participants had three trial jumps with one minute's rest in between each trial. After the familiarisation process the participants were required to perform three more jumps with the same rest period between, the highest jump was recorded. For a jump to be deemed acceptable participants were required to place their hand on their hips and when prompted by the assessor squat down to a self-selected depth, with their feet shoulder width apart and jump vertically as high as possible, landing back on the jump mat with both feet simultaneously. The maximal vertical displacement of the participant's jump was assessed with the use of a just jump mat (Just Jump, Probotics, Huntsville, AL, USA). Vertical displacement was estimated from flight time, which is measured via interruption of an electrical circuit when the subject's feet are not in contact with the mat. Previous studies have researched the reliability of the just jump mat for measuring jump height by comparing it to the gold standard method of motion capture. A study by Leard et al. (2007) found The Pearson r between the video and Just Jump to be 0.967. Both correlations were significant at the 0.01 level.

3.2.3 QUALITATIVE ANALYSIS OF SINGLE LEG SQUAT (QASLS)

As previously discussed a significant amount of evidence suggests insufficient neuromuscular control of the lower and upper body increases the risk of an ACL injuries (Benis et al., 2016; Huebscher et al., 2010; Mandelbaum et al., 2005; Soligard et al., 2018; Zech et al., 2010). The gold standard method of assessing limb and trunk alignment is through 3D motion capture however, this technique can be expensive, time consuming and often unrealistic within context (Herrington and Munro, 2014). Due to the impracticalities of 3D motion capture, various researchers have developed qualitative methods of analysing limb control (Crossley et al., 2011; Onate et al., 2010). This study adopted the qualitative analysis of the single leg squat test (QASLS) which was developed by Herrington and Munro (2014) to assess participants' risk

of an ACL injury as well evaluating the effectiveness of the programme performed by the intervention group in comparison to the control group.

This is a simple functional test that allows for a safe clinical examination when compared to the popular single leg landing test (Yamazaki et al., 2010). The QASLS is a scoring system (see table 2 and figure 4) developed by Herrington and Munro (2014), it requires the participants' SLS movement to be recorded and reviewed, scoring the movement at different regions of the body, refer to table 2 for further details (arm, trunk, pelvis, thigh, knee and foot). Participants can score the lowest of a zero and at the highest a 10, a higher score indicates that a person is at higher risk of injuring their ACL due to poor neuromuscular control. This scoring system was based on the scoring system created by Whatman et al. (2012) and Crossley et al. (2011). The QASLS has demonstrated promise in previous studies, for example Herrington and Murno (2014), found the percentage of agreement between the QASLS and 3D motion capture was 98% (range 97%-100%) and the mean kappa measure of agreement found was $K = 0.9$ (95% CI 0.83-1.00). Another study adding to the credibility of the QASLS was conducted by Almangoush et al. (2014) who tested the inter and intra reliability of the measurement tool. Overall, the percentage of agreement for inter-observations was excellent (range 88%-100%) and the kappa measure of agreement ranged from $K = 0.63$ to 1.00 which is considered good to almost perfect. The intra-observations percentage of agreement for participants was excellent (range 95% to 100%), the kappa measurement of agreement was $K = 0.9$ which is very good/ excellent.

TABLE 2. QASLS SCORING SHEET DEVELOPED BY HERINGTON AND MUNRO (2014).

Qualitative analysis of single leg loading			
QASLS	Task: Single leg squat	Left	Right
Arm strategy	Excessive arm movement to balance		
Trunk alignment	Leaning in any direction		
Pelvic plane	Loss of horizontal plane		
	Excessive tilt or rotation		
Thigh motion	WB thigh moves into hip adduction		
	NWB thigh not held in neutral		
Knee position	Patella pointing towards 2 nd toe (noticeable valgus)		
	Patella pointing past inside of foot (significant valgus)		
Steady stance	Touches down with NWB foot		
	Stance leg wobbles noticeably		
Total			

This study adopted the same protocol from the Herrington and Munro (2014) paper. It required each participant to position themselves 5 m away from the video camera (Sony Handycam CX250). They were then required to stand one leg and squat down to a depth of 45° and no deeper than 60°, they were asked to perform this movement over a 5 s period. The participants were given the opportunity familiarise themselves with the depth of SLS with the use of a goniometer and three trials on each leg with a timer in front of them so they stayed within the 5 s period. Participants were then required to perform three recorded single leg squats on each leg and were only accepted if the squat was within the desired depth. Once the scores for each leg was collected, the three scores for each leg were averaged out and this gave the research the overall result for the left and right leg.



FIGURE 4. START, MID AND END POSITION OF THE QASLS FOR BOTH THE RIGHT AND LEFT LEG.

3.2.4 ILLINOIS AGILITY TEST

The Illinois agility test was chosen to assess the participant's agility for both the intervention and control group. This performance measurement was taken as there is a demand for the participants to accelerate, decelerate and change direction when training and competing within

their respective court sport (Bonto et al., 2018; Junior et al., 2017). Prior to performing three tests as fast as possible, the participants were asked to jog the agility test to familiarise themselves with the route. Once the participants had familiarised themselves with the route they were asked to complete three agility tests as quick as possible, the participants were allocated three minute's rest in-between each test. All agility tests were recorded with the use of timing gates (Smart Speed, Fusion Sport, Queensland, Australia), the start and finish of the test was marked with masking tape. All sprints were from a standing start and the toe of the leading leg was placed behind start line.

3.3 REPRODUCIBILITY OF MEASURES

As a prerequisite, each performance measurement underwent reproducibility testing to ensure the measurements chosen were deemed suitable and reliable (Hopkins, 2007). 10 female netball players (mean \pm SD: age = 19 ± 4 years, stature = 1.66 ± 0.26 m, mass: 57.4 ± 6.2 kg) completed the reproducibility testing. The participants completed the standardised warm up and all four measurements described in the procedures section (20 m sprint, CMJ, QASLS and Illinois agility test) on three separate occasions, with a day's rest in-between each.

The data captured from the reproducibility testing was analysed using the Hopkins (2007) consecutive pairwise trials for reliability spreadsheet. This spreadsheet calculates reliability statistics for consecutive pairs of trials and for the means of these statistics. Hopkins (2007) established typical error as a percentage (TE %) [90% confidence intervals (CI)]. Low TE is considered to be under 2% and moderate TE is between 3-10% (Hopkins, 2007; Stone et al., 2011) in assessing the variability of performance assessment measures, respectively. As demonstrated by table 3 TE for all tests were low to moderate (0%-3.7%) meaning all assessments can be used with confidence.

TABLE 3. MEAN (SD) FOR ALL PHYSICAL ASSESSMENTS FOR EACH TRIAL AND ASSOCIATED TYPICAL ERROR (TE) AS A % (90% CI) FOR TRIALS 1-2, 2-3 AND AS A MEAN ACROSS ALL TRIALS AND SMALLEST PRACTICAL EFFECT (SPE) OF CHANGE FOR EACH ASSESSMENT

Assessment	Trial 1	Trial 2	Trial 3	TE T1-T2 (%)	TE T2-T3 (%)	Mean TE (%)
20 m Sprint	3.77 (0.28)	3.80 (0.30)	3.79 (0.27)	1.7 (0.05 – 0.11)	0.8 (0.02 – 0.05)	1.3 (0.04 – 0.07)
CMJ	40.1 (6.1)	40.2 (6.2)	40 (6.2)	1.2 (0.34 – 0.76)	1.0 (0.25 – 0.57)	1.1 (0.31 – 0.59)
QASLS RL	3.4 (1.1)	3.4 (1.1)	3.5 (1.1)	0.0 (0.00 – 0.00)	2.9 (0.07 – 0.15)	2.0 (0.05 – 0.09)
QASLS LL	2.7 (1.7)	2.7 (1.7)	2.7 (1.8)	2.4 (0.07 – 0.15)	2.2 (0.10 – 0.22)	2.3 (0.09 – 0.17)
Illinois agility Sprint	17.79 (1.20)	17.94 (1.24)	18.28 (1.29)	1.0 (0.13 – 0.29)	3.7 (0.49 – 1.10)	2.7 (0.38 – 0.72)

3.4 INTERVENTION GROUP

The participants in the intervention group were required to perform a neuromuscular training programme. In addition to the neuromuscular training, the intervention group were asked to continue with their habitual training regimes. The training programme was an adapted version of the Fifa 11+ training protocol and was performed by each participant twice a week over an eight week period (Bizzini and Dvorak, 2015). The Fifa 11+ training programme was developed by both Santa Monica Sports Medicine Foundation (SMSMF), and the Oslo Sports Trauma and Research Centre (OSTRC) to prevent injuries (i.e., ankle and knee sprains and muscle strains) in football players. The programme includes exercises that are designed to activate neuromuscular pathways through several carefully chosen movements (Bizzini et al., 2013; Soligard et al., 2008). A small section of the original Fifa 11+ protocol included football specific drills and these were deemed irrelevant as the participants included within this study partake in court sports. The irrelevant drills were therefore removed from the protocol and replaced with alternative exercises to increase the opportunity for neuromuscular

improvements specific to the sports involved (Benis et al., 2015; Bonato et al., 2018). Prior to beginning the training programme, the participants were provided with a familiarisation session to allow them to become accustomed to the training protocol. The participants were also handed a print out of neuromuscular training protocol which included a description of each exercise and how to perform the exercises correctly, it also included the progressions for each exercise. The adapted version of the Fifa 11+ protocol performed by the intervention group can be observed in table 4. Images of the less conventional exercises can be found in the Appendix A (pg. 60-61).

TABLE 4. ADAPTED VERSION OF FIFA 11+ PROTOCOL (SOLIGARD ET AL., 2008) PERFORMED BY THE INTERVENTION GROUP

Exercise and section	Sets and repetitions
Warm up (cones 10 metres apart) <ul style="list-style-type: none"> • Straight ahead • Hip out • Hip in • Circle partner • Single leg bounding (added from main work out section) • Quick forwards and backwards 	All exercises are to be performed 2 x in the allocated area
Main workout <ul style="list-style-type: none"> • Plank (3 levels of difficulty) • Side plank (3 levels of difficulty) • Nordic curls (3 levels of difficulty) • Test your partners balance (single leg) (football removed) • Box jumps (3 different heights) (replaced for jumps) • Inline lunges (3 levels of difficulty) • Depth jumps (3 different heights) (added) • Running and cutting (3 different levels of difficulty) 	1 min rest between each set and exercise <ul style="list-style-type: none"> • 2 x 60 seconds • 2 x 60 seconds (each side) • 3 x 6, 8, 10 • 3 x 60 seconds (each leg) • 2x30 seconds • 2 x 16 (each leg) • 2 x 6 • 2 sets within 10 metre space
Cool down (added)	Full body static stretch

The participants performed the intervention twice per week over an eight-week period. All sessions were delivered and overviewed by an investigator who was a Register of Exercise

Professionals level three qualified personal trainer. The investigator ensured all participants were performing the correct techniques for each exercise and had the duty of assessing whether participants could increase the difficulty of the exercises. All participants began each exercise of the training protocol at level one, progressions for an individual were not considered until their participation of the third session. It took the participants approximately 35 minutes to complete the training programme. The participants were allowed a minimum of a day's rest and a maximum of two day's rest before completing the programme a second time within seven days.

3.5 CONTROL GROUP

During the eight-week period the control group were asked to continue with their habitual training regimes within their respective sports. The control and intervention group participants trained on average once a week, in addition participants from both groups competed once a week. The only difference between the groups was the addition of the two FIFA 11+ sessions for the intervention group.

3.6 STATISTICAL ANALYSIS

Results are presented as mean (\pm standard deviation) unless stated. A 2 (Control vs. Intervention) x 2 (Pre vs. Post – within subjects) mixed ANOVA was performed using the IBM SPSS statistic version 22 to determine any significant differences between the two groups (control vs intervention) performance measurements (20 m sprint, CMJ, Illinois agility test and QASLS) after eight weeks. Statistical difference was determined at $P < 0.05$. Assumptions of sphericity were assessed using Mauchly's test of sphericity. Where a significant main effect existed a post-hoc pairwise comparison was conducted using the Bonferroni correction. Within effect size of intervention and control groups pre to post results was calculated using Cohen's D. The Cohen's D levels of significant were determined as 0.1= trivial, 0.2 = small, 0.5 = medium and 0.8 = large.

4.0 RESULTS

The two-way ANOVA test demonstrated significant differences in trial x group interaction in the CMJ and the QASLS for both the right and left leg. Pairwise comparisons demonstrated within-group significant improvements for the intervention group in CMJ height, 20 m sprint and QASLS scores for both legs pre to post. The comparison tests also demonstrated the interventions groups post CMJ and QASLS results significantly differed from the control groups results post eight weeks. Table 5 outlines group means and standard deviations for all pre and post measurements.

TABLE 5. GROUP MEANS AND STANDARD DEVIATION OF ALL MEASUREMENTS (\pm) FOR BOTH PRE AND POST TESTING SESSIONS.

Measurement	CON group		INT group	
	Pre	Post	Pre	Post
20 m (s)	3.78 (\pm 0.23)	3.75 (\pm 0.24)	3.63 (\pm 0.24)#	3.55 (\pm 0.17)#
Illinois Agility (s)	18.36 (\pm 1.24)	18.38 (\pm 1.37)	17.40 (\pm 0.69)	17.28 (\pm 0.67)
CMJ (cm)	39.90 (\pm 5.16)	38.21 (\pm 4.81)+	40.83 (\pm 3.63)#	44.99 (\pm 4.40)#+
QASLS RL (1-10 rating scale)	4.11 (\pm 1.21)	4.08 (\pm 1.24)+	3.75 (\pm 1.51)#	1.91 (\pm 1.05)#+
QASLS LL (1-10 rating scale)	4.05 (\pm 1.54)	4.23 (\pm 1.62)+	3.72 (\pm 1.34)#	0.98(\pm 0.94)#+

#= Post hoc pairwise comparisons showed the intervention group demonstrated significant within improvements for Sprint times, CMJ jump and QASLS scores for both legs pre to post. += Post hoc pairwise comparisons also revealed the intervention post CMJ and QASLS (both legs) results significantly differed from the control groups results.

4.1 COUNTER MOVEMENT- JUMP

The two way ANOVA demonstrated post eight-weeks a significant trial x group interaction between the control and intervention groups CMJ heights was apparent ($F(1, 18) = 34.53, P = 0.0001$) (see figure 5 for mean group changes in CMJ between conditions). Pairwise comparisons revealed that the intervention group increased their height significantly from pre to post ($P = 0.0003$), whereas the control group experienced a significant decrease in CMJ height ($P = 0.028$). Cohen's effect size value suggested a 'large' practical effect ($d = 1.03$) for the intervention groups pre to post CMJ heights. Although the control group demonstrated a significant reduction in CMJ height, the Cohen's effect size value for their pre to post CMJ scores was considered to be of small practical significance ($d = 0.33$). During the pre-test the control and intervention groups CMJ heights did not significantly differ ($P = 0.652$), however in the post test CMJ significantly differed between the intervention and control group ($P = 0.004$). On average the intervention group increased their CMJ height by 9.7% whereas the control group demonstrated a reduction in their CMJ by 2.8%.

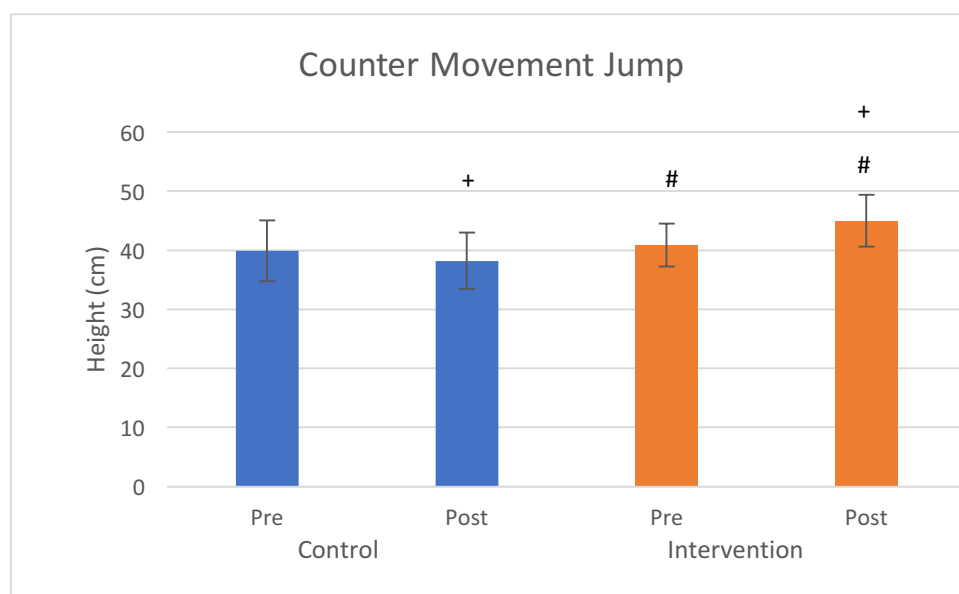


FIGURE 5. MEAN GROUP CHANGE FROM BASELINE FOR CMJ COMPLETION BETWEEN CONDITIONS. # INDICATES A SIGNIFICANT WITHIN GROUP CHANGE AND + INDICATES A SIGNIFICANT DIFFERENCE BETWEEN THE CONTROL AND INTERVENTION GROUPS POST RESULTS

4.2 QASLS

Post eight weeks the two way ANOVA demonstrated a significant trial x group interaction between the control and intervention groups QASLS right leg scores ($F(1, 18) = 13.88, P = 0.002$) and left leg scores ($F(1, 18) = 50, P = .000001$) (see figure 6 and 7 for mean group changes in QASLS scores between conditions for right and left leg). The pairwise comparisons showed that the intervention group reduced their RL and LL QASLS scores significantly from pre to post ($P = 0.001$ and $P = 0.00002$, respectively), the control group scores were unchanged (RL $P = 0.931$, LL $P = 0.545$). Cohen's effect size value suggested a large practical significance (RL $d = 1.41$, LL $d = 2.36$) for the intervention groups pre to post QASLS scores for both legs, the control groups Cohen's effect size value for their pre to post QASLS scores was considered to be a trivial practical significance for both legs (RL $d = 0.02$, LL $d = 0.11$). The pre tests for the intervention and control groups QASLS scores for the RL and LL did not significantly differ ($P = 0.565$ and $P = 0.617$, respectively), however in the post test QASLS scores for both the RL and LL significantly differed between the two groups ($P = 0.001$ and $P = 0.00003$, respectively). On average the intervention group decreased their QASLS score on their left leg by 2.74 (117%) and their right leg by 1.84 (65%). The control group increased their overall score on their left leg by 0.18 (4.3%) and decreased their score on the right leg by 0.03 (0.7%).

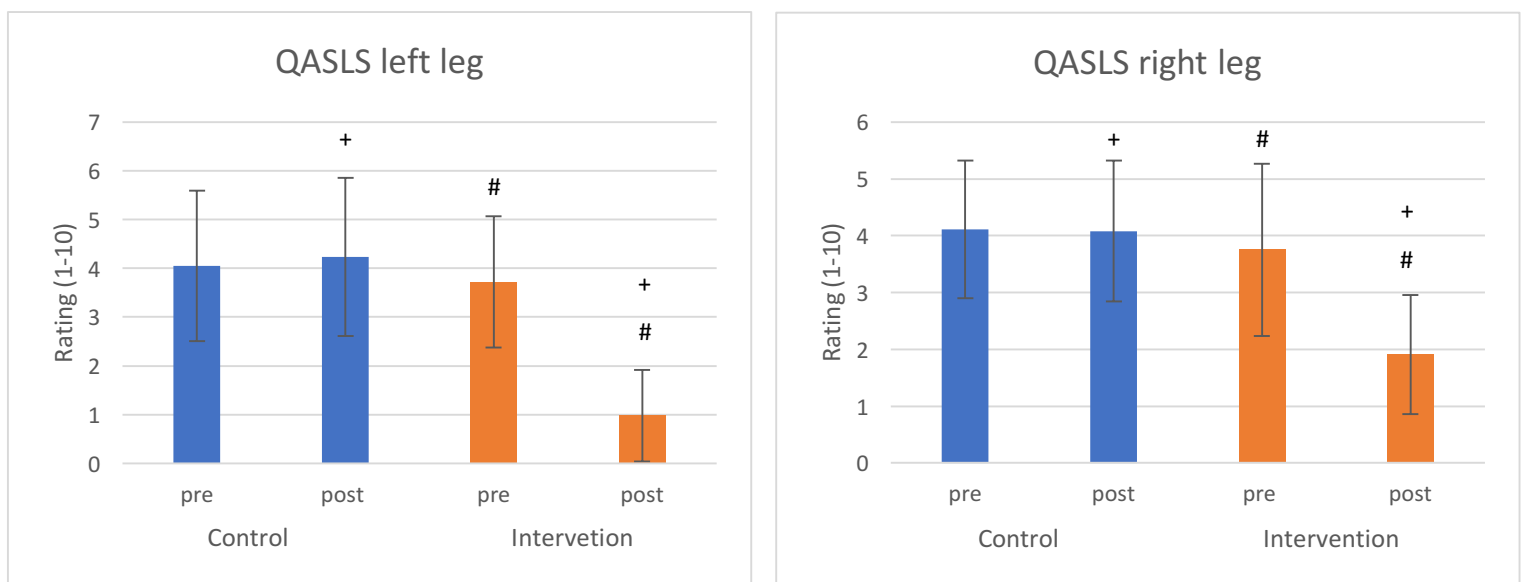


FIGURE 6 AND FIGURE 7. MEAN GROUP CHANGES FROM BASELINE TO COMPLETION FOR QASLS SCORES ON BOTH LEGS BETWEEN CONDITIONS. # INDICATES A SIGNIFICANT WITHIN GROUP CHANGE AND + INDICATES A SIGNIFICANT DIFFERENCE BETWEEN THE CONTROL AND INTERVENTION GROUPS POST RESULTS.

4.3 20 M SPRINT

The two way ANOVA revealed no significant trial x group interaction between the intervention and control groups sprint times post eight weeks ($F(1, 18) = 1.06, P = 0.316$) (see figure 8 for mean group changes in 20m sprint time between conditions). The post hoc tests showed the intervention significantly reduced their 20 m sprint time pre to post ($P = 0.024$), the control group did not ($P = 0.104$). Cohen's effect size value suggested a small to moderate practical significance ($d = 0.38$) for the intervention groups pre to post sprint times, the control groups Cohen's effect size value for their pre to post sprint times was considered to be of a trivial practical significance ($d = 0.12$). The pre and post tests comparison between the intervention and control groups sprint times did not significantly differ from one and other ($P = 0.192$ and 0.056 , respectively). The control group reduced their sprint times by 0.03 seconds (0.8%) and the intervention group experienced a 0.08 second (2.2%) mean decrease.

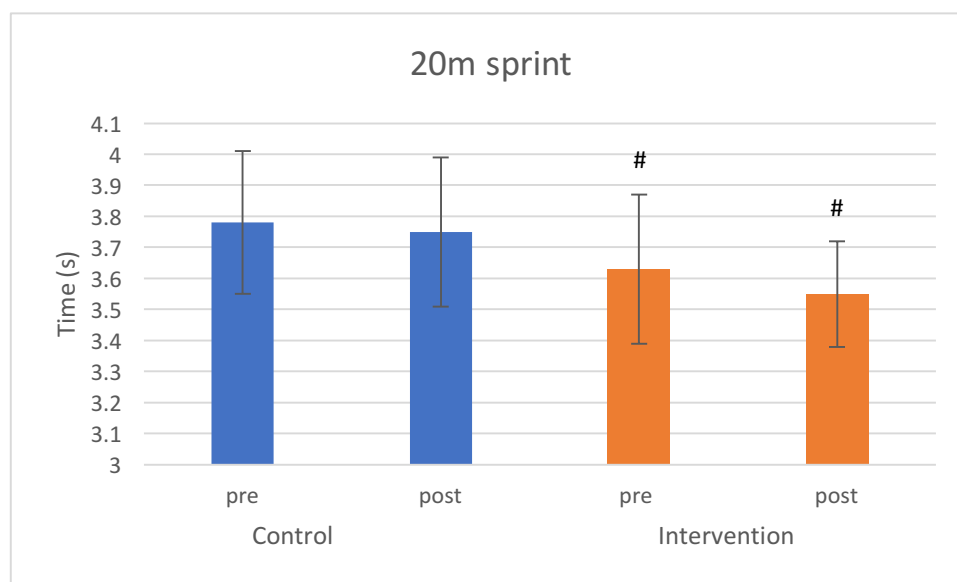


FIGURE 8. MEAN GROUP CHANGE FROM BASELINE FOR 20M SPRINT COMPLETION BETWEEN CONDITIONS.

4.4 ILLINOIS AGILITY TEST

No significant trial x group interaction between the two groups agility times post eight weeks was found ($F(1, 18) = .91, P < 0.354$). The post hoc comparisons showed the intervention ($P = 0.275$) and control ($P = 0.865$) group did not significantly reduce their agility times from pre to post. Cohen's effect size value suggested a small practical significance ($d = 0.17$) for the

intervention groups pre to post agility times, the control groups Cohen's effect size value for their pre to post agility times was considered to be a trivial to small practical significance ($d = 0.01$). On average the intervention group reduced their Illinois agility times by 0.12 s (0.7%) whereas the control group increased their time by 0.02 s (0.11%).

5.0 DISCUSSION

5.1 STUDY AIMS AND KEY FINDINGS

This study was designed to investigate if a revised Fifa 11+ neuromuscular training protocol increased performance indicators and reduced the risk of ACL injuries in female court sport athletes when performed two times a week over an eight-week period. The results demonstrate the Fifa 11+ protocol significantly increased CMJ height and reduced QASLS scores indicating a reduced risk of ACL injuries when compared to the control group outcomes. The post hoc tests also suggested significant within improvements for the intervention group's CMJ, QASLS and 20 m sprint times. No significant difference was found between the control and intervention group for 20 m sprint and Illinois agility.

Previous studies have demonstrated neuromuscular training programmes can improve performance indicators such as sprint time, lower body power, agility, and proprioception as well as reduce the risk of ACL injuries in females (Owoeye et al., 2014; Steffen et al., 2008). Although neuromuscular training programmes have demonstrated the aforementioned beneficial effects, there is an apparent lack of research focusing on reducing the risk of ACL injuries in female court sport athletes through the implementation of a neuromuscular training programme, the aim of this study was to investigate this specific area.

5.2 CMJ

Post eight weeks the intervention group significantly increased their CMJ in comparison to the control group. Post hoc comparisons also demonstrated a significant increase within the intervention groups CMJ height pre to post, along with a large practical effect. The pre-tests between the control and intervention groups CMJ heights did not significantly differ, however in the post test CMJ significantly differed between the intervention and control group. On average the intervention group increased their CMJ height by 9.7% whereas the control group demonstrated a reduction in their CMJ by 2.8%. This study included exercises such as box jump and depth jumps which are designed to elicit increases in lower body power (Hernandez et al., 2018; Pensini et al., 2002).

There are several potential reasons why the CMJ height increased significantly within the intervention group; the neuromuscular training programme used within this study included

exercises such as planks, nordic curls, unilateral balancing and bounding runs. Previous studies have highlighted the positive relationship between increased neuromuscular activity within the core, hip and leg muscles all of which contribute towards the efficiency of a CMJ (Akbari et al., 2017; Benis et al., 2016). Although the previously mentioned exercises may assist in increasing CMJ height the movement specific exercises included in the intervention group programme such as depth jumps and box jumps are more likely to be the reason why CMJ height significantly increased (Hernandez et al., 2018). These exercises are considered plyometric in nature (Gjinovci et al., 2017) and this form of training can elicit neural adaptations within the motor unit, meaning the participants within the intervention group may have improved the firing rates of fast twitch muscles through bypassing the size principle (Zatsiorsky et al., 2006). Plyometric based exercises are also considered to increase power output due to one's ability to utilise the energy within elastic components and the stimulation of the stretch reflex with the muscles spindles (stretch shorting cycle) (Gjinovci et al., 2017).

Previous routines including exercises such as box jumps and depth jumps have also yielded similar results to this study, for example a study conducted by Hernandez et al. (2018) discovered significant increases in male basketball players CMJ heights ($P = 0.05$) when incorporating a plyometric jumping programme twice a week over a seven-week period. The Hernandez et al. (2018) study is of interest as the experimental group completed exercises such as drop jumps, bounding exercises and box jumps all of which were implemented into this study. Another relevant study by Hermassi et al. (2015) recruited 24 male handball players and randomly assigned the participants either to the control group or intervention group. The intervention group performed a training programme which included plyometric exercises such as drop jumps, biweekly over an eight-week period. Post eight weeks the intervention groups CMJ height significantly increased in comparison to the control group ($P = 0.01$). Hermassi et al. (2015) speculated the increase in CMJ height may have been due to neuromuscular adaptations and one's ability to overcome the amortization phase of CMJ which in turn allows an individual to utilise the energy provided by the stretch shorting cycle (Gjinovci et al., 2017). These studies rationalise why the intervention group yielded a significant increase their CMJ height as the exercises used within the neuromuscular training programme were identical to those included the reviewed studies (Hermassi et al., 2015; Hernandez et al., 2018).

As discussed, neuromuscular training programmes including plyometric exercises have shown to increase CMJ, moreover, a highly relevant study composed by Bonato et al. (2018) used the

content from the Fifa 11+ programme to create an almost identical neuromuscular training programme. Participants were required to perform the programme four times a week over a basketball season, the control group also performed their routine four times a week which included light aerobic exercises, basketball drills and dynamic stretching. CMJ was recorded pre and post season, it was concluded CMJ height significantly increased within the intervention group compared to the control group ($P = 0.004$). Bonato et al. (2018) speculated an increase in postural control due to performing the neuromuscular training programme may have attributed toward a significant increase in the intervention groups CMJ height. Rossler et al. (2016) also found significant improvements in CMJ height ($P = 0.03$) in comparison to the control group after the intervention group performed the Fifa 11+ training programme twice week for 10 weeks. Another study which yielded similar results was conducted by Akbari et al. (2017) who observed how the Fifa 11+ training programme affected vertical jump performance. Akbari et al. (2017) had their participants perform the Fifa 11+ training three times a week over an eight week period. After this experimental period, vertical jump height had significantly increased ($P = 0.002$) for the Fifa 11+ group (pre 45.33 ± 5.06 cm vs post 51.00 ± 4.95 cm) in comparison to the control group (pre 44.25 ± 4.78 cm vs post 44.58 ± 3.75 cm).

As previously discussed there are several potential reasons why CMJ height increased within the intervention group. However, these results provide compelling evidence that a slightly revised version of the Fifa 11+ training programme improves desirable physical attributes needed to perform court sports such as jump height (Phomsoupha et al., 2015; Junior et al., 2017; Cosmin et al., 2016).

5.3 QSALS

With the use of the QASLS test this study indicated a significant reduction in the risk of ACL injuries in female court sport athletes for both the right and left ACL. On average the intervention group decreased their QASLS score on their left leg by 2.74 (117%) and their right leg by 1.84 (65%). The control group increased their overall score on their left leg by 0.18 (4.3%) and decreased their score on the right leg by 0.03 (0.7%). The post hoc pairwise comparisons showed that the intervention group reduced their RL and LL QASLS scores significantly from pre to post. The Cohen's effect size value suggested a large practical

significance for the intervention groups pre to post QASLS scores for both legs. The pre-tests for the intervention and control groups QASLS scores for the RL and LL did not significantly differ, however in the post test QASLS scores for both the RL and LL significantly differed between the two groups. These findings correspond with other studies regarding the benefit of neuromuscular training programme for reducing the markers of ACL risk injuries in females (Hewett et al., 2016; Silvers-Granellie et al., 2015; Zazulak et al., 2007). The QASLS test was chosen to assess the participants' risk of an ACL injury as it has demonstrated strong reliability for assessing limb and trunk alignment when compared to 3D motion capture (Herrington and Munro, 2014).

The training protocol used within this study included exercises designed to elicit neural adaptations between the motor cortex and the targeted muscle (Pensini et al., 2002). The revised Fifa 11+ protocol was designed to activate the following muscles: piriformis; superior and inferior gemelli; obturator internus / externus and the quadratus femoris; hamstrings and quadriceps. Nguyen et al. (2017) found female athletes often fail to recruit the muscles targeted by the intervention programme which in turn cause misalignments in the lower body. Subsequently this places a significant amount of pressure on the ACL and its ability to prevent anterior tibial subluxation, a common cause of ACL rupture (Gabriel et al., 2004; Silvers, 2009). This study included exercises specially chosen by Santa Monica Sports Medicine Foundation and the Oslo Trauma and Research Centre (i.e. nordic curls, unilateral balancing, box jumps, inline lunges and depth jumps) with the intentions of recruiting the aforementioned muscle groups responsible for protecting the integrity of the knee (Silvers-Granellie et al., 2015).

In agreement with Bonto et al. (2018) and Soligard et al. (2008) this study provides supporting evidence for the chronic use of a neuromuscular training programme to improve lower body alignment due to potential neural adaptations. A study conducted by Zebis et al. (2008) analysed twelve female football players and eight female handball player's neuromuscular activity at the knee joint whilst performing a side cutting manoeuvre before and after a full season. During the season (eighteen weeks) the participants performed an adapted version of the Fifa 11+ training programme twice a week. Post eighteen weeks the EMG activity within the semitendinosus muscle significantly increased ($P = 0.01$) during the cutting manoeuvre which prevented the knee moving into a valgus position, reducing the risk of ACL injuries. Another study which yielded similar results was conducted by Reis et al. (2013), participants

were required to perform the Fifa 11+ programme twice a week over a 12 week period. Isokinetic testing demonstrated significant increases pre to post ($P = 0.05$) in the hamstring muscle. The increase in neuromuscular activity within the hamstring is deemed essential for preventing the knee falling into a valgus position and increasing the risk of ACL injury (Hewett et al., 2016; Zazulak et al., 2007). These studies clearly demonstrate the Fifa 11+ training programme or slightly amended version increased the activity in favourable muscle groups which protect the ACL by ensuring lower limb alignment, this offers a convincing explanation why improvements in the QASLS scores were found for the intervention group.

In addition to measuring lower limb alignment the QASLS test also assess a person's ability to maintain trunk alignment (Herrington and Munro, 2014) as it has been demonstrated that females have a decreased ability to maintain trunk alignment compared to males during sporting movements (Hewett et al., 2010; Zazulak et al., 2007). Previous studies have demonstrated increases in core strength due to the inclusion of identical exercises (Benis et al., 2016; Bonto et al., 2018; Soligard et al., 2008) used within this study. This evidence supports the claim that an increase in core strength within the intervention group may have also contributed towards the improvements within the intervention group's pre-post QASLS test results due to an increased ability to maintain trunk alignment. A study conducted by Caraffa et al. (1996) supporting this study had 300 male football players complete similar balancing exercises included within this study over a football season and found a significant decrease in ACL injuries ($P = 0.001$). Another study proving the effectiveness of core / balancing exercises was conducted by Wedderkopp et al. (2003), this study included 16 female handball teams (163 participants). 88 players performed standardised strengthening exercises whilst the intervention group completed a programme which had a combination of strengthening exercises and balance training. Both training programmes were performed over a season, injury incidences were also recorded. Injury incidences within the control group were recorded at 6.9 per 1000 playing hours whereas the intervention group significantly reduced theirs in comparison ($P = 0.044$) to 2.4 injuries per 1000 playing hours. The neuromuscular training programme used in this study included exercises such as planks, side planks and unilateral balance exercises all of which were imbedded within the Caraffa et al. (1996) and Wedderkopp studies.

5.4 20 M SPRINT

No significant differences between the control and intervention group were discovered post eight-week study period. A significant within reduction in 20 m sprint times pre to post for the intervention group was apparent, the Cohen's D effect size suggested a small to moderate practical significance for the interventions pre to post sprint times. Both the intervention and control group experienced marginal reductions in 20 m sprint times post eight weeks. The control group reduced their sprint times by 0.03 seconds (0.8%) and the intervention group experienced a 0.08 second (2.2%) mean decrease.

Similar to this study others have found the Fifa 11+ protocol or similar training programmes to be adequate for improving sprint performance; Kilding et al. (2008) found significant decreases in male football players 20 m sprint ($P = 0.05$). After performing the Fifa 11 training programme for six weeks participants reduced their 20 m sprint times by 2% when compared to their pre tests. However, it is important to note the participants performing the Fifa 11 training programme did so five times a week which increased the intensity and number of times performing the training programme in comparison to other studies (Palazon et al., 2016; Steffen et al., 2008). A study by Reis et al. (2013) yielded similar results and found significant improvements in the 30m (-3.3% reduction) sprint times for the intervention group who performed the Fifa 11+ training programme two times a week over a 12 period ($P = 0.05$). The enhancements in sprint performance for the participants in the previously mentioned studies and this study may have been due to improvements within the motor neurons and their ability excite certain or an increased number of muscle fibres needed to improve sprint mechanics and power output (Gamble, 2013; Pensini et al., 2002).

Not all studies have found the Fifa 11+ protocol an effective training regime for improving sprint performance. For example Palazon et al. (2016) measured whether any chronic physical benefits were elicited through having participants complete the Fifa 11+ three times a week over a four-week period. One performance indicator measured by Palazon and colleagues (2016) was 20 m sprint time. After the four-week period 20 m sprint had not significantly increased within the Fifa 11+ group when compared to the control group ($P > 0.05$). Palazon et al. (2016) stipulated within their paper that the lack of improvements may have been due to the short training stimuli period however, this is in contrast to findings from Steffen et al. (2008). Steffen et al. (2008) had their participants complete an almost identical training programme to that of the Fifa 11+ three times a week over a ten-week period. Post 10 weeks

no statistical differences between the intervention and control group 40 m sprint time was found ($P = 0.53$). Although no significant interaction was discovered between the control and intervention group, and the Cohen's D effect size suggested only a small to moderate practical significant difference between the interventions pre to post sprint times, a significant within improvement for the interventions sprint times was discovered. Taking this study and other pieces of evidence into consideration the Fifa 11+ or a slightly amended version of the programme (Soligard et al., 2018; Benis et al., 2016; Bonato et al., 2018) can be considered a useful tool to maintain or reduce 20 m sprint times in court sport athletes.

It is worth noting the distance of the training area may be a reason why 20 m sprint times did not significantly differ between the two groups (Reis et al., 2013). In this study the intervention group performed the neuromuscular intervention indoors to prevent the risk of adverse weather conditions affecting participant retention. The indoor area used to perform the adapted Fifa 11+ training programme was approximately 25 m in length, and to ensure participants safety the training area for the running exercises was kept at a 10 m distance to give enough room for deceleration between the end of the exercise area and the wall. The original Fifa 11+ programme (Owoeye et al., 2014; Soligard et al., 2008) requires players to perform the running aspect of the routine over a 25 m distance, this distance is without doubt considered a more relevant interval than 10 m to provoke an improvement in 20 m sprint times (Bizzini et al., 2013). However, the rationale for choosing a 10 m space to perform the running aspect performed by the intervention group was inspired by Kilding et al. (2008) paper who had their participants perform the running aspect of the Fifa 11 routine over a 10 m distance yet still recorded significant reductions in 20 m sprint times.

5.5 AGILITY

No significant differences between the intervention and control groups sprint times or agility post eight weeks was discovered. Cohen's effect size value suggested a small practical significance. for the intervention groups pre to post agility times, the control groups Cohen's effect size value for their pre to post agility times was considered to be a trivial practical significance. Small numerical differences were found between the two groups; on average the intervention group reduced their Illinois agility times by 0.12 s (0.7%) whereas the control group increased their time by 0.02 s (0.11%).

Kilding et al. (2008) study also used the Illinois agility test to measure if the Fifa 11 training programme improved agility in their male football participants. No improvements in Illinois agility times were apparent ($P = 0.275$) post six weeks. The Kilding et al. (2008) study did find insignificant differences between the intervention and control group; post six weeks the control group reduced their agility times by 0.6% whereas the intervention group reduced their times by 2%. These findings correspond with this study as the agility times within the intervention group decreased more so on average in comparison to the control group (see table 5). Steffen et al. (2008) also assessed the effects a 10 week Fifa 11 training programme had on agility. The intervention group performed the Fifa 11 routine three times a week whilst the control group performed football based running drills. Post 10 weeks no significant differences in the control and intervention groups agility times were apparent ($P = 0.75$ and $P = 0.91$). Steffen and colleague (2008) recognised the post testing may have been a limitation to their study, the tests were conducted four weeks after the competitive season and this may have affected their physical condition.

Although no significant differences in agility times were apparent between the intervention and control group, as alluded to previously the intervention group did reduce their agility sprint times on average more so than the control group. Taking this study into consideration the slightly amended Fifa 11+ programme can be considered an effective neuromuscular regime in reducing agility times. It is also important to note studies have previously been published demonstrating a significant improvement in agility performance after performing the Fifa 11 and 11+ protocol (Impellizzeri et al, 2013., Steffen et al., 2008). A study conducted by Rossler et al. (2016) observed whether performing the Fifa 11+ programme twice weekly for 10 weeks improved certain performance measurements, including agility. Post 10 weeks the intervention group significantly improved their agility performance in comparison to the control group ($P = 0.008$). The participants included with the Rossler et al. (2016) study were aged between 7-12. It is well documented neuromuscular adaptations are more likely to take place in children in comparison to adults after performing a neuromuscular training programme (Rossler et al., 2016; Haapala et al, 2016), this may be a reason why the participants in the Rossler et al. (2016) study significantly increased their agility scores. However, the Fifa 11+ and 11 training programme hasn't only significantly improved agility in adolescents as demonstrated in a meta-analysis conducted by Gomes Neto et al. (2016) who analysed eleven Fifa 11 studies, including 4700 participants most of whom were adults. Once all studies included within the review were analysed Gomes Neto et al. (2016) discovered significant improvements in participant's agility

times ($P = 0.04$) and concluded the Fifa 11 can be considered an effective tool for improving performance measurements such as agility.

5.6 ADHERENCE RATES

The retention of participants within this study may be another reason why the intervention group successfully reduced their risk of ACL injuries and increased performance measurements. In total 90% of the intervention group participants completed all 16 sessions. Participant adherence for neuromuscular training programmes which are relatively short in duration such as the one implemented within this study (approximately 35 minutes to complete), is essential for achieving improvements in physical performance and reducing the risk of sport related injuries. A systematic review conducted by Ter Stege et al. (2014) supported this claim and concluded neuromuscular training programmes approximately twenty-five minutes long with compliance rates of 75% significantly reduced the risk of lower extremity injuries. Another study conducted by Steffen et al. (2013) created three different groups to assess how adherence rates of the Fifa 11+ programme affect the risk of injury, participants were either assigned to unsupervised group (control), a group with a coach and physiotherapist (comprehensive) or a group with a coach and no physiotherapist (regular). The comprehensive, regular and control group achieved 85.6%, 81.3% and 73.4% completion of total possible sessions, respectively. After all groups were assessed using the Star Excursion Balance Test (SEBT), single-leg balance, triple hop and jumping-over-a-bar test it was concluded the group with the highest completion rate were at a 57% reduced risk of suffering an ACL injury due to the improvements in functional balance.

In contrast to the studies which achieved high compliance rates a paper by Steffen et al. (2008) found no significant differences in injury incidences over an eight month period between the intervention group who completed the Fifa 11 programme and the control group ($P = 0.94$). The authors of this study stated only 52% of the participants within the intervention group completed the required number of sessions. Subsequently Steffen and colleagues (2008) believed the reason injury incidences did not significantly differ between the two groups was due to low compliance rates. Taking these pieces of research into consideration, it is justified to suggest the high compliance rates of the participants performing the neuromuscular training

programme in this study may have contributed towards the positive changes in performance and injury risk measurements in comparison to the control group.

5.7 PRACTICAL APPLICATIONS

This study provides evidence to support the use of neuromuscular training programmes in the reduction of ACL injuries in female court sport athletes. This study and previous studies have also demonstrated the effectiveness and reliability of the QASLS scoring system for highlighting limb and trunk misalignments (Almangoush et al., 2014; Herrington and Munro, 2014) The QASLS scoring scale is considered a cost effective and time saving method of indirectly assessing an individual's risk of an ACL injury (Crossley et al., 2011; Onate et al., 2010) making it a practical and realistic way for coaches, strength and conditioners to assess their athletes risk of a ACL injury.

Not only did the neuromuscular training programme result in lower QASLS scores it also significantly improved the participants CMJ height and 20 m sprint performance. As previously mentioned the training programme performed by the intervention was a slightly amended version of the Fifa 11+ routine, to perform this programme minimal equipment is required, it can be performed in thirty minutes and each exercise includes progressions and regression to ensure inclusion for all who decide to partake (Owoeye et al., 2014; Soligard et al., 2008). However, no significant differences were observed within either groups agility performance post eight weeks. Taking this into consideration a slightly amended Fifa 11+ programme performed twice a week can be considered an appropriate neuromuscular training to induce improvements in certain performance indicators as well as reduce the risk of ACL injuries in female court sport athletes. Strength and conditioning specialists should therefore explore the use of neuromuscular training programmes in sports such as court based sports which have a high prevalence of ACL injury especially in female populations.

The Fifa 11+ training programme has often been completed as a warm up within studies (Palazon et al., 2016; Steffen et al., 2008) however, this research demonstrates the Fifa 11+ programme does not have to be performed as a warm up routine alone, it can also be performed as a separate strength and conditioning session. Considering the Fifa 11+ routine requires minimal equipment to perform and since not all sporting/athletics clubs possess exercise

equipment, coaches may find the Fifa 11+ routine a pragmatic and realistic tool to increase performance and reduce the risk of ACL injuries in a multitude of different athletes.

5.8 FUTURE RESEARCH

Research into the prevalence of female ACL injuries in court sports is still limited and therefore there is scope to expand and extend the findings of this study to provide further evidence to support its use. In addition, studies have examined injury incidences in court sport athletes (Bahr and Reeser, 2003; López González et al., 2017; Shariff et al., 2009) and stipulated which part of the body was injured when playing a court sport e.g. the knee. However, few studies researching the injury incidences in female court sports athletes tend to record what type of knee injury was sustained, such as an ACL injury. More pieces of research detailing the type of injury sustained at the specific body region, for example the knee, may highlight further the prevalence of ACL injuries in court sports. This would rationalise the demand for preventative measures to reduce the risk of ACL injuries, such as neuromuscular training programmes.

As stipulated earlier in the paper, the neuromuscular training programme used within this study was a slightly revised Fifa 11+ protocol. Research comparing the effectiveness of the training programme used within this study and the original fifa 11+ protocol would help justify whether the amendments made to the original Fifa 11+ protocol was necessary. If this topic was to be researched additional performance indicators should be measured such as electromyography and isokinetic dynamometry of the hamstring and quadriceps in order to give a definitive answer on the effectiveness of the revised Fifa 11+ training programme.

5.9 LIMITATIONS OF THE STUDY

Participants from this study performed in the BUCS leagues for their chosen sport, the athletes who take part in this league play at different levels and have varying years of playing experience which can affect one's physical capabilities. Taking this into consideration the researcher was concerned about the possibility of large discrepancies between the participant's physical performance measurements. This in turn can affect the credibility of data gathered at baseline and post study. The variance in playing years and level of performance can have a profound effect on post-performance measurements. If a participant hasn't been subjected to a

neuromuscular training regime as frequently as others prior to the commencement of taking part in a structured neuromuscular training programme motor performance is more likely to significantly increase (Bonato et al., 2018). Although difference in performance measurements were apparent between the participants within this study it did not seem to affect the post results and therefore the studies credibility.

Participants in the control group were asked to continue with their normal training regimes. The author of this paper noted how frequent each participant trained in attempted to ensure participants in the control group did not perform an advantageous amount of training. It was a concern of the author that some control group participants may be disingenuous and take part in additional training. It appeared that the control group participants did not perform an advantageous amount of training and the results provide strong evidence that the changes were due to neuromuscular training performed by the intervention group.

5.10 CONCLUSION

This aim of this study was to investigate if a revised Fifa 11+ neuromuscular training protocol increased performance indicators and reduced the risk of ACL injuries in female court sport athletes when performed twice a week for eight weeks.

Most noteworthy the modified Fifa 11+ programme proved effective in significantly reducing QASLS scores which in turn indicates a reduction in the risk of ACL injuries. Taking into account that females are up to eight times more likely to suffer an ACL injury in comparison to men (Elliot et al., 2010; Mall et al., 2014), and that the sporting movements performed by court sport athletes during performance can contribute further to the risk of an ACL injury (Cosmin et al., 2016; James et al., 2014), preventative regimes such as the Fifa 11+ programme can be performed twice a week over an eight week period to help combat the high prevalence of ACL injuries in female athletes. The neuromuscular training programme also proved to significantly increase CMJ height in comparison to the control group and lead to a within-group improvement in 20 m sprint for the intervention group. This demonstrated the Fifa 11+ training programme can be used for improving a desirable physical attribute for court sport athletes such as lower body power. No significant improvements in the other performance indicators between the intervention and control group post eight weeks were found however.

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7.0 APPENDICES

Appendix A Exercises included with the neuromuscular training programme

Straight ahead



Hip out



Hip in



Circle partner



Single leg bounds



Test partners balance



Running and cutting

