The Effect of a School Based Sports Injury Prevention Program in Youth Females

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Abstract

Sport is the leading cause of injury in youth, with the lower extremity being the most common injury location. Additionally, more injuries occur during the period of peak growth and maturation and are more prominent in females compared to males. In order to reduce injury risk, injury prevention (IP) programs have been developed and successfully implemented in youth. However, there is limited research specifically targeted at youth females, including what components of an IP program are most beneficial in this group. The overall purpose of this thesis was to examine the effects of an IP program embedded in the school curriculum on injury risk factors, injury rates and athletic performance measures in youth females. Additionally, there was a focus on better describing injuries in this population, possible association between injury and the phases of the menstrual cycle, and the role strength plays in performance.

To better understand the rate of injuries in this population and to see if an association existed between injuries and phase of the menstrual cycle, an online questionnaire (using an all physical problem definition of injury) was used to record training and competition exposure and self-reported injuries over 30 weeks. On average, girls trained 3.4 hours/week and competed for one hour/week. During the study, 74 participants reported 595 injuries. The average weekly prevalence of all injuries was 20.7% (95% CI: 20.0-21.3), of which 8.6% (95% CI: 8.3-9.0) were acute injuries and 12.0% (95% CI: 11.4-12.6) were gradual onset/overuse injuries. The overall rate of sport and PE injuries was 10.4 injuries/1000 hours of exposure. The most common acute injury involved the ankle (35%), whereas the most common gradual onset/overuse injury involved the knee (51%). There was no significant association between the stage of the menstrual cycle and the likelihood of injury ($P = 0.18$). There were significant differences between strength groups (strong, average and weak as measured by isometric mid-thigh pull) for all performance measures. Strong girls (SG) had significantly faster sprint times than average girls (AG). Additionally, SG and AG performed significantly better than weak girls in all assessments. The results from both studies demonstrate the need for an IP program targeting the lower extremity.

Finally, the effect of an IP program, integrated into the school curriculum, on injury risk factors and athletic performance measures in youth females was examined [intervention (INT) n = 43, control (CON) n = 49]. The INT group completed a 23 week IP program whereas the CON group continued normal physical education class. The overall adherence to the IP program was 82%. Significant improvements were found in movement skill (approximately 80% more likely to have an improved movement skill as measured by the back squat assessment and drop vertical jump) and balance (as measured by the y-balance) for the INT group compared to the CON group [mean difference (95% CI) = 2.07 cm (0.48 to 3.66 cm) and 2.66 cm (1.03 to 4.29 cm), respectively]. A significant difference was found in weekly training and competition hours with the INT group (who competed at a much higher level of competition) reporting greater sports participation than the CON group (4.15 vs 2.19 training hours and 0.77 vs 0.55 competition hours). There was no significant difference found in any of the injury rates between the two groups.

These findings highlight that a long-term IP program integrated into the school curriculum can improve movement quality and balance in youth females and it may be protective against increased injury risk for youth females competing at higher levels of competition. It is recommended that practitioners implementing this program should ensure good adherence, individual progression and a focus on movement technique.

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"So we say with confidence, 'The Lord is my helper;

I will not be afraid. What can man do to me?'"

Hebrews 13:6

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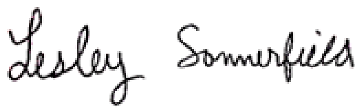
Attestation of Authorship

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



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Lesley Michelle Sommerfield

Co-Authored Works

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Ethics Approval

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Chapter 1 : Introduction

Rationale

Sport and physical activity has many health and physical benefits in youth, such as enhanced functioning of the cardiorespiratory and muscular systems [1], bone mass [2], self-esteem [3], cognitive functioning [4] fundamental movement skills and a lower risk of diabetes and obesity [1]. Additionally, there is evidence that sport participation in youth can lead to a lifetime of involvement in sports and physical activity [5]. Nevertheless, participating in sports comes with risk of injury as many countries have reported that sport is the main cause of injury in children and adolescents [6-10]. Worse, injuries in youth sport can negatively impact present and future participation in physical activity [11, 12]. However, sports injuries in children and adolescents may be reduced by targeting neuromuscular deficits [13]. Given the negative consequences of injuries in youth sport, the development and early implementation of injury prevention programs is crucial.

There is increased risk of injury during the period of rapid growth and maturation in both males and females [14]. Growth refers to the quantifiable change in anthropometrics, body composition, body size, or the size of specific regions of the body, and is a constantly evolving process, whereas maturation refers to the qualitative structural and functional system change towards a mature state and is variable among body systems [15]. The increase in height of the center of mass and body mass seen during the adolescent growth spurt without corresponding neuromuscular adaptations could lead to altered movement patterns and the development of risk factors for injury [16]. This is especially evident during peak height velocity (period of accelerated growth, PHV) which occurs at the age of 11-12 in girls and 13-14 in boys [17]. This period of growth results in biomechanical and neuromuscular differences between the sexes and may contribute to the increased rates of injuries reported in youth females. For instance, high school female athletes have shown significantly greater rates of injury than males [14]. One reason for this could be that the increase in body mass in males is primarily due to gains in skeletal tissue and muscle mass, whereas for females it is primarily due to an increase in fat mass [18]. Additionally, males demonstrate a 'neuromuscular spurt' (increase in strength and power during maturational growth and development) while females do not [16, 19]. Specifically, research has shown that females have only about half as much lower extremity strength development compared to males [20]. This may lead to deficits in neuromuscular abilities and therefore injury [21]. For instance, research shows that males jump higher and suffer smaller landing forces compared to females [19]. Furthermore, multiple studies have shown that throughout maturation females display significantly greater knee abduction moment and motion during drop-jumping compared to males during the later stages of maturation(circa and post-peak height velocity) [16, 22-24]. Research also shows that these kinetics and neuromuscular deficits may contribute to the higher rate of injury in females [25]. Although limited research is available in youth females, developing strength to enhance development during maturation may be beneficial. More research is needed to determine the relationship strength plays in the physical ability of youth females.

The onset of menarche may also affect injury risk in young female athletes. During the menstrual cycle, the levels of progesterone and estrogen hormones fluctuate. The complex interaction of these hormones may play a role in the susceptibility of females to lower extremity injuries [26]. However, studies investigating injury risk during a certain phase of the menstrual cycle are contradictory. For instance, some report that females are at greater risk of injury during the ovulatory phase [26], while others report greater risk during the luteal phase [27, 28]. Moreover, some researchers have found a greater risk of injury during menses in the follicular phase [29]. All the above studies targeted adult female populations, except for one study that also included middle and high school age participants [28]. Unfortunately, this study did not report on the age of participants. Therefore, more research is needed to determine if a link exists between injury risk and the phases of the menstrual cycle in youth females.

The Translating Research into Injury Prevention Practice (TRIPP) model is a framework for developing injury prevention strategies [30]. According to the TRIPP model, prevention strategies can only be developed and implemented (stage 3) after injury surveillance (stage 1) is established and risk factors for injury (stage 2) are identified (Figure 1.1). Risk factors in sport are any factors that may increase the possibility of injury [31]. These factors can be intrinsic or extrinsic and modifiable or non-modifiable [32]. Intrinsic (within the body) risk factors previously reported include sex, hormonal, anatomic [33], neuromuscular and biomechanical factors [34]. Extrinsic (outside the body) risk factors include environmental conditions, level and type of activity, playing surface, rules and equipment [33, 34]. Modifiable risk factors are those that can be altered by injury prevention strategies, while non-modifiable risk factors cannot be altered [31]. Identification of these risk factors, especially intrinsic modifiable factors, will help determine who is most at risk of injury and guide the development of appropriate injury prevention programs.

Figure 1.1: Translating Research into Injury Prevention Practice (TRIPP) theoretical framework (Finch, 2006).

Injury surveillance research has identified that the lower extremity is the most commonly injured area during sport in youth [35]. Although limited, evidence has shown the ankle and knee to be the most common injury sites in youth females [36]. Specifically, in youth female soccer, basketball and gymnastic athletes the ankle, knee, and the thigh are the most common acute injury locations [37]. Although there is consensus about the lower extremity being the most common injury location, there is a lack of consensus about the rates of injuries in youth females. For instance, the rate of injuries in youth female soccer, basketball and gymnastics has been reported as 8.6 injuries per 1000 hours of sports exposure [37]. Alternative evidence suggests injury rates per 1000 hours exposure range from 2.5-10.6 in soccer, 3.6-4.1 in basketball and

0.5-4.1 in gymnastics [25]. The differences between the rates of injuries may be due to the definition of injury used (all injury versus time-loss). Research has shown that time-loss and medical attention injury definitions can underestimate injury rates in youth [38]. Given that many athletes continue to play and train despite having an injury, studies that use a time-loss definition are likely to underestimate the rate of injury [39]. In fact, it has been suggested that an all injury definition can identify more than 10 times as many injuries as a time-loss method [40]. Thus, there is a need for more research using an all injury/physical problem definition in youth females to capture the true rate of injuries in this population.

In response to the growing number of sports injuries in youth, injury prevention (IP) programs have been developed to target risk factors and reduce injury rates and/or improve athletic performance. These IP programs are typically composed of one or more exercise components and executed in sports that demand high rates of contact, jumping/landing, accelerating/decelerating and/or rapid changes of direction as these actions have been linked to injury [41]. Based on the evidence available, IP programs have the potential to improve strength, power and neuromuscular control and reduce muscle imbalances in youth females [42]. Previous research has shown that these benefits can be enhanced with high adherence as well as programs that consist of multiple components progressed based on the ability of the participant [43]. However, most IP programs investigated to date have not been set-up to maximize adherence, individually progressed, acute in nature or included real world implementation. Accordingly, there is a need for the investigation of such programs to better understand their true potential for impacting injury risk in youth females.

Purpose

The overall purpose of this thesis was to examine the effects of an IP program embedded in the school curriculum on injury risk factors, injury rates and athletic performance measures in youth females. Specifically, there were five aims of this thesis:

1. Review the literature related to injury risk factors and injury prevention programs in youth females to help guide practitioners in designing prevention measures.

2. Examine sport and physical education injury rates in youth females during a school year and investigate if an association exists between injury and phase of the menstrual cycle.
3. Examine the relationship between maximum strength and measures of athletic performance and movement skill in youth females.
4. Investigate the effects of an injury prevention program on injury risk factors and athletic performance in youth females.
5. Investigate the effects of an injury prevention program on injury rates in youth females.

Significance of Thesis

Injury prevention programs in youth sport are becoming more popular due to an increased number of injuries, particularly to the lower extremity and with higher rates in girls than boys. Existing research on IP programs has targeted reducing injury risk factors, injury rates and/or athletic performance [42, 44]. However, due to the variety of IP programs currently available in the literature, it may be difficult for practitioners to know what factors make a successful program. This thesis will compare previous IP programs and provide a comprehensive understanding of what makes a successful IP program in youth females. Despite the growing popularity of IP programs, most sport coaches and secondary school physical education teachers do not have the essential knowledge or expertise to design and implement IP programs [45]. Therefore, this thesis will provide a real world example to help guide practitioners, coaches and physical education teachers in the use of an IP program in an all girls' secondary school curriculum.

Previous injury prevention research has focused on reducing risk factors for injury, injury incidence and/or improving athletic performance in youth athletes, but not in combination. Additionally, few studies have focused on girls, most programs have been acute in nature, have not been embedded in the school curriculum, and have not considered maturation or menstruation. Further research is needed investigating evidence-based injury prevention programs in youth females to better understand the potential for modification of risk factors, reduction in injury rates and improvements in athletic performance. This thesis will add to the limited literature by investigating a post-PHV cohort over an academic school year. This thesis could have a substantial influence on practitioners working in a high school setting by providing guidelines and empirical evidence on how to design and implement a successful IP program in a school setting.

Thesis Structure

The thesis is comprised of eight chapters and three main sections (Figure 1.2). The first section contains a comprehensive literature review examining injury risk factors in females and injury prevention programs in youth (chapters 2 and 3). The second section consists of prospective and cross-sectional studies examining the injury rates in youth females and the relationship of strength to performance in youth females (chapters 4 and 5). The final section consists of longitudinal, controlled studies on the injury prevention program (chapters 6 and 7). All chapters except the first, second, seventh and eighth were written in the format of the respective journal to which they were submitted. Chapters 2-7 begin with a preface that explains how each chapter is linked in the larger narrative. Due to the nature of the thesis structure (pathway two, thesis by publication), there may be some repetition between thesis chapters.

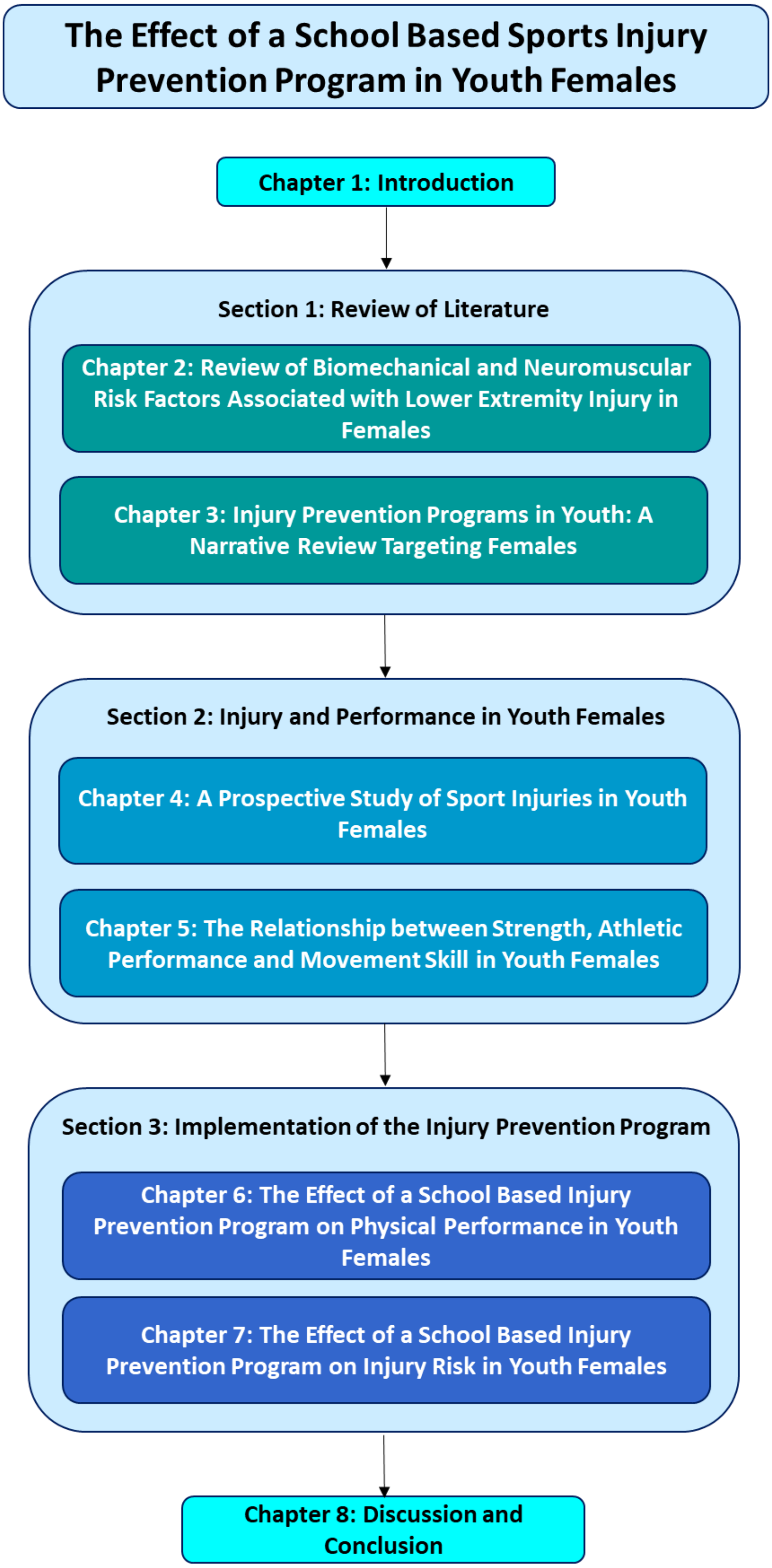

Figure 1.2: Thesis structure.

Chapter 2 : Review of Biomechanical and Neuromuscular Risk Factors Associated with Lower Extremity Injury in Females

Introduction

Sports related injury has been shown to be the primary cause of injury in youth [6-10], with the lower extremity the most commonly injured area [35]. These injuries can negatively impact present and future participation in physical activity and reduce quality of life in adulthood [11, 12]. However, sports related injuries in youth may be reduced using appropriate injury prevention strategies [31]. An understanding of the extent of the problem, who is most at risk, and risk factors for injury must be established before prevention strategies can be implemented [30].

Injury risk factors in sport are any influences that may increase the possibility of injury [31]. These factors can be intrinsic or extrinsic and modifiable or non-modifiable [32]. Intrinsic (within the body) risk factors previously reported include sex, hormonal, anatomic [33], neuromuscular and biomechanical factors [34]. Extrinsic (outside the body) risk factors include environmental conditions, level and type of activity, playing surface, rules and equipment [33, 34]. Modifiable risk factors are those that can be altered by injury prevention strategies, while non-modifiable risk factors cannot be altered [31]. Identification of these risk factors, especially intrinsic modifiable factors, will help determine who is most at risk of injury and guide the development of the most appropriate injury prevention training intervention.

Reviews of injury risk factors in sport typically address individual sports and focus on studies in adult populations [46]. Moreover, the literature around youth sports injury is generally sports-specific. There is a need for further reviews targeting females and youth, with a focus on risk to the lower extremity. Therefore, the purpose of this review is to identify the modifiable biomechanical and neuromuscular risk factors associated with lower extremity injury in females. A narrative approach was used as it not only provides an interpretation and critique of the relevant studies but allows a deeper understanding of the topic [47].

A comprehensive search of seven electronic databases (MEDLINE [EBSCO], OVID, PubMed, ScienceDirect, SPORTDiscus, Web of Science and Google Scholar) was conducted over the period February to December 2017. The following search terms were used and combined using Boolean operators: 'injury risk factors', 'sports injury', 'athletic injury', 'females', 'women', 'girls', 'neuromuscular', 'biomechanical'. The search was limited to full text, English language studies published in peer reviewed journals. The study selection process involved removing duplicates, examining for relevance based on title and abstract and finally examining the full-text articles to confirm the studies focused on evidence of lower extremity injury risk factors in females.

Biomechanical Risk Factors

Lower extremity injury is common among sports that involve jumping and landing, running and decelerating, and changing direction [41]. Understanding the biomechanics of these sporting actions can offer insight into the mechanisms of injury risk. When reviewing studies of biomechanical risk factors for lower extremity injury, mechanics at the hip and knee joint were apparent. Therefore, this section will focus on sagittal, frontal and transverse actions at the hip and knee.

Hip biomechanics

Several biomechanical factors at the hip have been related to injury risk. First, increased hip flexion with landing or cutting has been identified as a risk factor. For example, researchers found that high school, college, and professional female basketball players landed with increased hip flexion compared to male players during ACL injuries [48]. Furthermore, evidence demonstrates a significantly greater hip flexion moment when comparing the landings of ACL injured to non-injured female soccer, basketball and volleyball athletes [49]. There is also evidence that women with patellofemoral pain syndrome (PFPS) land with greater hip flexion during single leg jumps than those without PFPS [50]. Landing in a position of increased hip flexion may be due to weakness of the hip extensor musculature (gluteus maximus, semimembranosus, semitendinosus, and biceps femoris) [51]. The hip weakness may also result in an inability of the hip musculature to absorb ground reaction forces, causing more load to be absorbed at the knee and ankle [52]. Increased hip flexion from forward trunk lean shifts the center of mass closer to the knee joint, which may result in the knee being in a position of increased abduction, a position of potential increased injury risk [53].

Increased hip adduction has also been associated with lower extremity injury. Women with PFPS demonstrated a significantly larger degree of hip adduction during single leg jumps than those without PFPS [54]. Similarly, researchers found greater hip adduction angle and lower hip abduction strength among women with PFPS during single leg jumps [50]. Excessive hip adduction causes the knee joint to move medially, shifting the center of mass over the stance limb, and potentially leading to increased knee abduction [55]. Knee abduction can be attributed to decreased hip musculature control and has been shown to contribute to knee, particularly ACL, injuries [49]. Studies have found that hip adduction is the main contributor to excessive knee abduction [56, 57], which is especially evident in females compared to males [58, 59]. Researchers concluded that frontal plane motion at the hip (hip adduction) was the only significant predictor of knee abduction during cutting maneuvers [60].

Despite hip adduction being linked to lower extremity injury by some authors, other research has found no connection [61, 62]. Specifically, females with PFPS failed to show a difference in peak hip adduction compared to those without PFPS during running, a drop-jump and a step-down [62] and stair-step task [61]. It was proposed that the lack of differences observed between groups may have been the result of compensation for potentially painful motion [62]. In addition, the authors hypothesized that the relatively low demand of some tasks may have also contributed to the lack of peak hip adduction in females with and without PFPS [61].

A third biomechanical factor at the hip thought to be related to injury risk is excessive hip internal rotation. Research has shown that repetitive jumping, landing, and cutting with the hip in excessive internal rotation can lead to the development of PFPS [63]. Additionally, females with PFPS showed greater hip internal rotation compared to controls during running, a drop jump, and a step-down [62]. Excessive hip internal rotation and knee abduction can be linked to weakened hip extensors and external rotators, primarily the gluteus maximus and medius, which may contribute to increased lateral forces at the patellar-femoral joint [64] potentially contributing to PFPS.

Although some studies found an association between excessive hip internal rotation and injury, several studies have not shown a correlation [61, 65]. Females with PFPS were found to produce less hip internal rotation during single-leg jumps than those without PFPS [54, 65]. Decreased internal rotation was thought to be a compensatory mechanism used with those who have PFPS to limit potentially painful motion.

Furthermore, no differences in hip internal rotation were found between those women with or without PFPS during a stair descent [61]. This study concluded that the task (stair descent at a heart rate of 96 beats per minute) might not have been challenging enough since all participants had ample hip strength to sustain lower extremity alignment.

Based on the evidence reviewed, excessive hip flexion, adduction and internal rotation have been repeatedly linked to lower extremity injury. The contribution of excessive hip motion in the frontal and transverse planes to lower extremity injury risk is less certain than in the sagittal plane. Specifically, it is unclear if differences in hip motion and strength are the cause or result of PFPS. Most current research compares injured to non-injured participants with few prospective studies and thus the ability to identify true risk factors for injury is limited. Therefore, there is a need for more prospective studies on healthy populations to determine if these factors are a cause or effect of lower extremity injury. There is also a need for more work on the biomechanical factors at the hip in youth populations due to a paucity of available research.

Knee biomechanics

Injury risk during landing or cutting has also been linked to biomechanics of the knee joint, particularly a position of the knee near full extension. For instance, females with PFPS showed a decreased knee flexion angle compared to those without PFPS during a jump-landing task [63]. Furthermore, video analysis of ACL injuries in female football athletes found that ninety-two percent of the non-contact ACL injuries occurred with 30° or less of knee flexion [66]. Likewise, video analysis of ACL injuries in female handball athletes revealed that at the time of injury the knee had little flexion in addition to being abducted and externally rotated [67]. On the other hand, similar knee flexion angles were reported at impact of a jump-landing task between female soccer, basketball and volleyball athletes with and without an ACL injury [49]. However, maximum knee flexion angles were 10.5° less in injured than uninjured athletes [49]. Knee flexion angles between 0° and 30° have been shown to increase the strain on the ACL [41, 66, 67], with the highest strain shown at 15° of knee flexion [68]. Strain on the ACL may also increase due to neuromuscular imbalance between the hamstrings and quadriceps causing increased anterior shear of the tibia on the femur [69].

Even though landing or cutting with less knee flexion is linked to injury risk, authors have reported that sagittal plane forces alone are unlikely to rupture the ACL [49, 70, 71]. Excessive frontal plane forces at the knee, however, are thought to be sufficient to rupture the ligament [70, 71]. For example, knee abduction moments were found to be the main predictors of ACL injury risk in female soccer, basketball and volleyball athletes [49]. Additionally, differences in knee abduction exist between males and females. For instance, increased knee abduction upon landing has been shown in female ACL-injured athletes compared to male ACL-injured and female controls [72]. Similarly, video analysis of handball and basketball athletes revealed that women demonstrated higher knee abduction angles compared to men during ACL injuries [73]. Furthermore, dynamic abduction was the main predictor of ACL injury [48, 58, 67, 74]. Indeed, research has shown that female players have 5.3 times higher relative risk of sustaining a knee valgus collapse than males [48]. An increase in knee abduction moments and motion observed in females indicates decreased neuromuscular control of the lower extremity in the frontal plane, which could be due to neuromuscular deficits at the hip and trunk [42, 75]. Additionally, excessive eversion or pronation at the foot coupled with internal tibial rotation may increase knee abduction and stress on the ACL as well as the patellofemoral joint [76].

Excessive knee abduction has also been linked to increased risk of PFPS. For example, female basketball players who developed PFPS over the course of a season landed with an increased knee abduction moment during a preseason drop vertical jump [77]. The onset of PFPS was attributed to repetitive landing in dynamic knee abduction [77]. This is thought to increase the quadriceps angle (Q-angle) as the knee shifts medially [78]. A larger Q-angle increases the lateral forces acting on the patella which alters the stress on the patellofemoral joint and results in PFPS [78].

Knee abduction combined with internal rotation has also been linked to increased risk of injury. For instance, landing and cutting with a position of increased knee abduction was found to be coupled with increased internal rotation in ACL injury video sequences of women's handball and basketball athletes [73]. Additional evidence from video analysis of female Australian football athletes showed the knee most commonly gave way in abduction (47.4%) and internal rotation (42.1%) [66]. Video analysis of ACL injury in female handball athletes showed either increased internal or external rotation was linked with knee abduction and flexion angles [67]. In contrast, Boden et al. [41] found that the amount of internal and external rotation was minimal at the time of ACL injury when analyzing video of female and male football, basketball, soccer and volleyball athletes. However, the results of this study were not divided by sex (16 males, seven females) which may explain why the results are not in accordance with previous research in females. Therefore, it is important to always report sex differences in the results in order to determine if a difference exists.

The evidence at the knee joint points to increased knee extension, abduction and internal rotation as contributing to injury risk in females. The most substantial evidence for injury risk is excessive abduction of the knee joint in the frontal plane. Additionally, there is good evidence that differences in sagittal and transverse plane motion combined with excessive knee abduction contribute to greater risk of injury in females. Similar to studies on biomechanics at the hip joint, there is a need for more prospective research in youth females as only one study was done in females under 18 years old [49]. Also, the studies examining biomechanical risk factors mainly focus on ACL injury or PFPS and there is a need for studies looking at all lower extremity injuries.

Neuromuscular Risk Factors

Altered neuromuscular control has been linked to increased injury risk, especially in the lower limb [16, 49]. Neuromuscular control is the precise muscle activation that allows for a coordinated and efficient action during dynamic sporting actions [79]. For example, video analysis of ACL injury in female handball players revealed that contact with another player prior to the injury appeared to alter the athlete's intended movement [67]. As a result, understanding how neuromuscular risk factors influence injury risk is important to guide appropriate prevention programs. Key neuromuscular considerations include deficits in strength, balance and proprioception. Therefore, this section will focus on those three neuromuscular risk factors.

Strength

Deficits in the ability to produce force (i.e., strength) may limit neuromuscular control and, in turn, increase injury risk. To protect the lower body from injury during sporting maneuvers, dynamic stabilization via coordinated and co-activated muscles is crucial. At the knee joint, co-activation of the quadriceps and hamstrings may improve stability and reduce loads associated with injury [80]. However, altered coordination, co-activation or muscle imbalances may lead to quadriceps dominance (when the quadriceps dominate over the hamstrings to stabilize the knee joint). Quadriceps dominance may lead to a decrease in the hamstrings to quadriceps (HQ) strength ratio, with a HQ ratio lower than 60% found to be a precursor for ACL injury [81, 82]. Females are prone to use quadriceps dominance more than their male counterparts, possibly due to structural and hormonal differences between sexes [13, 83]. This has been shown when isokinetic knee flexion/extension strength was compared between female athletes who had an ACL injury to age matched male and female controls and results demonstrated a combination of decreased hamstring strength but not quadriceps strength in female injured subjects [82]. In contrast, females who were not injured showed a decrease in quadriceps strength and similar hamstrings strength compared to male athletes [82]. This suggests a decreased HQ ratio may be a risk factor for future lower extremity injuries. Indeed, HQ strength ratio was tested in NCAA Division III female basketball and soccer athletes and results revealed that injured athletes had a HQ ratio less than 60% [84]. All five of the female soccer athletes who had an ACL injury during their season were found to have an HQ ratio of less than 55% [85]. Conversely, measurements of five strength variables (isokinetic quadriceps and hamstring torques, HQ ratio, isometric hip abduction strength and one-repetition maximum seated leg press) in female handball and football players were not found to be associated with an increased risk for ACL injury [86]. This study measured the HQ ratio at 60°/s, which is slower than typical sporting actions. Additionally, the length of time between baseline testing and an ACL injury was relatively long (average 1.8 years), which suggests that baseline strength levels may have changed before the injury occurred. Taken together, these may help explain why a decreased HQ ratio was not found between injured and non-injured athletes in this study. Another study in female football athletes found that after one season, HQ strength ratios were not significantly different between those injured and non-injured athletes, indicating that low isokinetic strength was not a risk factor [87]. This study had both elite and non-elite football athletes, so it is unclear if level of play has an effect on the HQ ratio.

Poor gluteus maximus and medius strength may also play a role in injury [88]. The gluteal muscles assist in the maintenance of a stable pelvis and in the prevention of excessive hip adduction and internal rotation [89]. Excessive hip adduction and internal rotation observed during ACL injury leads to knee abduction and tibial external rotation [90]. Interestingly, this same alignment has been shown in overuse injuries such as PFPS [90]. For instance, isometric hip strength was tested in athletes with and without PFPS. Injured subjects had significantly lower hip abduction and external rotation strength compared to the controls [90]. Additionally, male and female futsal, soccer, volleyball, basketball and handball athletes were measured for isometric hip abduction and internal rotation strength at the start of their season. Athletes who experienced an ACL injury during the season had significantly lower hip strength compared to the uninjured athletes [91]. These studies suggest poor hip strength is related to lower extremity injury risk.

Based on the studies reviewed there is consistent evidence that deficits in knee and hip muscle strength, specifically the hamstring and gluteal muscles, increase the risk of injury in females. However, all of the studies on strength and its relationship to injury risk are in adult females, except one study in high school and collegiate athletes that does not report ages. Therefore, more research is needed in youth females.

Balance/proprioception

Dynamic balance is the integration of perceptual information and neuromuscular control strategies to regulate the stability of the body's center of mass during dynamic tasks [79]. The relationship between balance measured by postural sway and lower extremity injury risk is currently unclear. For instance, male and female high school basketball players performed unilateral balance tests assessed by postural sway scores with both eyes opened and closed during the preseason and those athletes who displayed poor balance (high postural sway) had almost seven times more ankle sprains than those athletes with good balance [92]. Additionally, female soccer players who had low postural sway scores (good balance) were found to have an increased risk of leg injuries [85]. In contrast, postural sway in lacrosse, football and field hockey athletes was not found to be a risk factor for ankle injury in both males and females [93]. The differences found between these studies could be due to the fact that there is not a widely acceptable technique for measuring postural sway and the three studies used a different measurement system.

Although there is not a clear relationship between postural sway scores (balance measure) and injury, there is evidence that the Star Excursion Balance Test (SEBT) is linked to injury. For example, male and female NCAA Division I collegiate athletes tested for balance via the SEBT preseason demonstrated that those athletes who sustained a noncontact ankle or knee injury had a significant side-to-side asymmetry in the anterior direction [94]. Similarly, male and female high school athletes performed a battery of functional performance testing and results showed that when those injured athletes were matched with uninjured athletes, significant differences were found in the SEBT anterior reach direction [95]. These results are consistent with prior studies that showed lower extremity injury in high school athletes was linked to poor balance and SEBT reach deficits [92, 96]. A recent study, however, found no correlation between the modified SEBT and injury in female handball or basketball athletes [97]. These results may differ as the Steffen et al. [97], only measured ACL injury where the other studies measured all lower extremity injury.

Diminished proprioception of the trunk may also lead to increased injury risk of the lower extremity. A lack of neuromuscular control at the trunk can result in uncontrolled trunk movement which may compromise dynamic stability of the lower extremity placing the knee in a valgus position and excess strain on the knee ligaments [49, 64]. For instance, the effects of isolated trunk displacement after a perturbation were measured in male and female athletes over a three year period and results showed that lateral trunk displacement was greater for those injured athletes compared to those uninjured athletes [98]. Additional evidence based on trunk proprioception measured via active and passive repositioning found those females with knee injuries showed deficits in active repositioning compared to those who did not sustain a knee injury [99]. The authors concluded that impaired trunk control and trunk proprioception predicted future injury to the knee in females but not males [98, 99].

The evidence for diminished balance as a risk factor as measured by postural sway is unclear. However, when using the SEBT to measure balance, there is a clear link to injury risk. While research is limited there is preliminary evidence that trunk proprioception is linked to injury risk. Of note, all the current research is in adult populations so more research is needed in youth. Ideally further research should be prospective, focused on youth and record all injuries to best inform design of injury prevention programs.

Conclusion

The identification of modifiable injury risk factors is needed to inform the development of preventative measures. Current evidence suggests that in females, biomechanical factors at the hip and knee are of particular importance. Specifically, there is evidence that landing or cutting in a position of increased hip flexion, adduction and/or internal rotation, increased knee extension, abduction and/or internal rotation can lead to increased injury risk. In terms of neuromuscular factors, deficits in knee and hip musculature strength, balance and proprioception of the trunk have been linked to increased injury risk in females. These risk factors can help inform the programming of exercises for intervention strategies that target improved neuromuscular function of the lower extremity during sporting movements. Training programs that include a focus on hip and knee control during functional tasks (e.g. plyometric and agility exercises), lower extremity strength, core strength and balance are likely to be most successful. As most studies have been conducted in adults, there is a need for further prospective studies focused on youth females.

Chapter 3 : Injury Prevention Programs in Youth: A Narrative Review Targeting Females

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Prelude

According to the TRIPP model, injury risk factors should be established before prevention strategies can be implemented. The review of literature in chapter 2 evaluated the evidence for risk factors in females and identified specific biomechanical and neuromuscular factors. These factors included increased knee abduction and hip flexion during landing as well as a lack of strength and balance for lower extremity injury. Alongside evidence for these risk factors, it was important to determine what factors have made previous IP programs effective in youth. Thus, the aim of chapter 3 was to review previous research on IP programs in youth targeted at reducing injury risk factors, injury incidence and/or improving athletic performance. The findings provide coaches and practitioners with insights into what makes a successful IP program in youth females and may assist with developing IP programs. It also guided the development of the IP program presented in chapter 6.

Introduction

Sport is the main cause of injury in children and adolescents [6-10]. Approximately three million youth in the United States and one in four Canadian adolescents seek medical attention for a sports related injury annually [7, 100]. Unfortunately, the high prevalence of injury in youth sport negatively impacts present and future participation in physical activity [11, 12]. For example, high injury rates result in time loss from participation and a decrease in physical activity due to fear of injury or re-injury, accordingly [101]. This is of particular concern for female athletes as they have shown significantly greater rates of injury than males (e.g. 14% higher injury rate, in youth female compared to youth male soccer athletes) [14]. Injuries in youth may be a result of risk factors that fall into one of two main categories: extrinsic (outside the body) and intrinsic (within the body) [32]. Extrinsic risk factors for injury include environmental factors such as weather, playing surface, and equipment, increased training and competition loads, poor coaching and sport specialization [7, 33, 34, 36, 102]. Intrinsic risk factors include neuromuscular and biomechanical factors that can be modified for example, under developed athletic competencies such as strength and fundamental movement skills [32-34]. In response to the growing number of sports injuries in youth, injury prevention (IP) programs that target these modifiable intrinsic risk factors have been developed [103, 104].

Research shows that exercise-based IP programs can reduce overall injury rates by about 40% in youth sport [105], reduce injury risk factors [44] and lead to increased athletic performance [106, 107]. These IP programs are commonly carried out with sports where the demands of the sport are linked to injury such as a high rate of contact, jumping/landing, accelerating/decelerating or rapid changes of direction [41]. Injury prevention programs typically comprise one or multiple exercise components (e.g., plyometrics, speed, agility, strength, balance) that target specific biomechanical and neuromuscular injury risk factors, rates of specific injuries and/or athletic performance. For the purpose of this paper, IP programs have been grouped by when they are delivered (as a warm-up or independently). Warm-up interventions generally last five to 25 minutes and are implemented before a sports training, whereas independent training interventions are separate from a sports training and are typically longer in duration (10-90 minutes).

Whether implemented as a warm-up or independent training intervention, IP programs in youth are significantly affected by growth and maturation [46, 108]. Growth is defined as an increase in the size of the body, whereas maturation is defined as progress towards a mature state [109] and both are considered to be a risk factor for injury in youth [46]. Youth, which includes both children (up to age 11 in girls and age 13 in boys) and adolescents (aged 12-18 in girls and 14-18 in boys) [109], experience a period of accelerated growth during their development [109]. Referred to as the 'adolescent growth spurt', this accelerated growth comprises a phase of increasing height and mass that starts around age 10 in females and age 12 in males [15]. These changes have been shown to disrupt motor control and movement patterns [108], and as a result, increase the risk of injury [16]. This is especially evident during peak height velocity (PHV), the period of maximum growth that occurs at approximately 11-12 years in females and 13-14 years in males [17]. For example, Hewett et al. [49] found that excessive knee abduction and hip adduction motion and torque were linked to ACL injury risk during PHV in females. In addition, excessive frontal plane motion at the ankle and decreased knee flexion during sporting movements (e.g., jumping and landing, changing direction) may also increase injury risk during this phase of development [64, 74]. Decreased trunk and hip muscular co-activation, poor core stability, quadriceps dominance and leg dominance have also been identified as injury risk factors more common in youth, particularly during growth and maturation [98, 110].

Biomechanical and neuromuscular factors associated with athletic performance and injury risk differ between sexes during PHV. For instance, during a drop vertical jump (DVJ) males have been shown to increase vertical jump height and reduce landing force while females did not [19]. Additionally, multiple studies have shown that post-PHV females display significantly greater knee abduction moment and motion during a DVJ compared to males of the same developmental stage [16, 22-24]. These differences are possibly due to greater gains in skeletal tissue and muscle mass in males compared to females [18]. Moreover, males demonstrate a 'neuromuscular spurt' during adolescence (i.e., an increase in strength and power), while females do not [16, 19]. The lack of lower body strength and muscular imbalances shown between the quadriceps and hamstrings are additional risk factors for lower extremity injury in females [108, 111]. Research shows that neuromuscular deficits in youth females compared to males may contribute to the higher rates of injury seen [25]. For example, adolescent females have a four to six times higher rate of ACL injury during a pivoting or jumping sport than adolescent males [16, 81]. Together, these factors demonstrate a greater need for more IP programs implemented with female athletes.

Identifying and summarizing the evidence for the effectiveness of IP programs in youth (especially females) may provide coaches and other practitioners with insight into the components of a successful IP program. Many of the IP programs for youth females are targeted towards improving neuromuscular coordination (strength, power, balance, etc.) to decrease risk of injury and improve athletic performance. Consequently, the purpose of this review is twofold: 1) to examine existing IP programs and evaluate their effectiveness for males and females, and 2) provide practical IP recommendations for females. This review will highlight independent and warm-up based IP programs in females first, followed by males and finally both sexes. Finally, the review will provide practical recommendations for the use of IP programs in females and identify areas for future research.

A comprehensive search of seven electronic databases (MEDLINE [EBSCO], OVID, PubMed, ScienceDirect, SPORTDiscus, Web of Science and Google Scholar) was conducted over the period December 2017 to September 2018. The following search terms were used and combined using Boolean search: 'prevention programs', 'youth or adolescents or young people or young adult', 'sports injury or athletic injury'. The search was limited to full text, English language studies published in peer reviewed journals. The study selection process involved removing duplicates, examining for relevance based on title and abstract and finally examining the full-text articles to confirm studies focused on evidence for the effect of an IP program in youth sport. Thirty-three studies, with age range nine to 24 years, were found to be appropriate for the scope of the review, twenty-four with female participants, four with male participants, and five with both female and male participants. A summary of the characteristics of the IP programs can be found in Table 3.1, 3.2 and 3.3.

Injury Prevention Programs in Youth

Females

Injury prevention programs used with females have been shown to improve athletic performance measures including upper and lower body strength [112], single and double leg jump height and speed [42]. They can also decrease risk factors for injury by improving balance [44, 113, 114], improving neuromuscular imbalances between the quadriceps and hamstrings [115] and improving landing technique (i.e., increasing knee flexion and hip abduction, decreasing knee abduction and hip internal rotation) [116-118]. Furthermore IP programs have been shown to decrease prevalence of lower extremity injury [119], overuse injuries [120-122], severe injuries [120-122] knee injuries [123], gradual onset injuries [124], acute injuries [124], ankle sprains [124], and ACL injuries [125, 126]. The majority (58%) of IP programs reported in the literature that target females utilize an independent IP training program rather than a warm-up IP program. Of these, 17 reported positive outcomes, six reported negative outcomes and one reported both positive and negative outcomes (Table 3.1).

Table 3.1: Injury prevention programs in youth females.

First author, yr	Participants	Type of IP program	Frequency and/or duration of IP program	Injury prevention program details	Key outcomes
Augustsson, 2011	volleyball athletes 14-20 years	Independent	26 weeks	Individualized resistance training	Significant improvements in 1RM squat (67%) and bench (16%) and number of push-ups (122%) and sit-ups (55%)
Filipa, 2010	soccer athletes 13-17 years	Independent	2x/week 8 weeks	Core stability and lower extremity strength	Significant improvements in the composite score for the SEBT
Heidt, 2000	soccer athletes 14-18 years	Independent	3x/week 7 weeks	Conditioning, plyometrics, sport coordination drills, strength and flexibility	Occurrence of injury significantly less in trained group (14.3% versus 33.7%)
Hewett, 1999	soccer, volleyball and basketball athletes no reported age	Independent	60-90 min 3x/week 6 weeks	Plyometrics, stretching and weight training	Significantly less incidence of knee injury
Lim, 2009	basketball athletes 15-17 years	Independent	20 min 8 weeks	Stretching, strengthening, plyometrics and agility	Higher knee flexion angles and knee abduction torques and lower HQ ratios and max knee extension torques
McLeod, 2009	basketball athletes 14-16 years	Independent	70 min 6 weeks	Plyometrics, strengthening, balance and stability-ball	Significant decrease in total BESS errors and increased SEBT
Myer, 2005	basketball, soccer and volleyball athletes 13-17 years	Independent	90 min 3x/week 6 weeks	Plyometrics, core strengthening, balance, resistance training and speed	Increased 1RM squat (92%), bench press (20%), single leg hop distance, VJ height, speed and knee flexion angle at landing and decreased knee valgus (28%) and varus (38%)
Myer, 2007	soccer and basketball athletes 15-17 years	Independent	3x/week 7 weeks	Neuromuscular training -no details reported	High risk group decreased knee abduction torque (13%) at landing while the low risk group did not
Pfeiffer, 2006	soccer, basketball and volleyball athletes no ages reported	Independent	20 min 2x/week In-season	Plyometric program	No significant difference in incidence of noncontact ACL injuries
Pollard, 2006	soccer athletes 14-17 years	Independent	2-3x/week In-season	Stretching, strengthening, plyometrics and agility	Significantly less hip internal rotation and greater hip abduction at landing. No significance in knee valgus or angles
Soligard, 2008	soccer athletes 13-17 years	Independent	20 min In-season	Running, strength, balance, plyometrics and agility	Significantly lower risk of overall injuries, overuse injuries and severe injuries
Vescovi, 2010	soccer athletes 13-18 years	Independent	3x/week 12 weeks	Stretching, strengthening, plyometrics and agility	Small non-significant improvements in speed but not in CMJ or agility
Wedderkopp, 1999	handball athletes 16-18 years	Independent	10-15 min 10-month season	Ankle disc program	Significantly reduced the number of traumatic and overuse injuries

Wedderkopp, 2003	handball athletes 14-16 years	Independent	10-15 min 10-month season	Ankle disc program	Significantly fewer moderate, major and traumatic injuries
Grandstrand, 2006	soccer athletes 9-11 years	Warm-up	20 min 2x/week 8 weeks	Agility, plyometrics, strength and flexibility	No significant differences in landing mechanics (knee abduction and adduction)
Kiani, 2010	soccer athletes 13-19 years	Warm-up	20-25 min 2x/week 12 weeks preseason and in-season	Harmonknee program: muscle activation, balance, strength and core stability	Significantly lower incidence of any knee injury (77%) and non-contact knee injuries (90%)
LaBella, 2011	basketball and soccer athletes 15-17 years	Warm-up	20 min 3-4x/week In-season	Strength, plyometrics, balance and agility	Significant reduction in gradual-onset injuries (65%), acute noncontact injuries (56%) and noncontact ankle sprains (66%)
Lindblom, 2012	soccer athletes 12-16 years	Warm-up	15 min 2x/week 11 weeks	Core stability, balance, landing technique and proper knee alignment	No significant improvements in performance (SEBT, CMJ, 3-step jump, 10 and 20 m sprint and modified Illinois agility test)
Mandelbaum, 2005	soccer athletes 14-18 years	Warm-up	20 min 2-seasons	Stretching, strengthening, plyometrcs and agility	Significant decrease in ACL injuries (88%)
Otsuki, 2014	basketball athletes 12-14 years	Warm-up	20 min 3x/week 6 months	Lower body strength, plyometrics and agility	Significant decreases in knee valgus and increases in knee flexion
Steffen, 2008	soccer athletes 13-17 years	Warm-up	20 min 8 months	FIFA 11+: core stability, lower extremity strength, balance and agility	No significant differences in distribution of type, location or severity of injuries
Steffen, 2008	soccer athletes 16-18 years	Warm-up	3x/week 10 weeks	FIFA 11+: core stability, lower extremity strength, balance and agility	No difference in performance measures (isokinetic and isometric HQ ratios, DVJ and CMJ, 40 m sprint, and slalom dribble)
Steffen, 2013	soccer athletes 13-18 years	Warm-up	2-3x/week 4-5 months	FIFA 11+: core stability, lower extremity strength, balance and agility	Higher adherence to the IP program led to improvements in y-balance (4-7%) and a reduction in injury risk
Walden, 2012	soccer athletes 12-17 years	Warm-up	15 min 2x/week In-season	Core stability, balance and proper knee alignment	Significant reduction in rate of ACL injury (64%) but non-significant in severe or acute knee injury

1RM = 1 repetition maximum, SEBT= star excursion balance test, HQ = hamstring: quadriceps ratio, BESS = balance error scoring system, VJ = vertical jump, ACL = anterior cruciate ligament, CMJ = counter-movement jump, DVJ = drop vertical jump.

Independent IP Training Programs

The prescription of independent IP training programs in youth females ranges from two to three times per week for six to 26 weeks (majority six to eight weeks) and includes one or more of the following components: stretches, lower body and/or core strength, plyometrics, agility, balance, conditioning and speed [42, 81, 112-117]. For example, high school female basketball, soccer and volleyball athletes (13-17 years) underwent six weeks of an IP program consisting of four parts: plyometrics and movement, core strengthening and balance, resistance training and speed training, three times a week for 90 minute sessions [42]. Trained participants compared with controls showed increases in predicted one repetition maximum squat and bench press, right and left single leg hop distance, vertical jump height and speed (9.1 m sprint). The IP program group also showed significantly lower knee valgus and varus torques during a DVJ compared to the control group [42]. In addition to positive impacts on athletic performance and risk factors for injury, independent IP training programs have also reduced the prevalence of injury in youth females [119-122]. In particular, 42 high school female soccer players (14-18 years) participated three times per week, for seven weeks in an independent IP training program that incorporated conditioning, plyometrics, strength and flexibility exercises. Results showed that the occurrence of injury was significantly less in the trained group compared with the control [119]. An additional independent IP training program utilizing plyometrics, stretching and weight training targeted knee injuries in high school soccer, volleyball and basketball athletes [81]. This IP program was done for 60-90 minutes, three times per week for six weeks in female athletes who were compared against a female and male control group (untrained groups). Results demonstrated a significant reduction in knee injury in the trained females compared to the female control, but no significance when compared to the males [81], indicating that discrepancies in neuromuscular deficits between sexes can be reduced.

Despite the positive effects shown by some independent IP training programs in youth females, others have shown little or no impact [127, 128]. For example, in a study designed to target noncontact anterior cruciate ligament (ACL) injuries, high school soccer, basketball and volleyball athletes underwent a plyometric training program twice a week for the duration of their season. The results demonstrated no significant difference in the injury incidence between groups [127]. The program primarily focused on jump-landing and run-deceleration mechanics, which alone may not have been enough to reduce the ACL injury rate. Indeed, IP programs that have shown a reduction in ACL injuries have incorporated strength exercises [81, 125]. In another study, only small improvements in speed (10, 20, 30 and 40 m sprint) and no improvements in counter-movement jump height or agility were found when female soccer players participating in a 15 minute independent IP training program were compared to a control group [128]. The lack of improvement may have been due to the instructions given for the IP program, which were to perform drills at a slow speed, thus minimizing neuromuscular stimulation beyond a normal soccer match.

Warm-up Based IP Programs

Warm-up based IP programs in youth females have also been shown to reduce risk factors for lower extremity injury and incidence of injury in youth females. More specifically, programs ranging from 15-20 minutes per session, one to four times per week for eight weeks to six months have lowered the incidence of noncontact knee injuries [123], gradual-onset injuries, acute noncontact injuries, noncontact ankle sprains [124], and ACL injuries [125, 126]. Warm-up based IP programs have also been shown to significantly improve biomechanical risk factors at the knee during landing (increased flexion, decreased abduction) [118] and balance [44] in youth females. For instance, lower body strength, plyometrics and agility exercises were performed by basketball players (12-14 years) for 20 minutes, three times per week. After six months of training, knee abduction was significantly decreased and knee flexion significantly increased during a DVJ compared to the control group [118]. A similar warm-up intervention in soccer athletes (14-18 years) showed an 88% reduction in ACL injury after one season and a 74% reduction after two seasons compared to the control group [125].

Although some warm-up based IP programs in youth females have shown positive effects, others have shown no beneficial effects on injury risk or athletic performance [129-132]. One warm-up based IP program that has received a lot of attention is the FIFA 11+, a 20 minute warm-up program developed to reduce the risk of lower extremity injury in soccer players age 14 and over. The FIFA 11+ consists of 15 exercises divided into three parts, including initial and final running exercises with a focus on cutting, jumping and landing techniques, core and leg strength, balance, plyometrics and agility exercises (part two). The exercises in part two have varying levels of progression [120]. A group of adolescent female soccer players (16-18 years) took part in a 10 week IP program consisting of the FIFA 11+, three times per week for 15 minutes. Participants and controls were tested for isokinetic and isometric strength of the quadriceps and hamstrings, hip adductors and abductors, vertical jump, sprint and soccer skills. Results showed no difference between groups in any of the performance measurements [131]. The FIFA 11+ has also been utilized to target reducing the prevalence of all injuries. After a season of the program, female soccer athletes were not found to have any significant differences in distribution of type, location or severity of injuries compared to the control group [132]. Low compliance to this IP program (only used during 52% of all training sessions) may explain the lack of difference found.

Based on the available evidence, implementing an IP program in youth females can decrease risk factors for injury, decrease the prevalence of injury, and/or improve athletic performance. Following the independent IP training programs, benefits were found in one or more of these components in 86% of studies reviewed, where only 60% of warm-up based IP programs reported benefits. This suggests that an independent IP training program is more likely to be beneficial in youth females.

Males

The current research in youth males has also investigated the effects of IP programs on injury prevalence, risk factors and athletic performance. The programs have been shown to aid in lowering injury rates for lower extremity injuries as well as improving performance measures of balance, jump height and sprint time. The majority of studies (three out of four) investigating IP programs have used a warm-up to a sports training, with the FIFA 11+ being the most commonly investigated IP program. Three programs report positive outcomes and one reports positive and negative outcomes (Table 3.2).

Table 3.2: Injury prevention programs in youth males.

First author, yr	Participants	Type of program	Frequency and/or duration of IP program	Injury prevention program details	Key outcomes
Kilding, 2008	soccer athletes 9-11 years	Independent	5x/week 6 weeks	FIFA 11+: core stability, lower extremity strength (minus hamstring exercise), balance and agility	Significant improvements in CMJ (6%), 3-step jump (3.4%) and speed (20 m sprint 2%)
Ayala, 2017	soccer athletes 15-17 years	Warm-up	3x/week 4 weeks	FIFA 11+: core stability, lower extremity strength, balance and agility Harmonknee: muscle activation, balance, strength and core stability	FIFA 11+ group: improved y-balance (anterior 2.5% and posteromedial 7.2%), single leg hop limb symmetry (8.3%), sprint times (10 m 8.4% and 20 m 1.8%) and jump height (9.1%) Harmonknee group: improved sprint times (10 m 2.7% and 20 m 2.9%) and jump height (9.7%)
Longo, 2012	basketball athletes 11-24 years	Warm-up	20 min 3-4x/week 9 months	FIFA 11+: core stability, lower extremity strength, balance and agility	Significant lower injury rates for overall injuries, training injuries, lower extremity injuries, acute injuries and severe injuries
Zech, 2014	field hockey athletes 12-18 years	Warm-up	20 min 2x/week 10 weeks	Running, agility, balance, strength and plyometrics	Only BESS decreased significantly more in the intervention. No effects were found for SEBT, TTS and COP sway velocity

CMJ= counter-movement jump, BESS = balance error scoring system, SEBT = star excursion balance test, TTS= time to stabilization, COP = center of pressure.

Independent IP Training Programs

The FIFA 11+ is typically done as a warm-up to a sports training, but it has been used as an independent IP training program in youth males as well [133]. This IP program used all of the exercises from the FIFA 11+ except the hamstring exercise due to the younger population of nine to 11-year old athletes. The program was done five times per week for six weeks and measured performance variables including counter-movement jump (CMJ), three-step horizontal jump, prone hold, 20 m sprint and Illinois agility test. After the six week duration, CMJ, three-step jump and speed were significantly improved [133] thus showing performance benefits of the FIFA 11+.

Warm-up Based IP Programs

Two other studies used the FIFA 11+ for the intended use as a warm-up IP program in youth males. One of the studies compared the FIFA 11+ and the Harmonknee program (running exercises, muscle activation, balance, strength and core stability) to a control group [134]. Both the FIFA 11+ and the Harmonknee were completed three times per week for four total weeks. For performance measures, the FIFA 11+ improved y-balance, single leg hop distance, speed (10 and 20 m sprints) and jump height (DVJ) whereas the Harmonknee improved speed and jump height. The other study that used the FIFA 11+ targeted reducing prevalence of injuries [135]. This IP program was done three to four times per week for the entire basketball season (nine months). After the season, results demonstrated significantly lower injury rates for overall injuries, training injuries, lower extremity injuries, acute injuries and severe injuries [135].

An additional study in males utilized a warm-up IP program that found both beneficial and non-beneficial results. This IP program included running, agility, balance, strength and plyometrics in field hockey athletes (age 12-18 years) 20 minutes, twice per week for 10 weeks. The intervention and control groups were measured for a range of balance measures (star-excursion balance test, balance error scoring system (BESS) time to stabilization and change of pressure during a single leg landing). Only the BESS significantly improved in the intervention compared to control, whereas there was no significant differences found for the rest of the balance measures [136]. Although balance was a component to this IP program, it was only a small portion which, when combined with the other components, might not have been specific enough to result in significant improvements in the balance measures.

Even though there are fewer studies examining IP programs in males compared to females, the programs have been successful in improving balance, speed, and power in soccer players (nine to 11 and 15-17 years) as well as reducing injury rates for all lower extremity injuries in basketball players (11-24 years). However, when balance measures were the only factor assessed improvements were not as successful, with only one out of four measurements improving. The FIFA 11+ was used with both female and male participants and proved to be more beneficial with male participants. This could be due to the higher compliance found in the programs with male participants than females (72% and 100% versus 60%, respectively). More research is needed in males to truly understand the effects of IP programs in order to make future recommendations.

Females and Males

Injury prevention programs have also been utilized in groups that include both males and females. Including both sexes in research will over time, inform the development of IP programs for females and males. Additionally, the programs can act as a guide for those who have both sexes in their sports team or physical education class. As these programs become developed and specific needs for each sex are understood, then moving to single sex programs may provide the most benefit. These IP programs target prevalence of injuries and have been used as a warm-up or as independent training [106, 137-141]. For these IP programs, two studies report positive outcomes, two studies report negative outcomes and one study reports both positive and negative outcomes (Table 3.3).

Table 3.3: Injury prevention programs in youth females and males.

First author, yr	Participants	Type of program	Frequency and/or duration of IP program	Injury prevention program details	Key outcomes
Cumps, 2017	basketball athletes 14-22 years	Independent	5-10 min 3x/week 22 weeks	Balance training	Significantly lower relative risk of lateral ankle sprains
McGuine, 2006	soccer and basketball athletes 15-17 years	Independent	10 min 3x/week	Balance training	Significantly lower rate of ankle sprains (38%)
Emery, 2007	basketball athletes 12-18 years	Warm-up	35 min 5x/week 18 weeks	Aerobic, static and dynamic stretches, balance and home-exercise program on wobble board	Non-significant reduction in acute onset injuries (29%)
Emery, 2010	soccer athletes 13-18 years	Warm-up	15 min 20 weeks	Dynamic stretches, eccentric strength, agility, plyometrics and balance	Non-significant reduction in all injury (38%) and acute-onset injury (43%)
Olsen, 2005	handball athletes 15-17 years	Warm-up	15-20 min 8 months	Running, cutting, landing technique, neuromuscular control, balance and strength	Significantly lower overall injuries, lower limb injuries, acute knee injuries, and upper limb injuries. Non-significant differences in acute ankle injuries (37%)

Independent IP Training Programs

Independent IP training incorporating balance exercises has also been investigated in combined male and female groups with the aim of reducing knee and ankle injuries. Two studies incorporated a balance training program that was done for five to 10 minutes, three times per week with basketball (14-22 years) and soccer (15-17 years) athletes and found a significant reduction in ankle sprains after the IP program [137, 140]. There were no significant differences in the incidence of ankle sprains found between sexes in the intervention group [137, 140].

Warm-up Based IP Programs

The warm-up IP programs in combined groups of youth males and females range from 10-20 minutes in duration and focus on combinations of the following components: stretching, agility, plyometrics, neuromuscular control, strength and balance. These IP programs have been used with basketball (12-18 years), soccer (13-18 years) and handball (15-17 years) athletes and have shown a significant reduction in overall, lower limb, acute knee and upper limb injuries [141] as well as a non-significant reduction in all injury and acute onset injuries [138, 139]. The studies where non-significance was found incorporated a home-based balance training program and compliance to that part of the program was low (<15% and 60%, respectively). This further adds to the importance of compliance being a major consideration when developing and implementing an IP program.

Although there have not been as many studies examining IP programs with both sexes as participants, the programs have been successful in reducing prevalence of ankle sprains, overall, lower-limb, acute knee, and upper limb injuries. More research is needed in IP programs with both sexes to make appropriate recommendations for future IP programs.

Conclusion

Injury prevention programs have been developed in the attempt to reduce sports related injuries in youth. Of particular importance in youth are changes that occur during the adolescent growth spurt. This period can result in an increased risk of injury, especially in females. For females, independent IP training programs have been more commonly investigated and shown more successful than warm-up IP programs. In contrast, warm-up based IP programs were used more with male groups and both types of programs proved equally likely to be of benefit. In both sexes, the warm-up and independent IP training programs demonstrate that prevalence of injuries can be reduced.

Practical Applications and Areas for Future Research

Several limitations of the research to date can help inform the design of future IP programs. First, poor subject compliance (minimum session attendance) has been shown to limit the effectiveness of a program. Accordingly, a minimum session attendance of approximately 80% is recommended to optimize the effectiveness of a program. In order to maximize compliance, it is important to enlist the key stakeholders (parents, coaches, teachers, administrators, athletes, etc.) in the IP program as well as explain the purpose of the exercises to the participants throughout implementation. In addition, higher compliance may be attained when the IP is administered within a regularly attended setting such as a school, for example, the physical education program.

Second, exercises should appropriately match the skill level of the target population. When exercises are too challenging, time is wasted regressing rather than progressing the difficulty. Therefore, accurately assessing the skill level of the target population at the start of an IP program and prescribing exercises and activities specific to the individual is essential. Similarly, to ensure maximum benefit, exercise volume and intensity should be set in accordance with the goal of the program. For example, if the goal is to improve biomechanical factors during landing from a jump, then the volume and intensity of the exercises should be sufficient to facilitate this (maximum effort jumps versus solely sub maximum effort). Given the need for individual assessment and prescription, IP programs are best delivered by a suitably trained practitioner (e.g. strength and conditioning coach).

Third, speed of movement should be considered. The IP program should allow for progressions to the exercises so that the speed of movements can be advanced to mimic real-time sporting actions. Exercises should be progressed appropriately by starting with body weight exercises that focus on correct positions of the body. When the athlete has shown proficient technique, minimal equipment for moderate resistance (e.g. medicine balls or dumbbells) should be added. Finally, heavier weights or more dynamic movements should be added. Example progressions can be found in Figure 3.1.

Fourth, when the aim of the program is to reduce injury, components such as lower body strength, core stability, plyometrics, agility and balance should be implemented two to three times per week for 20 minutes or longer. Lastly, when time is not a limiting factor, independent IP training programs should be preferred over warm-up based programs. Since these programs are done separately from a sports training, they allow for more time and focus to be devoted to the program, which results in a greater stimulus to make changes in strength, risk factors, etc. A summary of recommendations for female IP programs can be found in Figure 3.2.

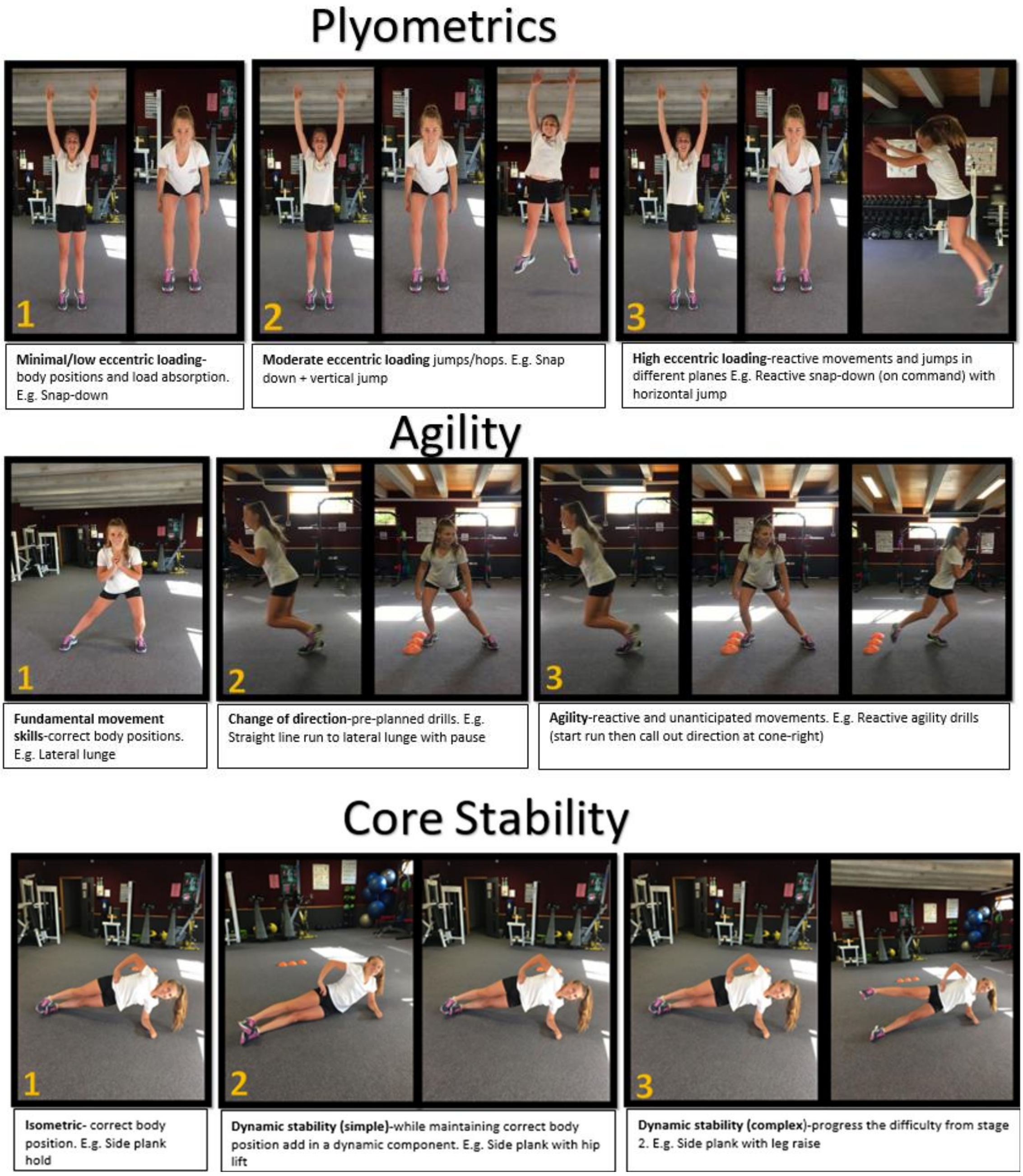

Figure 3.1: Examples of plyometric, agility and core stability progressions in youth females, starting with 1) low intensity body weight exercises, progressing to 2) moderate intensity with minimal equipment and sub maximum effort jumps and agility exercises, then progressing to 3) high intensity with more resistance and maximum effort jumps and agility exercises.

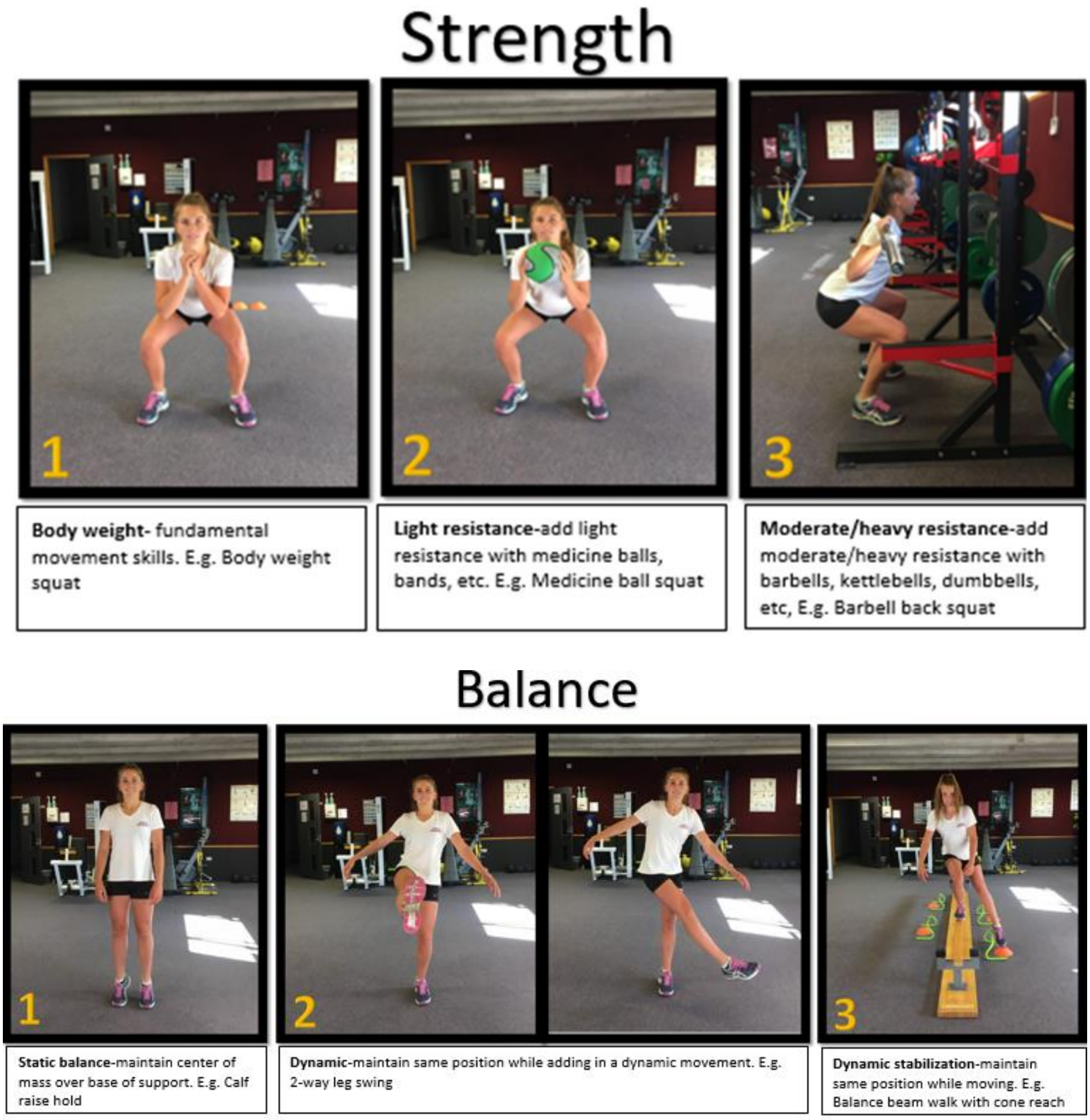

Figure 3.1 (continued): Examples of lower body strength and balance progressions in youth females, starting with 1) low intensity body weight exercises, progressing to 2) moderate intensity with minimal equipment and sub maximum effort jumps and agility exercises, then progressing to 3) high intensity with more resistance and maximum effort jumps and agility exercises.

Figure 3.2: Components of a successful IP program in females. Aim to achieve movement competence first and then progress to sport specific movements.

Chapter 4 : A Prospective Study of Sport Injuries in Youth Females

This chapter comprises the following article published ahead of print in *Physical Therapy in Sport.*

Reference:

Sommerfield L.M., Harrison C.B., Whatman C.S., and Maulder P.S. (2020). A prospective study of sport injuries in youth females. *Physical Therapy in Sport,* Published ahead of print.

Prelude

The first step in the TRIPP model is to establish injury surveillance in youth females in order to have an understanding of the type, site and occurrence of injuries before developing an IP program. However, most of the available research is sport specific and/or conducted with elite athletes and uses an injury definition (time-loss) that underestimates the rates of injury. Therefore, the aim of this chapter was to describe sport and physical education injuries in youth females over a school year. A questionnaire with an all physical problem definition was implemented, accordingly.

Introduction

Many youth across the world participate in sport. In New Zealand for example, 81% of five to 17 year olds participate in organized sport (physical education classes at school, sports competitions/tournaments and training or practicing with a coach/instructor) [142]. Although there are many health-related benefits of physical activity, participating in sport at a young age involves risk of injury [143]. Specifically in New Zealand in 2016, there was a total of 494,860 insurance claims related to sports injury with an associated cost of approximately $506 million NZD [144]. Additionally, from 2012-2017 there was a 19% increase in sports-related injuries in youth 18 years and under [145]. Increased injuries may be a result of increased training and competition loads which often occur alongside under developed athletic competencies such as strength and fundamental movement skills [7, 36, 102]. Injuries in sport may result in reduced game or competition time, or worse, an early finish to the sports season. Furthermore, injuries can have long-term consequences that limit sport participation and lifelong physical activity [25, 46]. For example, knee and ankle injuries may result in an increased risk for osteoarthritis later in life [143]. Consequences from sports injury can be especially problematic for young girls, as they have shown greater rates of injury than boys [14]. Given the negative consequences of injuries in youth sport, injury prevention strategies should be implemented early. Prevention strategies include use of appropriate equipment and facilities, rule modifications and adequate physical preparation [146]. Appropriate training programs, adequate recovery, and participating in a variety of sports are also possible injury prevention strategies [147].

The complex interaction of the sex hormones that occurs with the onset of menarche may play a role in the susceptibility of females to sports injuries [26]. For instance, estrogen can affect blood pressure, heart rate and rhythm and vascular flow, substrate metabolism and brain function. Additionally, progesterone effects thermoregulation, ventilation and fuels needed for energy [148]. Furthermore, due to the fluctuation of hormones, ACL laxity, neuromuscular function and thus athletic performance may change throughout the menstrual cycle [149]. Studies investigating the relationship between injury risk and the menstrual cycle are, however, contradictory. For instance, some researchers report that females are at greater risk of injury during the ovulatory phase [26], some report greater risk during the luteal phase [27, 29], while other researchers report greater risk during menses in the follicular phase [28]. Additionally, previous studies are limited to adult females (>19 years) and there are few prospective studies. Therefore, more research is needed to determine if a link exists between injury and the different phases of the menstrual cycle in youth females.

In response to the growing number of injuries in youth sport, there has been increased focus on injury prevention programs. The Translating Research into Injury Prevention Practice (TRIPP) model is a framework for developing injury prevention strategies [30]. According to the TRIPP model, prevention strategies can be developed and implemented only after injury surveillance and risk factors for injury are established. Thus, to develop and implement effective injury prevention programs, an understanding of the type, site, occurrence, average duration, and exposure times of injuries in the target population is needed. Little is known about the patterns of injuries in youth females with the available evidence specific to certain sports and/or elite athletes and to our knowledge there are no previous reports on physical education (PE) injuries [150-152].

Therefore, the main objective of this study was to describe sport and PE injuries in youth females over one school year. An additional objective was to investigate if an association exists between injury and phases of the menstrual cycle.

Methods

Participants

One hundred and three girls (mean ± SD; age = 14.0 ± 0.6 y; height = 162.6 ± 5.8 cm; mass = 57.4 ± 9.8 kg) from PE classes at a girls' secondary school in New Zealand participated in this study. The participants were recruited from four PE classes. The classes were determined prior to the school year based on the PE teachers agreeing to let the primary researcher use time from their classes for this study. The girls participated in a variety of sports outside of PE class including netball, soccer, field hockey, lacrosse, swimming, athletics, badminton, and rowing. The University Ethics Committee approved the study. Informed parental consent and participant assent was obtained from all girls.

Procedures

Injury data was collected prospectively over three school terms (30 weeks) using an online questionnaire via Google Forms. Participants were familiarized before the study began, then sent an email reminder to complete the questionnaire at the start of their PE class once a week for the duration of the study. Injuries were defined as any physical problem affecting training or competition in the previous week. Weekly follow-up by the primary researcher was used to confirm and classify the injuries correctly. This allowed for those responses reported as a sickness/illness (e.g. conjunctivitis) or those occurring outside of sports and PE to be appropriately removed. Based on the questionnaire responses and weekly interviews with all participants who reported an injury, the number of new injury cases was determined, and all injuries were further defined as acute or gradual onset/overuse by the researcher. An acute injury was one that could be linked to a specific event whereas an gradual onset/overuse injury could not [153]. The participants reported injuries over the previous week as well as their training and competition (match) exposure. Training and competition exposure were determined from participant responses to Question 1 and 2 of the questionnaire (Figure 1) and PE exposure was determined from attendance and participation in PE class (number of 60 minute PE classes converted to hours per week). If no response was received within two days, a further email reminder was sent.

Reporting of Injuries

The questionnaire used in this study was a modification of the Oslo Sports Trauma Research Centre (OSTRC) questionnaire [150, 154] and consisted of two parts. Part 1 included six questions covering: training exposure, game/competition (match) exposure and the impact of any injuries on sports participation, training volume, sports performance and the extent of any symptoms (Figure 1). If a participant reported an injury, they then completed Part 2 of the questionnaire, which asked about the anatomical location of the injury and how and when the injury occurred. For all new injury cases reported, the average duration in weeks (as determined by follow-up from the primary researcher) was also reported. If the participant had more than one injury, the questionnaire repeated itself, allowing for registration of additional injuries. Finally, participants were asked what day they were on in their menstrual cycle. To do this, participants downloaded either the FITrWoman or My Calendar App (depending on Apple or Android device-both gave day of cycle) prior to the commencement of the study and tracked their menstrual cycle (Figure 1). The participants simply switched from the questionnaire to one of the Apps, got the day of their cycle and then entered it into the questionnaire. If a participant did not have their menstrual cycle, then they put "N/A" and they were not included in the data for menstrual cycle and injuries (n=105). For this study the menstrual cycle was divided into three phases: menses, follicular and luteal. In menses (days 1 to 5) concentrations of estrogen and progesterone are low. During the follicular phase (start of menses to end of ovulation; for this study after menses, days 6 to 14) a surge in estrogen occurs prior to ovulation, followed by a decrease. In the luteal phase (days 15 to end of cycle) progesterone and estrogen levels rise steadily before decreasing at the end of the cycle [155]. The PE teachers included learning about the menstrual cycle at the start of the school year to correspond with this study.

Physical Problem Report Questionnaire

*Physical problem = injury, aches, pains, stiffness, swelling, etc. Does NOT include colds or sickness.

Question 1- Training Exposure

State in numbers, how many hours you have participated in your sport training during the past week?

Question 2- Match Exposure

State in numbers, how many minutes you have participated in your sport matches during the past week?

Question 3

Have you had any difficulties participating in normal training and competition due to physical problems during the past week?

☐ Full participation without physical problems
☐ Full participation, but with physical problems
☐ Reduced participation due to physical problems
☐ Cannot participate due to physical problems

Question 4

To what extent have you reduced your training volume due to physical problems during the past week?

☐ No reduction
☐ To a minor extent
☐ To a moderate extent
☐ To a major extent
☐ Cannot participate at all

Question 5

To what extent have physical problems affected your performance during the past week?

☐ No effect
☐ To a minor extent
☐ To a moderate extent
☐ To a major extent
☐ Cannot participate at all

Question 6

To what extent have you experienced symptoms during the past week?

☐ No symptoms
☐ To a mild extent
☐ To a moderate extent
☐ To a severe extent

Question 7- Physical Problem Area

Please select the location of your physical problem. If the physical problem involves several locations please select the main area. If you have multiple physical problems please complete a separate registration for each one.

☐ Head/face
☐ Neck
☐ Shoulder (including clavicle)
☐ Upper Arm
☐ Elbow
☐ Forearm
☐ Wrist
☐ Hand/fingers
☐ Chest/ribs
☐ Abdomen
☐ Thoracic spine (upper & mid back)
☐ Lumbar spine (low back)
☐ Pelvis and buttock
☐ Hip and groin
☐ Thigh
☐ Knee
☐ Lower leg

☐ Ankle
☐ Foot/toes
☐ Other

Question 8
This physical problem involved:
☐ Sudden onset & contact with another person or equipment
☐ Sudden onset & NO contact with another person or equipment
☐ Gradual onset/overuse
☐ Unknown

Question 9
Physical problems occurred during which of the following:
☐ Practice/sport specific training
☐ Game/competition
☐ Physical education class
☐ Active transport (e.g., biking to school)
☐ Other

Question 10- Menstrual Cycle
What day are you in your menstrual cycle according to the FITrWoman or My Calendar App?

Figure 4.1: Study questionnaire.

Statistical Analysis

Means and standard deviations were calculated for all demographics. The injury rate and corresponding 95% confidence intervals (CI) were calculated based on the number of new injury cases per 1000 hours of sport (training and competition) and PE exposure.

The prevalence of all injuries was calculated for each week of the study using methods previously published [150]. Specifically, the number of participants reporting injuries each week were divided by the number of respondents to the questionnaire each week. The prevalence of substantial injuries was also calculated based on the responses to Questions 4 and 5 of the questionnaire. Substantial injuries were those leading to moderate to severe reductions in training volume or sports performance, or complete inability to participate. If options 3-5 in Questions 4 and/or 5 were chosen, then the injury was classified as substantial. All prevalence estimates were presented as means with corresponding 95% CI.

Each week, an injury severity score ranging from 0 to 100 was also calculated from responses to Questions 3-6 as recommended by the authors who designed the questionnaire [40]. The responses to these questions were allocated a numerical value from 0 to 25, where 0 represents no problems and 25 the maximum. Questions 3 and 6 were scored 0-8-17-25, and Questions 4 and 5 were scored 0-6-13-19-25. The severity scores for each week an injury was reported were then summed in order to get a cumulative severity score. The cumulative severity score was then divided by the number of weeks the injury was reported to get an average weekly severity score [40]. Finally, for each new injury case the average duration of the injury (in weeks) was calculated.

The Pearson chi-square test was used to compare observed and expected frequency of injury based on the participant's date of injury in accordance to the phase of the menstrual cycle (menses, follicular, luteal). Similar to previously reported methods [26], we hypothesized there would be an equal chance of injury on any given day of the cycle. Thus, the expected frequency was determined by describing the length of each phase as a percentage of the entire cycle and using this as the expected injury frequency.

Results

Response Rate to Questionnaire

The overall response rate to the questionnaire was 92%, with the weekly response rate during school terms consistently over 90%. Response rate during school holidays (four weeks) dropped, averaging 60% (Figure 4.2).

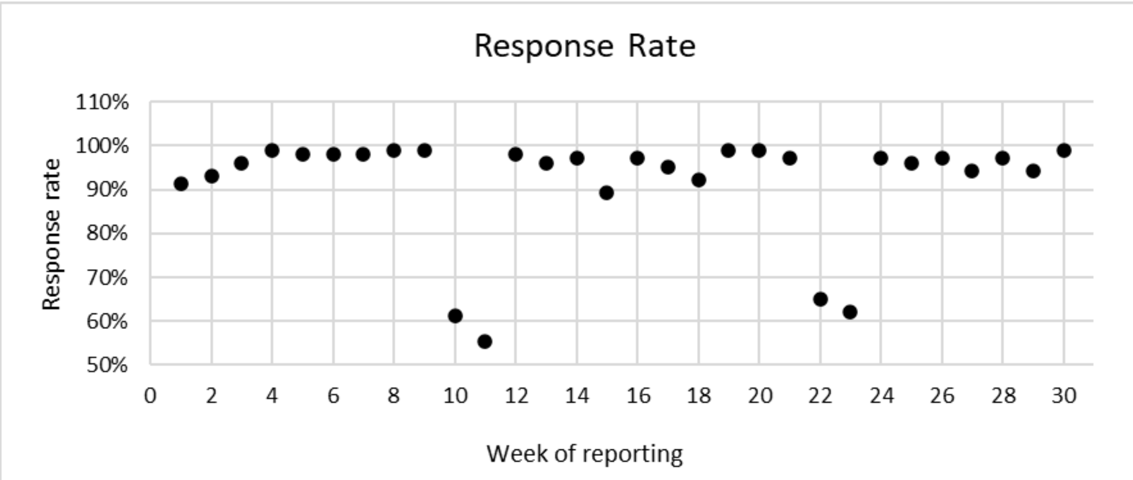

Figure 4.2: Weekly response rate during the 30-week study. The two drops in response rate occur during term breaks in the school year.

Training, Competition, PE Exposure and Injury Rates

A total of 18,351 hours of sport and PE exposure was reported over the 30-week study duration (9,641 hours during training, 2,048 hours during competition and 6,662 hours during PE). The average hours of training, competition and PE per week was 3.4 hours of training, one hour of competition and 2.2 hours of PE. The overall rate of sport and

PE injuries was 10.4 injuries per 1000 hours of training, competition and PE exposure. The rate of sport injuries was 15.3 injuries per 1000 hours (training 12.3 and competition 30.1 per 1000 hours). The rate of PE injuries was 2.6 injuries per 1000 hours of PE exposure.

Prevalence of Injuries

A total of 595 injuries were reported by 74 of the 103 participants. Twenty-nine participants (28%) reported no injuries over the course of the study, 42 participants (41%) reported one to two injuries, 24 participants (23%) reported three to four injuries and 8 participants (8%) reported more than four injuries. Of all reported injuries, 194 (33%) were categorized as substantial. The average weekly prevalence of all injuries was 20.7% and of substantial injuries was 6.7% (Table 4.1). The average weekly duration for new injury cases was 2.1 weeks and for substantial injuries 1.8 weeks (Table 4.1). Throughout the 30-week study duration, the prevalence of overall, acute and gradual onset/overuse injuries decreased (Figure 4.3).

Table 4.1: Average weekly prevalence, average duration, average weekly severity score and cumulative severity score of all reported injuries, acute injuries and gradual onset/overuse injuries.

Physical problem	Overall	Acute	Gradual onset/overuse
Overall	n = 595	n = 244	n = 351
Average weekly prevalence	20.6% (20.4-21.3%)	8.6% (8.3-9.0%)	12.0% (11.4-12.6%)
Average duration (weeks)	2.1 (1.9-2.2)	2.0 (1.8-2.3)	2.1 (1.8-2.3)
Average weekly severity score	32.4 (30.6-34.1)	33.5 (30.6-36.4)	31.6 (29.3-33.8)
Cumulative severity score	74.7 (65.7-83.7)	79.8 (64.9-94.6)	71.1 (59.8-82.4)
Substantial	n = 194	n = 92	n = 102
Average weekly prevalence	6.7% (6.4-7.0%)	3.3% (3.0-3.5%)	3.5% (3.1-3.9%)
Average duration (weeks)	1.8 (1.6-2.1)	2.0 (1.6-2.4)	1.7 (1.3-2.0)
Average weekly severity score	58.8 (55.8-61.9)	60.3 (55.9-64.6)	57.7 (53.3-62.1)
Cumulative severity score	116.6 (96.8-136.4)	136.3 (105.4-167.1)	101.2 (75.7-126.7)

Data are presented as mean values with (95% CI).

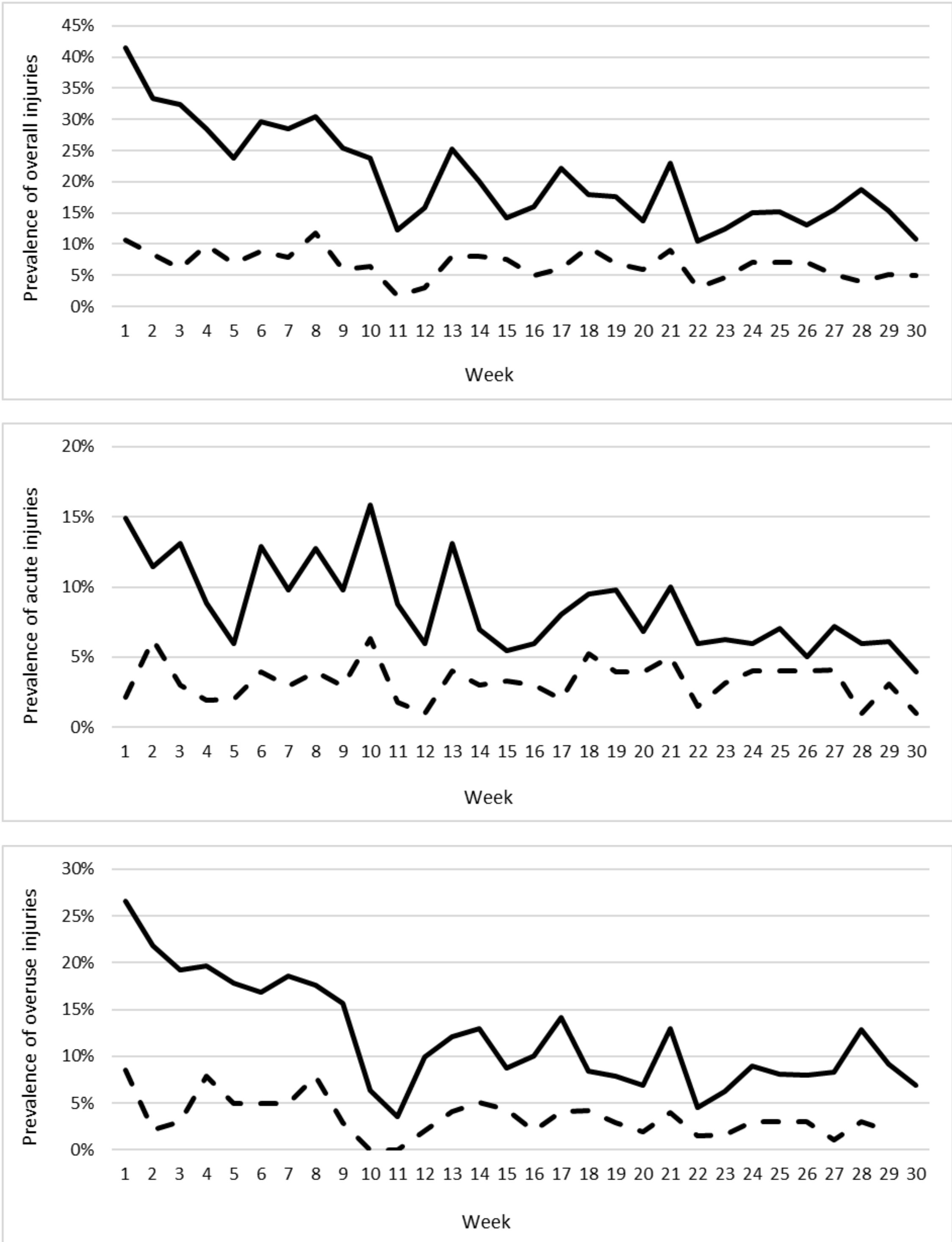

Figure 4.3: Weekly prevalence of injuries reported during the 30 weeks of the study. Solid lines represent all reported problems and dashed lines represent substantial problems.

Prevalence of Acute and Gradual Onset/Overuse Injuries

A total of 244 acute injuries and 351 gradual onset/overuse injuries were reported. The average weekly prevalence of acute injuries was 8.6% and gradual onset/overuse injuries was 12% (Table 4.1). The average weekly duration of new cases of acute injuries was two weeks and of gradual onset/overuse injuries was 2.1 weeks (Table 4.1). The most commonly reported acute injuries involved the ankle (35.2%) followed by knee (11.9%), while the most commonly reported gradual onset/overuse injuries involved the knee (51.3%) and lumbar spine (9.4%) (Table 4.2). The average duration, average weekly severity score and cumulative severity score for all injuries can be found in Table 4.1.

Table 4.2: Overview of reported injuries and duration by injured area.

Acute injury n = 244		Average Duration* (weeks)	Overuse injury n = 351		Average Duration* (weeks)
Ankle	86 (35.2%)	2.8	Knee	180 (51.3%)	2.7
Knee	29 (11.9%)	1.6	Lumbar spine	33 (9.4%)	3.3
Thigh	21 (8.6%)	1.5	Lower leg	22 (6.3%)	1.6
Shoulder	20 (8.3%)	4.0	Thigh	19 (5.4%)	1.3
Hand/fingers	20 (8.3%)	1.8	Shoulder	18 (5.1%)	2.6
Wrist	12 (4.9%)	2.4	Ankle	17 (4.8%)	1.2
Lumbar spine	12 (4.9%)	2.0	Hip/groin	15 (4.3%)	1.4
Foot/toes	12 (4.9%)	1.7	Foot/toes	15 (4.3%)	1.3
Thoracic spine	8 (3.3%)	2.0	Thoracic spine	12 (3.4%)	1.5
Lower leg	8 (3.3%)	1.6	Wrist	7 (1.9%)	7.0
Abdomen	3 (1.2%)	1.0	Pelvis/buttock	6 (1.7%)	1.5
Head/face	2 (0.8%)	1.0	Chest/ribs	3 (0.9%)	1.0
Neck	2 (0.8%)	2.0	Hand/fingers	2 (0.6%)	1.0
Upper arm	2 (0.8%)	2.0	Neck	1 (0.3%)	1.0
Elbow	2 (0.8%)	1.0	Forearm	1 (0.3%)	1.0
Chest/ribs	2 (0.8%)	1.0			
Forearm	1 (0.4%)	1.0			
Pelvis/buttock	1 (0.4%)	1.0			
Hip/groin	1 (0.4%)	1.0			

Data for physical problem area are presented as a frequency. * = based on new injuries reported.

Prevalence of Substantial Injuries

A total of 92 substantial acute and 102 substantial gradual onset/overuse injuries were reported. The average weekly prevalence of substantial acute injuries was 3.3% and substantial gradual onset/overuse was 3.5% (Table 4.1). The average weekly duration of substantial acute injuries was two weeks and of substantial gradual onset/overuse injuries was 1.7 weeks (Table 4.1). The average duration, average weekly severity score and cumulative severity score for substantial injuries can be found in Table 4.1.

Menstruation

There was no significant association between menstrual phase and proportion of injuries (chi-square = 3.42, p = 0.18). However, there were more injuries during the menses phase than expected (26 injuries, 25% observed, 18% expected). Conversely there were less injuries than expected in both the follicular (29 injuries, 27% observed, 32% expected) and luteal phases (50 injuries, 48% observed, 50% expected).

Discussion

This study demonstrated that on average, 21% of youth females from a girls' secondary school (12-15 years) experienced an injury during sports participation or PE each week. Gradual onset/overuse injuries were more common than acute injuries (59% versus 41%, respectively). The overall sports and PE injury rate was 10.4 injuries per 1000 hours of sports and PE exposure. Based on these findings, injury prevalence in youth females may be higher than previously reported.

Accurate injury rates in youth are critical to the development and evaluation of injury prevention programs. The OSTRC questionnaire used in this study has been shown to be a more valid tool to track injuries, as it captures all injuries rather than just time-loss [38]. Furthermore, Clarsen, Myklebust [40] suggested the OSTRC questionnaire method can identify more than 10 times as many injuries as the time-loss method. Thus the current study was designed to capture more than just time-loss injuries, with an "all physical problems" injury definition [150, 154]. The injury rate in this study (10.4 injuries per 1000 hours) is similar to that reported in the only other study we are aware of that used the OSTRC questionnaire in youth females [37]. In a cohort of 60 female soccer, basketball and gymnastic athletes (mean age 16.6 years), the injury rate over the course of one season (30-36 weeks) was 8.6 injuries per 1000 hours of sport participation [37].

We suggest the rates from the current study and the study by Richardson, Clarsen [37] represent a more valid indication of injury rates in youth females compared to the lower rates reported previously (2.3 to 4.8 injuries per 1000 hours) using a time-loss or medical attention definition [156-158]. To illustrate, a cohort of male and female ballet dancers (aged 11-30 years) completed weekly questionnaires (modified OSTRC questionnaire) using three injury definitions: 1) time-loss, 2) medical attention, and 3) any complaint for an academic year (31-40 weeks). The self-reported injury rates based on injury definition were 0.72 injuries per 1000 dance hours for time-loss, 0.99 injuries per 1000 dance hours for medical attention and 3.24 injuries per 1000 dance hours for any complaint [38]. Based on these results, it was concluded that time-loss and medical attention definitions underestimate injuries and therefore injury rates in youth as many athletes continue to play and train despite having an injury [39].

Although injury rates in the current study were higher than previously reported, most injury locations are in agreement with previous studies in youth females [36, 37]. In this study, the most injured area of the body for acute injuries was the lower extremity (64.7%), followed by the upper extremity (25.1%) and the trunk (10.2%). For gradual onset/overuse injuries, the lower extremity was still the most common (78.1%), followed by the trunk (13.7%) and then the upper extremity (8.2%). This is consistent with previous research, showing the ankle and knee to be the most common injury sites in youth females [36]. In the current study, the most common acute injury locations were the ankle, knee and the thigh, whereas the most common gradual onset/overuse injury locations were the knee, lumbar spine and lower leg. A similar distribution of acute and gradual onset/overuse injury locations has been reported in youth female soccer, basketball and gymnastic athletes with the ankle, knee, and the thigh the most common acute injury locations and the knee, thigh and lower back the most common gradual onset/overuse injury locations [37]. Thus, this supports the need for prevention programs designed to reduce lower extremity and lower back injury in youth females.

The average weekly prevalence of injury in the current study (20.7%) was similar to that reported by Pluim, Loeffen [151] in a study of elite youth tennis players aged 11-14 years (21.5%). The prevalence of acute (8.6% vs 3%, respectively) and gradual onset/overuse injuries (12% vs 12.1%, respectively) in the current study was also similar to that reported by Pluim, Loeffen [151]. However, the prevalence of substantial injuries found in our study (6.7%) was less than half of that reported by Pluim, Loeffen [151] (15.2%). The difference between the current study and Pluim, Loeffen [151] is likely due to the elite nature of the players in the Pluim, Loeffen [151] study and the injury definition which included illness. The average weekly duration for both acute (2 weeks) and gradual onset/overuse injuries (2.1 weeks) in the current study was also similar to that of Pluim, Loeffen [151] (2.2 and 2.5 weeks, respectively). According to previous research an average duration of two weeks (8-28 days) would be considered moderate severity [40, 150]. Based on the average weekly duration of acute and gradual onset/overuse injuries by injured area, our findings indicate that only 8.4% of acute and 10% of gradual onset/overuse injuries would be considered severe (>28 days) [40, 150, 159].

Although we did not find a link between injuries and the menstrual cycle , similar to previous studies in females [27-29], we found a greater number of injuries than expected (25% versus 18%, respectively) in the menses phase. Indeed, a study that divided the menstrual cycle into similar phases found that more injuries occurred in the menses phase, particularly on days 1 and 2 of the menstrual cycle [28]. Two other studies reported more injuries during both menses and luteal phases in women's soccer and handball athletes [27, 29]. In contrast, another study found a greater risk of injury during the ovulatory phase [26]. These different findings may be due to differences in the definition and timeframes of each phase. Alternatively it may be due to the fact that fluctuating levels of estrogen and progesterone can favor either tissue degradation or repair at specific times during the menstrual cycle [28]. Hormone levels may also affect the neuromuscular system, specifically motor performance during the different phases of the menstrual cycle, and motor skill deficits during certain phases could lead to potential injuries [160].

A strength of the current study was the high overall response rate (93%) and the weekly follow-up by the primary researcher to confirm the nature of any injury. An additional strength of the current study was that the PE teachers included learning about the menstrual cycle at the start of the school year to coincide with this study. This may have assisted the girls to accurately track their menstrual cycle and confidently answer any questions the primary researcher had regarding their menstrual cycle.

Conclusion

To our knowledge, this is the first study to report on sport and PE injuries over the course of an academic school year, as well as investigate if more injuries occur during a certain phase of the menstrual cycle, in youth females (12-15 years). We have shown that injury rates in youth females (based on an "all physical problem" definition) may be higher than previously reported and confirmed the lower extremity as the most common injury location. The high rate of injuries in this group corroborates the need for the implementation of injury prevention strategies.

Chapter 5 : The Relationship between Strength, Athletic Performance and Movement Skill in Youth Females

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Prelude

Previous chapters in this thesis have provided evidence to show that the lower extremity is an important area to target in youth females to prevent injury. Specifically, chapter 4 identified the lower extremity and lower back as the most common locations for injury in sport and physical education. Chapter 2 identified a lack of lower body strength as a risk factor for injury, and chapter 3 suggested that if time is limited, an IP program should focus on lower extremity strength. Though previous research has identified a relationship between strength, movement skill and athletic performance in male populations, such relationships are relatively unstudied and unclear in young females. Thus, the aim of this chapter was to examine the influence of strength on movement skill and athletic performance in youth females.

Introduction

Muscular strength in children and adolescents is associated with many health and physical benefits including enhanced functioning of the cardiorespiratory and muscular systems [1], enhanced bone mineral density and skeletal health [161], lower risk of obesity and sports injuries, as well as favorable changes and maintenance of body composition [162]. Strength also contributes to components of athletic performance [163] including power [164], speed and agility [42]. There is evidence that muscular strength is linked to enhanced movement skill development and an active lifestyle in adulthood [165].

As well as enhancing movement development and building confidence to participate, muscular strength is likely to reduce the risk of sport related injury, further contributing to increased participation in adulthood [36, 166]. Muscular strength has been shown to reduce sports-related injury risk in youth [167]. Injury risk has been linked to neuromuscular control during dynamic sporting actions, which are achieved by a combination of active muscle force and passive ligament restraints [49]. Deficits in strength may limit the ability for muscular co-contraction leading to reduced joint stability. A recent review on best-practice guidelines for preventing anterior cruciate ligament injuries in young females recommended that programs incorporate lower body strength exercises and focus on landing stabilization (e.g. neuromuscular control) [168]. Previous research that incorporated strength exercises as part of a training program showed a reduction in injuries in youth [138].

Given links to movement skill and injury risk, the development of muscular strength during youth seems of particular importance. Youth, defined as children (≤ 11 years in girls and ≤ 13 years in boys) and adolescents (aged 12-18 in girls and 14-18 in boys) [109], go through a period of accelerated growth. This growth spurt includes a phase of increasing height and mass, which have been shown to disrupt motor control and movement patterns [108]. During the growth spurt, differences between males and females become apparent in neuromuscular strength, power and coordination [18, 169]. The difference between sexes is possibly due to unique hormonal changes that lead to the unfavorable distribution of fat and muscle mass in females [18, 170], resulting in reduced relative muscle strength [16, 19]. Relative strength (takes into account a person's body mass) may be a better indicator than absolute strength of performance and movement tasks as a person has to move their own body mass through space [171]. Greater relative strength can also increase the ability to generate a higher impulse which could be beneficial for time constant tasks such as acceleration and deceleration. Furthermore, research has shown that, compared to youth males, youth females have half the lower extremity muscle strength development [20]. Thus, understanding strength and how it affects the young female athlete is of interest to best support their development.

Little is known about the relationship between maximum strength, athletic performance and movement skill in youth females. To our knowledge, only one study has reported on the relationship between strength and performance in youth females [172]. The findings showed that stronger athletes were significantly faster in sprint and change of direction and jumped higher than weaker athletes. However, the study did not examine the relationship between strength and movement skill and was limited to netball players. Therefore, the purpose of this study was to examine the relationship between maximum strength and measures of athletic performance and movement skill in youth females. Furthermore, this study aimed to determine whether higher relative strength is related to better athletic performance and movement skill.

Methods

Experimental Approach to the Problem

A cross-sectional design was used to examine the relationship between relative strength, measured via an isometric mid-thigh pull (IMTP), and athletic performance, including 10 and 20 m speed, double and single leg (R = right leg, L = left leg) countermovement jump (CMJ) and movement skill, as measured by the back squat assessment (BSA) and drop vertical jump (DVJ).

Subjects

One hundred and four youth females (mean ± SD; age = 14.0 ± 0.6 y; height = 162.6 ± 5.9 cm; mass = 57.3 ± 9.7 kg) from physical education (PE) classes at a girls' secondary school participated in this study. Descriptive characteristics can be found in Table 5.1. The girls participated in a variety of sports including netball, soccer, field hockey, lacrosse, swimming, athletics, badminton, and rowing. The University Ethics Committee approved the study and subjects and parents/guardians were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent/assent document to participate in this study. Informed parental/guardian consent and subject assent was obtained from all girls.

Procedures

Testing was performed across two separate PE classes at the start of an academic school term. Prior to testing on both days, subjects completed a standardized warm-up followed by exercise specific warm-ups (e.g. double and single leg CMJ at 70%, 80% and 90% maximum perceived effort) as instructed by the primary researcher. Day one consisted of anthropometrics (height, seated height and body mass), DVJ, IMTP and 10 and 20 m sprints. Day two consisted of BSA and double and single leg CMJ.

Isometric Mid-thigh Pull

The IMTP was performed using a portable strain gauge (MT501 Universal Load Cell) at a sampling rate of 1000 Hz and analysed with custom software. A straight barbell was fixed to a chain and the chain adjusted until the barbell was placed below the hip crease for each subject in order to assume a body position that replicates the start of the second pull position during the clean. Subjects stood with feet approximately shoulder width apart, a knee angle between 125-145°, a hip angle between 140-150°, hand grip a thumbs width away from the hips and torso upright as described previously [173]. Once stable, subjects were instructed to pull on the bar as hard and fast as possible for three seconds for two trials, with a minute rest between trials. Verbal encouragement was given to all subjects throughout the pull. Peak force (PF) was reported and divided by body mass to determine relative PF (relIMTP).

Maturation

Anthropometric variables of body mass, standing height and seated height were collected. Standing height was measured to the nearest 0.1 cm using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Seated height was measured to the nearest 0.1 cm using a meter stick taped to a wall above a 40 cm wooden box. Body mass was measured to the nearest 0.1 kg using a digital scale (Model: TI390150K; Tanita, New Zealand). Maturation was assessed using a sex-specific regression equation from Mirwald et al. [174] which has been found to be reliable, non-invasive and a practical solution for the measure of biological maturity.

Countermovement Jump

The CMJ, double and single leg, was performed on two portable force plates (Pasco, California, USA) at a sampling rate of 100 Hz. Subjects were instructed to keep their hands on their hips at all times to avoid interference from the upper body and to squat down to a self-selected depth and jump as high as possible. For the single leg trials, an additional instruction to start with one leg flexed to 90° at the hip was given. The subjects performed two trials of each jump with one minute rest between trials. Force-time data was analysed with custom-built LabVIEW software (version 14.0, National Instruments, Austin, TX, USA). The software used displacement (integral of velocity over time) to calculate CMJ height.

Sprints

The sprints (10 and 20 m) were performed in an indoor gymnasium using double-beam timing gates (SWIFT Performance, Alstonville, Australia). Subjects started with a self-selected foot forward, 50 cm behind the first set of gates, from a static position with no rocking or movement beforehand. Each subject completed two trials separated by at least one minute rest.

Drop Vertical Jump

Two tripod mounted iPads (one m high) were placed three m anterior and lateral to a 30 cm high bench. Subjects were instructed to stand with feet shoulder width apart on the bench, drop down off the box onto a tape marker 30 cm in front of the bench and immediately perform a maximum vertical jump. Performance was assessed using the land error scoring system, a 17 item assessment of jump-landing technique based on 'errors' in lower extremity and trunk position during initial ground contact and maximum knee flexion [175]. A lower score indicates a better jump-landing technique. Subjects performed three trials, with the average of the three trials used for analysis.

Back Squat Assessment

Similar to the DVJ, two tripod mounted iPads (one m high) were positioned three m anterior and lateral to the subject. Subjects were instructed to stand with feet shoulder width apart, hold a dowel in back squat position with a grip slightly greater than shoulder width, forearms parallel to torso and upper back musculature contracted. A researcher used the script suggested by Myer et al. [176], "please stand upright with feet shoulder width apart. Squat down until the top of your thighs are at least parallel to the ground, and then return to the initial starting position. Perform 10 continuous repetitions at a consistent, moderate pace or until you are instructed to stop." The BSA uses 10 criteria for scoring that are categorized into upper body, lower body and movement mechanics. If an undesired technique is found in two or more of the 10 repetitions then a deficit is scored. A lower score indicates better squat technique.

Statistical Analysis

Mean values and standard deviations were calculated for all descriptive data (Table 5.1). [177]. With-in session reliability was calculated using pairwise comparisons on log-transformed data to reduce the effects of any non-uniformity error [178]. The typical error was expressed as a coefficient of variation (CV) to determine absolute reliability and the intraclass correlation coefficient (ICC) was used to determine relative reliability. For the ICCs, 95% confidence intervals (CI) were reported. Acceptable within-session reliability of an ICC of ≥ 0.70 and CV ≤ 15% was used [179]. Kolmogorov-Smirnov tests revealed that all the data was normally distributed. The best effort was used for analyses of all performance measures except BSA and DVJ, which were rated on a scale. Pearson's product-moment correlation coefficient (r) was used to determine relationships between strength, athletic performance and movement skill. The correlation coefficients were classified as follows: 0.0-0.1 = trivial, 0.11-0.3 = small, 0.31-0.5 = moderate, 0.51-0.7 = large, 0.71-0.9 = very large, 0.91-1 = nearly perfect [180]. Due to multiple correlations performed, the p value was corrected for familywise error to $p < 0.01$. To further examine the influence of relative strength on performance variables the relMTP results were converted to z-scores and subjects classified as either weak ($z > -1.0$), average ($z = -1$ to 1) or strong ($z > 1$). A one-way between groups ANOVA was used to assess the differences in performance variables between strength groups. Bonferroni post-hoc tests were used to examine the differences between groups. Differences between groups are reported as percent difference and effect sizes according to Cohen's d were classified as follows: 0.0-0.19 = trivial, 0.2-0.49 = small, 0.5-0.79 = medium, ≥ 0.8 = large [177]. Descriptive data was analysed through Microsoft Excel 2013, whereas Pearson correlations and the ANOVA were analysed using SPSS (version 25; SPSS Inc, Chicago, IL). Statistical significance was set at $p < 0.05$.

Table 5.1: Subject characteristics for anthropometric and performance measures.

Subject characteristics (n = 104)	Mean ± SD
Age (years)	14.0 ± 0.6
Seated height (cm)	85.5 ± 3.1
Standing height (cm)	162.6 ± 5.9
Body mass (kg)	57.3 ± 9.7
Maturity offset (years from PHV)	1.8 ± 0.5
IMTP (N)	769.3 ± 189.9
relIMTP (N/kg)	13.5 ± 2.9
BSA+	4.8 ± 2.0
DVJ+	7.2 ± 1.8
10m sprint (s)	2.06 ± 0.11
20m sprint (s)	3.63 ± 0.25
CMJ height (cm)	21.8 ± 4.5
RCMJ height (cm)	11.3 ± 3.1
LCMJ height (cm)	11.1 ± 3.1

PHV = peak height velocity; IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; BSA = back squat assessment; DVJ = drop vertical jump; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump. + = rated on a scale; BSA out of 10 and DVJ out of 17.

Results

All tests achieved acceptable within-session reliability (Table 5.2). Descriptive characteristics for the anthropometric and performance variables can be found in Table 5.1. The relationship between strength and performance variables is shown in Table 5.3. Specifically, IMTP had significant small to large relationships with all performance variables ($r = 0.23$-0.62, $p < 0.01$) except RCMJ and LCMJ height ($r = 0.17$-0.23, $p > 0.01$). The relIMTP had significant moderate to large relationships with all performance variables ($r = 0.32$-0.60, $p < 0.01$).

Table 5.2: Reliability of tests.

Variable	ICC (95% CI)	CV (%)
IMTP (N)	0.91 (0.88 to 0.93)	8.3
relIMTP (N/kg)	0.89 (0.85 to 0.92)	8.3
10m sprint (s)	0.92 (0.89 to 0.94)	1.6
20m sprint (s)	0.85 (0.80 to 0.89)	2.8
CMJ Height (cm)	0.84 (0.79 to 0.89)	9.6
RCMJ Height (cm)	0.87 (0.81 to 0.90)	12.3
LCMJ Height (cm)	0.89 (0.85 to 0.92)	10.8
BSA+	0.98 (0.93 to 0.99)	12.4
DVJ+	0.98 (0.93 to 0.99)	6.8

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; BSA = back squat assessment; DVJ = drop vertical jump; + = rated on a scale; BSA out of 10 and DVJ out of 17, a lower score indicates a better performance.

Table 5.3: The association between strength and all performance measures.

Variable	IMTP (95% CI)	relIMTP (95% CI)
BSA	-0.31* (-0.49 to -0.12)	-0.42* (-0.59 to -0.23)
DVJ	-0.29* (-0.48 to -0.10)	-0.35* (-0.93 to -0.28)
10m sprint	-0.44* (-0.61 to -0.28)	-0.60* (-0.76 to -0.43)
20m sprint	-0.45* (-0.62 to -0.27)	-0.57* (-0.73 to -0.40)
CMJ height	0.27* (0.08 to 0.46)	0.45* (0.27 to 0.62)
RCMJ height	0.17 (-0.03 to 0.37)	0.32* (0.13 to 0.50)
LCMJ height	0.23 (0.03 to 0.41)	0.35* (0.16 to 0.53)

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; BSA = back squat assessment; DVJ = drop vertical jump; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; CI = confidence interval; *$p < 0.01$.

Results for all performance variables by groups based on strength can be found in Table 5.4. There were significant differences between strength groups for all performance measures (Table 5.5). Post hoc Bonferroni comparisons indicated that strong girls (SG) had significantly faster sprint times than average girls (AG) in the 10 m and 20 m sprints. Additionally, SG and AG performed significantly better than weak girls (WG) in all assessments.

Table 5.4*:* Performance variables by groups based on strength.

Variable	Strong (n = 14)	Average (n = 71)	Weak (n = 19)
	Mean ± SD	**Mean ± SD**	**Mean ± SD**
Age (years)	13.9 ± 0.54	14.1 ± 0.60	14.0 ± 0.57
IMTP (N)	994.43 ± 123.33	780.90 ± 153.64	560.32 ± 132.19
relIMTP (N/kg)	18.40 ± 1.31	13.66 ± 1.50	9.37 ± 1.40
BSA+	3.9 ± 1.8	4.7 ± 1.8	6.1 ± 2.0
DVJ+	6.28 ± 0.89	6.95 ± 1.55	8.46 ± 2.25
10m sprint (s)	1.97 ± 0.05	2.05 ± 0.10	2.17 ± 0.11
20m sprint (s)	3.43 ± 0.09	3.61 ± 0.20	3.86 ± 0.33
CMJ height (cm)	24.3 ± 3.9	21.8 ± 4.0	18.2 ± 3.4
RCMJ height (cm)	12.1 ± 3.6	10.9 ± 2.8	9.2 ± 1.8
LCMJ height (cm)	12.2 ± 3.0	10.8 ± 2.6	8.9 ± 2.0

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; BSA = back squat assessment; DVJ = drop vertical jump; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; + = rated on a scale; BSA out of 10 and DVJ out of 17.

Table 5.5: Differences in performance between groups based on strength.

Variable	ANOVA		Strong vs Average			Strong vs Weak			Average vs Weak		
	F (2, 101)	P	% difference	ES	P	% difference	ES	P	% difference	ES	P
Maturity offset (yrs from PHV)	0.78	0.467									
IMTP (N)	36.13	<0.001*	40.1	2.47	<0.001	77.5	3.4	<0.001	26.7	1.25	<0.001
relIMTP (N/kg)	155.41	<0.001*	48.8	5.63	<0.001	96.5	6.66	<0.001	32	2.69	<0.001
BSA+	6.23	0.003*	-24.8	-0.71	0.448	-36.3	-1.13	0.004	-15.3	-0.49	0.015
DVJ+	8.28	<0.001*	-12.3	-0.65	0.543	-25.7	-1.39	0.001	-15.3	-0.64	0.002
10m sprint (s)	20.21	<0.001*	-5.2	-1.52	0.019	-9.5	-2.57	<0.001	-4.6	-1.01	<0.001
20m sprint (s)	15.13	<0.001*	-6.5	-1.7	0.036	-11.1	-2.05	<0.001	-5.0	-0.74	<0.001
CMJ height (cm)	10.36	<0.001*	11.5	0.64	0.297	33.4	1.66	<0.001	19.6	0.96	0.001
RCMJ height (cm)	5.86	0.004*	10.4	0.36	1.000	31.1	1.07	0.023	18.7	0.76	0.005
LCMJ height (cm)	7.07	0.001*	13.4	0.52	1.000	37.3	1.32	0.005	21.1	0.82	0.003

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; BSA = back squat assessment; DVJ = drop vertical jump; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; + = rated on a scale; BSA out of 10 and DVJ out of 17; *$p < 0.05$.

Discussion

This study examined the relationship between maximum strength and measures of athletic performance and movement skill in youth females. Our findings showed that strength was positively associated with sprint performance, jump height and movement ability (BSA and DVJ). In addition, the SG were significantly faster than the AG and WG and they performed better than the WG on all other tests.

These findings are in agreement with previous research that has shown moderate to strong relationships between maximal strength (one repetition maximum) and 10 m sprint ($r = 0.94$), 30 m sprint ($r = 0.71$) and CMJ height ($r = 0.78$) in elite adult male soccer players [181]. Relative strength had strong to very strong correlations with speed and change of direction ability in female softball players [182]. Similarly in adults, thigh muscular strength was significantly correlated with vertical jump and triple-hop distance [183]. The current study supports findings from existing evidence to reinforce the importance of relative strength on performance measures of speed and jump height.

In line with the positive correlations, group comparisons revealed that SG performed significantly better than both AG and WG in 10 m and 20 m sprint. A previous study found that, in a group of youth netball athletes, strong girls were significantly faster in 5 m and 10 m sprint compared to weak girls [172]. Both the findings from the current study and the study by Thomas et al. [172] demonstrate the importance of relative strength measures to sprint performance. Furthermore, collegiate male football players with high relative strength (measured by a back squat) compared to those with low relative strength had better sprint performance [184]. Since sprinting requires high levels of relative strength to generate the forces required to overcome the inertia of body mass, these findings make sense. Evidence in male youth football athletes suggests that increases in relative strength occur alongside increases in sprint performance [185].

As well as being faster, SG also jumped higher than WG. These findings agree with a previous study that found stronger netball players (measured by IMTP) were able to produce significantly greater vertical jump heights than weaker players [172]. In a group of male and female collegiate athletes, stronger athletes (measured by IMTP) jumped higher than weaker athletes [186]. The current study supports findings from existing evidence in confirming that isometric measures of strength are related to sprinting and jumping and that stronger athletes are faster and jump higher. Accordingly, to improve performance, developing strength relative to body mass is key in youth females, as the ability to change direction, accelerate, decelerate and jump are all dependent on the ability to move one's own body mass. Furthermore, increasing relative strength can lead to the ability to generate sufficient impulse which could be beneficial for time constant tasks such as acceleration and deceleration.

In agreement with the performance measures, SG also showed better movement skill than WG. Although variation exists in the tests that were utilized, previous research has found a link between strength and movement scores. In youth male soccer players, a significant association was found between reactive strength index and the functional movement screen total score [187]. Likewise, relative strength (measured by the IMTP) was the greatest predictor and significantly correlated with the resistance training skills battery [171]. It has been reported that children who do not have sufficient strength may be less competent in movement skill on the playground and sport field [188]. Without opportunities to gain strength in order to be competent in their abilities to move, youth will be less likely to engage in physical activity throughout life [189]. Additionally, because relative muscular strength is associated with movement ability, it may reduce injury risk by improving neuromuscular control. Previous research has demonstrated that youth athletes are at a greater risk of sports-related injury if they do not possess adequate muscle strength [190]. This highlights the importance of improving relative muscle strength in youth to both improve physical activity trajectories and reduce associated injury risk.

In the current study, maturational status was measured with the intent to investigate any association with strength. As almost all (98 out of 104) of the subjects were post peak height velocity (period of maximum growth, PHV) females, we could not investigate the influence of maturity status. However, this was a strength of the study as maturity status was not a confounder. As most were post-PHV, future research should aim to include subjects in all three maturation groups. Recent research looked at the influence of maturity status on strength and movement skill in youth males and found that maturity status had a significant relationship with absolute strength but non-significant relationships with both relative strength and the resistance training skills battery [171]. To our knowledge, only one study has examined the relationship between maturity status and strength in youth female soccer players and found that post-PHV girls had higher relative strength than circa (in the period of maximum growth) and pre-PHV girls [191]. However, there is no research on maturity status and its relationship to movement skill in youth females. As females, compared to males, have reduced relative strength, power and coordination following the growth spurt, more research is needed to see if this exists across maturation groups. This information may assist practitioners and coaches in developing long-term athletic development programs according to maturation status.

Practical Applications

The results from the current study illustrate the importance of developing relative lower-body strength to enhance sprint performance, jump height and movement ability in youth females. Furthermore, strong girls demonstrated superior sprint times than both average and weak girls and superior jump height and movement skill than weak girls. Thus, it is recommended to coaches and practitioners that a large emphasis of training programs be placed on developing relative strength in order to improve performance and movement skill in youth females.

Chapter 6 : The Effect of a School Based Injury Prevention Program on Physical Performance in Youth Females

Prelude

In chapter 5, findings showed that relatively stronger girls were faster, jumped higher and had better movement skill than weaker girls, highlighting the importance of relative strength in young girls for performance and injury risk outcomes. Injury prevention programs have been used for multiple purposes, including to develop relative strength, reduce injury risk factors and increase athlete performance. However, most IP programs have been short in duration, generalized in their progression and implemented outside the school curriculum. Accordingly, chapter 6 aimed to further our understanding of an IP usefulness by examining the mechanistic and performance effects of a 23 week, progressive (length and complexity) program embedded in a school setting. The IP program developed and presented in this chapter is based on risk factors linked to injury in females identified in chapter 2 and integrates the components that have made IP programs successful identified in chapter 3.

Introduction

Sport and physical activity has many positive effects on the musculoskeletal, cardiorespiratory and psychological health of youth [3]. There is also evidence that when a young person participates in sport their level of physical activity as an adult is increased [5]. However, participating in sports comes with risk of injury. In fact, sport is the leading cause of injury in youth [6-8], with the lower extremity the most commonly injured area [35]. These injuries occur most frequently during sports that include jumping and landing, running and decelerating and changing direction [41]. Furthermore, injuries in youth can negatively impact present and future involvement in sport and physical activity [192]. For instance, limited competition time, an early finish to the sports season, and/or a reduction in physical activity due to the fear of re-injury [46]. Given the high incidence of lower extremity injuries during sport, preventative measures that reduce risk are warranted.

Increased injury risk and reduced performance in youth has been associated with changes in height and body mass shown to disrupt motor control and movement patterns [16]. This becomes more prominent during peak height velocity (PHV), a period of accelerated growth that occurs at approximately 11-12 years in females and 13-14 years in males [15]. Peak height velocity is a time where males start to physically outperform females. For example, research shows that males jump higher and suffer smaller landing forces compared to females [19]. Moreover, post-PHV females have been shown to exhibit significantly greater knee abduction moment and motion during drop-jumping compared to their male counterparts [16, 22]. These changes may contribute to the increased injury risk in youth females [14, 25]. In summary, the natural development of skeletal tissue and muscle mass during PHV appear to result in a neuromuscular spurt (i.e., increase in strength and power) for young males. Such changes are missed out on by young females, increasing their risk of injury [18, 19].

Injury prevention (IP) programs have been shown to reduce injury incidence, risk factors for injury and/or improve athletic performance in youth athletes [42, 44]. The benefits of an IP program designed for females may result in increases in strength, power and neuromuscular control as well as a reduction in muscle imbalances [42]. These benefits can be optimized with programs consisting of multiple components, individually progressed based on participant ability and with high adherence [43]. Most IP programs, however, have been acute in nature, have not been individually progressed, have not been embedded in the school curriculum to maximise adherence, and have not considered maturation. Investigations into an evidence-based IP program in youth females is required to better understand the potential for reduced injury risk and improved performance in this at-risk population. Therefore, the purpose of this study was to examine the effects of an IP program, integrated into the school curriculum, on injury risk factors and athletic performance measures in youth females.

Methods

Experimental Approach to the Problem

A non-randomized controlled trial was used to determine the effects of an IP program done during the physical education (PE) curriculum on injury risk factors and athletic performance in youth females. Two PE classes were used for the intervention (INT) group and two PE classes of the same grade level were used for the control (CON) group. For the INT group, girls were selected based on their level of interest and physical ability in a 10 m sprint and beep test. Both groups included one year nine and one year 10 class. The INT group completed an IP program during PE class, while the CON group completed their regular PE class. The IP program was done twice per week over three school terms. When data collection weeks and school term breaks were accounted for, the INT group completed 23 weeks of the IP program (Figure 6.1). Both groups completed the same battery of tests four times throughout the intervention period (Figure 6.1). These included athletic performance measures of speed (10 and 20 m sprint), jump height and power assessed by single and double leg countermovement jump (CMJ), and modifiable factors associated with injury risk including strength (isometric mid-thigh pull [IMTP]), balance (y-balance) and movement skill assessed by the back squat assessment (BSA), and drop vertical jump (DVJ).

Month	JAN	FEB				MAR				APR				MAY				JUN				JUL				AUG				SEP				OCT				NOV			
School Term	Term 1											Term break	Term 2										Term break	Term 3										Term break	Term 4						
School Week #	1	2	3	4	5	6	7	8	9	10	11		12	13	14	15	16	17	18	19	20	21		22	23	24	25	26	27	28	29	30	31		32	33	34	35	36	37	38
Microcycle #														1	2	3	4	5	6	7	8			1	2	3	4	5	6	7	8	9			1	2	3	4	5	6	
Mesocycle Blocks													Data Collection	1				2				Data Collection		3			4			5			Data Collection		6			7			Data Collection
Phase Focus	Pilot Testing/ Familiarization												Body-weight exercises											Light resistance											Moderate-high resistance						
Duration													10 minutes											20 minutes											40 minutes						

Figure 6.1: Overview of the annual plan of the injury prevention program and timeline of data collection.

Subjects

Ninety-two youth females from PE classes at a girls' secondary school participated in this study. Forty-three girls from year nine and 10 PE classes were in the INT group and 49 girls from year nine and 10 PE classes were in the CON group. The girls participated in a variety of sports including netball, soccer, field hockey, lacrosse, swimming, athletics, badminton, and rowing. The University Ethics Committee approved the study and subjects and parents/guardians were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent/assent document to participate in this study. Informed parental/guardian consent and subject assent was obtained from all girls.

Procedures

Testing was done during two separate PE classes at the start of an academic school term then at the end of each school term for four sessions total. Prior to testing on both days, participants completed a standardized warm-up followed by exercise specific warm-ups (e.g. double and single leg CMJ at 70%, 80% and 90% maximum perceived effort) as instructed by the primary researcher (an experienced strength and conditioning coach). Day one consisted of anthropometrics (height, seated height and body mass), DVJ, IMTP and 10 and 20 m sprints. Day two consisted of BSA, double and single leg CMJ and y-balance. The PE classes were divided into even groups and performed the tests in a randomized order on the first testing session. For the subsequent testing sessions, the participants performed the tests in the same order. This approach was used due to the number of participants and the time constraint of a school curriculum.

Maturation

Anthropometric variables of body mass, standing height and seated height were collected. Standing height was measured to the nearest 0.1 cm using a stadiometer (Model: WSHRP; Wedderburn, New Zealand). Seated height was measured to the nearest 0.1 cm using a meter stick taped to a wall above a 40 cm wooden box. Body mass was measured to the nearest 0.1 kg using a digital scale (Model: TI390150K; Tanita, New Zealand). Maturation was assessed using a sex-specific regression equation from Mirwald et al. [174], which has been found to be reliable, non-invasive and a practical solution for the measure of biological maturity. Maturation was classified into three groups based on PHV: pre-PHV = ≤ -0.51 years of the estimated time of PHV, circa-PHV

= - 0.5 to 0.5 years of the estimated time of PHV, post-PHV = ≥ 0.51 years post estimated time of PHV.

Sprints

The sprints (10 and 20 m) were performed in an indoor gymnasium using double-beam timing gates (SWIFT Performance, Alstonville, Australia). Participants started with a self-selected foot forward, 50 cm behind the first set of gates, from a static position with no rocking or movement beforehand. Each participant completed two trials separated by at least one minute rest. Ten and 20 m sprint were used because they are a common field based speed test and have been shown to be reliable in youth, with ICCs ranging from 0.88-0.98 and CVs ranging from 0.83-2.07% [193].

Countermovement Jump

The CMJ, double and single leg, was performed on two portable force plate (Pasco, California, USA) at a sampling rate of 100 Hz. Participants were instructed to keep their hands on their hips at all times to avoid interference from the upper body and to squat down to a self-selected depth and jump as high as possible. For the single leg trials, an additional instruction to start with one leg flexed to 90 degrees at the hip was given. The participants performed two trials of each jump with one minute rest between trials. Force-time data was analysed with custom-built LabVIEW software (version 14.0, National Instruments, Austin, TX, USA), with 30 N being the force threshold to determine the onset of movement. The software used displacement (integral of velocity over time) to calculate CMJ height. Using the CMJ height data, CMJ power was then calculated with the following formula by Mihalik et al.[194]: Power = [(61.9 * (vertical jump height in cm)) + (36 * mass) - 1822]. Double and single leg CMJ were used as they are a common field based power test and acceptable reliability in youth has been reported previously (ICC = 0.62) [195].

Isometric Mid-thigh Pull

The IMTP was performed using a portable strain gauge (MT501 Universal Load Cell) at a sampling rate of 1000 HZ and analysed with custom software. A straight barbell was fixed to a chain and the chain adjusted until the barbell was placed below the hip crease for each participant. Participants stood with feet approximately shoulder width apart, a knee angle between 125-145°, hand grip a thumbs width away from the hips and torso upright as described previously [173]. Once stable, participants were instructed to pull on the bar as hard and as fast as possible for three seconds for two trials, with a minute rest between trials. Verbal encouragement was given to all participants throughout the pull. Peak force was reported and divided by body mass to determine relative PF (relIMTP). The IMTP was chosen as it is a time-efficient, inexpensive way to measure strength. A portable IMTP with a fixed load-cell has been shown to be reliable in adult and youth males [196, 197]. We found similar within-session reliability in pilot testing with youth females (ICC = 0.93; CV=6.0%).

Y-balance

The y-balance was performed by having the participant place their hands on their hips and stand on one leg, with the distal aspect of the great toe behind the center line. The maximum reach distance was measured by pushing the target reach indicator in the anterior, posteromedial and posterolateral directions. Each participant performed two successful trials in each direction. A trial was discounted and repeated if one of the following occurred: the participant's hands were removed from the hips, their stance foot or heel was moved, they did not return to the starting position in a controlled manner, or they visibly kicked the target reach indicator. The greater of the two trials were used for analysis. Composite reach distance was assessed for overall performance on the test. The y-balance assessment is a widely accepted measure of balance and has been reported as reliable in youth [198].

Back Squat Assessment

Two tripod mounted iPads (one m high) were positioned three m anterior and lateral to the participant. Participants were instructed to stand with feet shoulder width apart, hold a dowel in back squat position with a grip slightly greater than shoulder width, forearms parallel to torso and upper back musculature contracted. A researcher used the script suggested by Myer et al. [176], "please stand upright with feet shoulder width apart. Squat down until the top of your thighs are at least parallel to the ground, and then return to the initial starting position. Perform 10 continuous repetitions at a consistent, moderate pace or until you are instructed to stop." The BSA uses 10 criteria for scoring that are categorized into upper body, lower body and movement mechanics. If an undesired technique is found in two or more of the 10 repetitions then a deficit is scored. A lower score indicates better squat technique. The BSA was chosen as it is a way to measure movement skill and mimics the squatting pattern used in the IP program.

Drop Vertical Jump

Similar to the BSA, two tripod mounted iPads (one m high) were placed three m anterior and lateral to a 30 cm high bench. Participants were instructed to stand with feet shoulder width apart on the bench, drop down off the box onto a tape marker 30 cm in front of the bench and immediately perform a maximum vertical jump, similar to previous procedures [199]. Performance was assessed using the landing error scoring system [200], a 17 item assessment of jump-landing technique based on 'errors' in lower extremity and trunk position during initial ground contact and maximum knee flexion [175]. A lower score indicates a better jump-landing technique. Participants performed three trials, with the average of the three trials used for analysis. The DVJ is a widely used way to measure the presence or absence of biomechanical risk factors at the lower extremity and trunk and has been reported as reliable in youth ($\kappa = 0.92$, CI 0.829-0.969) [199].

Injury Prevention Program

Due to the nature of school terms in New Zealand, the IP program was divided into three phases lasting eight, nine and six weeks separated by two-week school holidays between terms (Figure 6.1). Each phase of the IP program was divided into two or three mesocycles lasting three or four weeks, with a focus on movement skill via plyometrics, agility, lower body strength, core stability and balance. The first phase of the program was a 10 minute session incorporating body-weight exercises. The second phase was a 20 minute session including light resistance exercises. After the 10 and 20 minute sessions were completed, participants participated in their regular PE class for the remainder of the class period. The third and final phase of the IP program lasted for the entire PE class (40 minutes) and incorporated moderate to high resistance exercises. Proper technique, movement and landing mechanics were emphasized throughout the IP program. Each IP session was run by the primary researcher who was a certified strength and condition specialist and had a PE teacher present throughout the intervention period. In order to account for adherence to the IP program, the rating of perceived exertion scale was used to track who completed the IP program each session. The IP program by duration and exercise progressions can be found in Table 6.1.

Table 6.1: Exercise progressions to the injury prevention program.

		Plyometrics	Agility	Lower Extremity Strength	Core Stability	Balance
10 minute program	*Phase 1*	DL snap downs SL snap downs	Weight-shifters 5 m DL deceleration 5 m SL deceleration	Squat DL glute bridge	Side plank Superman hold	Calf raises Airborne leg-swings
	Phase 2	DL snap downs + VJ, + HJ SL snap downs + VJ, + HJ	Step + recover 10 m DL deceleration 10 m SL deceleration	Squat SL glute bridge	Side plank Superman (repetitions)	SL calf raises Airborne leg-swings
20 minute program	*Phase 1*	Reactive DL & SL snap downs (with pause) + VJ Reactive DL & SL snap downs (with pause) + HJ	Speed-skaters 5 m DL deceleration + VJ + backward deceleration 5 m SL deceleration + VJ + backward deceleration	Partner DL squat Lunges (in-place) Partner Nordic hamstring curls	Side plank + bent knee hip abduction holds	Slider-disc circles around cone
	Phase 2	Reactive DL & SL snap downs (no pause) + VJ Reactive DL & SL snap downs (no pause) + HJ	Lateral jump w/stick Run + Speed-skater to tennis ball (w/pause) 5 m forward DL deceleration + cone jump + backward deceleration 5 m forward SL deceleration + cone jump + backward deceleration	Squat with feet against bench Stationary reverse lunges w/slider 5s partner Nordic hamstring curls	Side plank + hip abduction (hips up/down)	Slider-disc y-shape
	Phase 3	Partner reactive DL & SL snap downs + VJ Partner reactive DL & SL snap downs + HJ	Lateral jump Run + speed-skater to tennis ball (no pause) 10 m DL deceleration + cone jump + backward deceleration 10 m SL deceleration + cone jump + backward deceleration	Goblet squat Walking lunges 7s partner Nordic hamstring curls	Side plank + hip abduction + leg lift (single reps)	Slider-disc y-shape w/cone push
40 minute program	*Phase 1*	Depth drop		Back squat DB walking lunges Sandbag RDL	Front-side-side plank	Balance beam cone touch
	Phase 2	Depth drop + VJ		Back squat DB walking lunges Sandbag split-stance RDL	Feet-elevated front-side-side plank	Balance beam cone touch

DL = double leg; SL = single leg; VJ = vertical jump, HJ = horizontal jump; DB = dumbbell; RDL = Romanian deadlift.

Statistical Analysis

An independent-samples t-test was conducted to compare descriptive characteristics, maturation and baseline performance, between the INT and CON groups. For all continuous outcome variables repeated measures regression models were used to evaluate the intervention over time. Ordered regression models were used to obtain an odds ratio to evaluate the effect of the intervention on the ordinal outcome measures (BSA and DVJ). Marginal analysis and slopes were carried out due to non-randomized allocation of INT and CON groups. From the marginal analysis, slopes of the predictive model for both groups and a comparison between groups were used. The best effort was used for analysis of all performance measures except BSA (rated based on 10 repetitions) and DVJ (rated based on an average score). For the dependent variables, within session reliability was calculated using pairwise comparisons on log-transformed data to reduce the effects of any non-uniformity error [178]. The typical error was expressed as a coefficient of variation (CV) to determine absolute reliability and the intraclass correlation coefficient (ICC) was used to determine relative reliability. For the ICCs, 95% confidence intervals (CI) were reported. For the BSA and DVJ, inter-rater reliability was calculated by rating 10 videos of each test and rating them again seven days later. Descriptive data was analysed using SPSS (version 25; SPSS Inc, Chicago, IL), whereas regression models, marginal analysis and slopes were analysed using Stata software (version 15.1; StataCorp LLC, College Station, TX). Statistical significance was set at $p < 0.05$.

Results

All tests achieved acceptable (ICC ≥ 0.70 and CV ≤ 15%) [179] within-session and intra-rater reliability (Table 6.2). Adherence to the IP program was 82%. Results of the independent sample t-test indicated no significant difference in any of the descriptive characteristics between the INT and CON groups, with most of the participants being in post-PHV maturation status (Table 6.3). However, a significant difference was shown in baseline performance measures with the INT group outperforming the CON group in all measures (Table 6.3) except right and left CMJ power. Movement quality in both the BSA and DVJ significantly increased in the INT group compared to the CON group (Table 6.4). Additionally, for the INT group, there was a significant improvement found for IMTP, double and single leg CMJ power, double and left leg CMJ height, and both right and left composite y-balance scores. There was no significant improvement for relIMTP, 10 or 20 m sprint, right CMJ height, or either asymmetry measure. In the CON group, there was significant improvement for both IMTP and relIMTP, 10 m sprint, single and double leg CMJ power and height, and left leg composite y-balance. There was no significant improvement for 20 m sprint, right leg composite y-balance, or either asymmetry measure. When comparing the mean difference between groups, significant differences were found in both y-balance measures in favor of the INT group and relIMTP in favor of the CON group. A summary of the results for all within and between group differences can be found in Table 6.5.

Table 6.2: Reliability of tests.

Variable	ICC (95% CI)	CV (%)
IMTP (N)	0.91 (0.88 to 0.93)	8.3
relIMTP (N/kg)	0.89 (0.85 to 0.92)	8.3
10m sprint (s)	0.92 (0.89 to 0.94)	1.6
20m sprint (s)	0.85 (0.80 to 0.89)	2.8
CMJ Power (W)	0.91 (0.88 to 0.93)	8.5
CMJ Height (cm)	0.84 (0.79 to 0.89)	9.6
RCMJ Power (w)	0.94 (0.92 to 0.96)	12.3
RCMJ Height (cm)	0.87 (0.81 to 0.90)	12.3
LCMJ Power (W)	0.94 (0.92 to 0.96)	12.2
LCMJ Height (cm)	0.89 (0.85 to 0.92)	10.8
Y-balance R Composite (cm)	0.77 (0.70 to 0.83)	3.5
Y-balance L Composite (cm)	0.84 (0.79 to 0.88)	2.9
BSA+	0.98 (0.93 to 0.99)	12.4
DVJ+	0.98 (0.93 to 0.99)	6.8

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; R = right leg; L = left leg; BSA = back squat assessment; DVJ = drop vertical jump; + = rated on a scale; BSA out of 10 and DVJ out of 17, a lower score indicates a better performance.

Table 6.3: Baseline descriptive characteristics for anthropometric and performance variables.

Participant characteristics	Overall (n = 92)	Intervention (n = 43)	Control (n = 49)	P
	Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)	14.0 ± 0.6	14.0 ± 0.6	14.1 ± 0.5	0.43
Height (cm)	162.5 ± 5.8	163.7 ± 5.7	161.4 ± 5.8	0.06
Body mass (kg)	57.1 ± 9.3	56.9 ± 9.5	57.4 ± 9.2	0.80
Maturity offset (years from PHV)	1.8 ± 0.5	1.9 ± 0.6	1.8 ± 0.5	0.45
IMTP (N)	752.98 ± 180.08	830.10 ± 168.52	685.31 ± 163.53	<0.001*
relIMTP (N/kg)	13.26 ± 2.82	14.68 ± 2.38	12.02 ± 2.59	<0.001*
10m sprint (s)	2.07 ± 0.11	2.02 ± 0.09	2.11 ± 0.12	<0.001*
20m sprint (s)	3.64 ± 0.26	3.54 ± 0.17	3.74 ± 0.29	<0.001*
CMJ Power (W)	1575.55 ± 380.65	1664.06 ± 386.86	1496.46 ± 360.90	0.04*
CMJ Height (cm)	21.7 ± 4.5	23.5 ± 4.4	20.2 ± 4.1	<0.001*
RCMJ Power (w)	930.12 ± 351.16	997.90 ± 351.48	869.56 ± 343.30	0.09
RCMJ Height (cm)	11.3 ± 3.2	12.7 ± 3.3	10.0 ± 2.5	<0.001*
LCMJ Power (W)	921.08 ± 361.31	986.11 ± 358.82	862.97 ± 357.30	0.11
LCMJ Height (cm)	11.2 ± 3.1	12.5 ± 3.2	9.9 ± 2.5	<0.001*
Y-balance R Composite (cm)	228.39 ± 14.41	231.74 ± 13.84	225.38 ± 14.38	0.04*
Y-balance L Composite (cm)	229.67 ± 15.39	233.41 ± 15.13	226.25 ± 15.0	0.03*
BSA+	4.94 ± 1.92	4.49 ± 1.64	5.33 ± 2.01	0.04*
DVJ+	7.23 ± 1.78	6.44 ± 1.34	7.29 ± 1.84	<0.001*

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; R = right leg; L = left leg; BSA = back squat assessment; DVJ = drop vertical jump; + = rated on a scale; BSA out of 10 and DVJ out of 17, a lower score indicates a better performance; *$p < 0.05$.

Table 6.4: Effects of the intervention on movement performance.

Variable	Odds Ratio (95% CI)	z	P
BSA+	0.14 ± 0.07 (0.05 to 0.35)	-4.15	<0.001*
DVJ+	0.20 ± 0.07 (0.10 to 0.38)	-4.77	<0.001*

BSA = back squat assessment; DVJ = drop vertical jump; + = rated on a scale; BSA out of 10 and DVJ out of 17, a lower score indicates a better performance; *$p < 0.05$.

Table 6.5: Slopes from marginal analysis by group and between group differences.

	Intervention			Control			Intervention vs Control		
Variable	**Slopes (95% CI)**	**z**	**P**	**Slopes (95% CI)**	**z**	**P**	**Slope difference (95% CI)**	**chi^2**	**P**
IMTP (N)	15.70 (4.89 to 26.54)	2.84	0.005*	28.76 (18.66 to 38.82)	5.58	<0.001*	-13.06 (-27.88 to 1.76)	2.98	0.08
relIMTP (N/kg)	0.004 (-0.18 to 0.19)	0.04	0.970	0.34 (0.17 to 0.52)	3.83	<0.001*	-0.34 (-0.60 to -0.08)	6.66	0.001*
10m sprint (s)	-0.004 (-0.011 to 0.002)	-1.39	0.163	-0.007 (-0.012 to -0.0007)	-2.19	0.028*	0.002 (-0.006 to 0.011)	0.25	0.61
20m sprint (s)	-0.002 (-0.014 to 0.011)	-0.25	0.806	-0.006 (-0.018 to 0.006)	-0.950	0.340	0.004 (-0.01 to 0.02)	0.23	0.63
CMJ Power (W)	59.55 (40.99 to 78.10)	6.29	<0.001*	52.95 (35.12 to 70.77)	5.82	<0.001*	6.60 (-19.13 to 32.33)	0.25	0.62
CMJ Height (cm)	0.004 (0.001 to 0.006)	2.36	0.018*	0.005 (0.002 to 0.007)	3.19	0.001*	-0.001 (-0.005 to 0.003)	0.26	0.61
RCMJ Power (w)	48.86 (33.12 to 64.59)	6.08	<0.001*	42.53 (27.41 to 57.66)	5.51	<0.001*	6.32 (-15.50 to 28.15)	0.32	0.57
RCMJ Height (cm)	0.002 (-0.0006 to 0.004)	1.49	0.137	0.003 (0.0005 to 0.005)	2.42	0.015*	-0.001 (-0.004 to 0.002)	0.36	0.55
LCMJ Power (W)	52.70 (35.38 to 70.03)	5.96	<0.001*	46.40 (29.77 to 63.04)	5.47	<0.001*	6.30 (-17.72 to 30.32)	0.26	0.61
LCMJ Height (cm)	0.003 (0.0002 to 0.005)	2.17	0.030*	0.003 (0.0006 to 0.005)	2.51	0.012*	-0.003 (-0.004 to 0.003	0.03	0.86
Y-balance R Composite (cm)	3.54 (2.37 to 4.72)	5.91	<0.001*	0.89 (-0.25 to 2.02)	1.53	0.125	2.66 (1.03 to 4.29)	10.20	0.001*
Y-balance L Composite (cm)	3.34 (2.20 to 4.49)	5.74	<0.001*	1.28 (0.17 to 2.38)	2.27	0.023*	2.07 (0.48 to 3.66)	6.49	0.01*

IMTP = isometric mid-thigh pull; relIMTP = relative isometric mid-thigh pull; CMJ = countermovement jump; RCMJ = right-leg countermovement jump; LCMJ = left-leg countermovement jump; R = right leg; L = left leg; *$p < 0.05$.

Discussion

To our knowledge, this is one of the few studies to incorporate a long term, progressive IP program into a school PE curriculum with youth females. Integrating the program into the school curriculum ensured high program adherence (82%), had positive benefits on movement skill and balance and made the study more relevant to implementation in a real-world setting. Additionally, this study is one of the few in this area to account for maturational status. The findings show that the participants were almost all post-PHV and that the athletes in the INT group performed better than the CON group consisting of primarily non-athletes, on all baseline physical measures. Movement skills and balance improved after the IP program in the INT group, whereas relative strength improved in the CON group.

Our study found that movement quality as measured by the BSA and DVJ can be improved by an IP program. The INT group had much better odds of an improved score in both the BSA and DVJ following the intervention period compared to the CON group. More deficits in both the BSA and DVJ indicate poor movement quality which has been linked to injury risk [20]. Additionally, improved movement quality has direct biomechanical and neuromuscular implications for successful performance [201]. Specifically the squat pattern is essential for daily activities such as sitting, lifting and sporting maneuvers [176], while good technique during jumping and landing is essential in many sports and it has also been linked to reduced injury risk [41]. Previous research in female youth basketball, soccer and volleyball athletes has also reported improvements in movement quality following an IP program [42, 115-118]. For example, a significant decrease in knee valgus (28%) and varus (38%) torques was found in youth female basketball, soccer and volleyball athletes after six weeks of an IP program consisting of plyometrics, movement, core strength, balance, resistance and speed training [42]. Thus IP programs, particularly in the school curriculum where high adherence rates are easier to obtain, can improve movement quality, potentially reducing injury risk and improving performance in youth females.

Similar to our findings, previous studies have also reported improvements in balance as a result of an IP program [113]. For instance, female soccer athletes significantly improved y-balance performance compared to a control group after an eight week IP program consisting of core stability and lower extremity strength exercises [113]. It has been suggested that improvements in y-balance scores are more likely to do with improved neuromuscular control and dynamic balance than increased lower extremity strength [202]. This is in agreement with the results from the current study that show balance and movement improved in the INT group, but not strength. Since poor balance as measured by the y-balance test has been linked to increased injury risk [92, 94-96], practitioners should incorporate balance exercises as part of an IP program in youth females.

The change in the absolute strength measure over time in this study (IMTP) did not differ between groups. However, the CON group improved their relative strength measure (relIMTP) more than the INT group, which is in contrast to other studies that have found significant increases in back squat strength following an IP program in youth female volleyball, soccer and basketball athletes [42, 112]. This could be due to the lack of specificity between the lower extremity strength exercises performed in the current IP program (e.g. hamstring curls and lunges) and the strength measure of the IMTP. The IMTP was chosen as it was a practical way to measure lower body strength due to the limited duration of a PE class and the high number of participants. More specific isokinetic measures of strength were considered, but for logistical reasons it was not possible to undertake these tests. Based on the exercise progressions and observations from the primary researcher, it did seem that hamstring strength improved throughout the study. Additionally, a lack of improvement in strength in the INT group relative to the CON may have been due to the higher relative strength levels in the INT group at baseline and therefore they were less likely to make improvements. The INT group may also be better at a max effort test as they are more familiar with max effort as athletes compared to the CON group. Of note, the CON group's post-test relative strength was still lower than the baseline relative strength of the INT group.

The IP program did not improve sprint speed, CMJ power or jump height in the present study. The exercises in the IP program were designed to target reducing injury risk, with a secondary goal to improve athletic performance measures. As a result, the IP program did not have a primary focus on sprint mechanics or developing speed which may explain why the intervention did not significantly improve sprint times. Similarly, the plyometric exercises in this study's IP program had an emphasis on proper movement patterns when jumping and landing, rather than jumping as high and as powerfully as possible.

This may further explain why neither single or double leg CMJ height nor power significantly increased following the intervention. The findings are in agreement with other research on IP programs in females that did not find significant improvements in sprint speed, jump power or height [112, 128, 130, 131]. In contrast, Myer et al. [42] found that jump height and sprint speed significantly improved in the INT group compared to the CON group after a six week IP program in female youth soccer, volleyball and basketball athletes. The conflicting results could be attributed to the fact that speed training was incorporated into their IP program. Therefore, if an additional goal of an IP program is to improve athletic performance, it is suggested that IP programs include speed and plyometric training at maximal effort.

Practical Applications

The results from the current study demonstrate that a long-term IP program integrated into the school curriculum significantly improved movement quality and balance in youth females. Practitioners implementing this program should ensure good adherence, individual progression and a focus on movement technique. To achieve improvements in strength, sprint and jump performance, the exercises selected should be similar to the tests (e.g. back squat exercise and back squat test). In addition, progressing to sport-specific movement speeds is recommended if the goal of the IP program is also to improve performance in youth females.

Chapter 7 : The Effect of a School Based Injury Prevention Program on Injury Risk in Youth Females

Prelude

Chapter 6 examined the effects of an IP program integrated into the school curriculum on risk factors for injury and athletic performance. Findings showed significant improvements in movement skill and balance following the IP program but no change in athletic performance. The final step, in relation to the TRIPP model, to establish the effectiveness of this IP program was to determine the influence on injury risk in this population. Therefore, the aim of this chapter was to examine the effects of the IP program from chapter 6 on training and competition injury rates in youth females. The findings from chapter 6 and this chapter provide coaches, teachers and practitioners with valuable insight into the design, implementation and effectiveness of an IP program integrated into the school curriculum in secondary school girls.

Introduction

Sport and physical activity participation by youth has many health and physical benefits, but inherently involves risk of injury [143]. Injuries in sport are costly to both the healthcare system [144] and the individual as injuries may result in reduced game time or an early finish to the sports season [25]. For example, in New Zealand in 2016 there was a total of 494,860 claims related to sports injury with an associated cost of approximately $506 million NZD [144]. Additionally, from 2012-2017 there was a 19% increase in sports-related injuries in youth 18 years and under [145]. In the worst case scenario, injuries can have long-term consequences that limit sport participation and life-long physical activity [46]. For instance, up to 50% of drop-outs in youth gymnastic athletes have been reported to be due to injury [192]. If physical activity in youth is reduced due to injury this can negatively impact health factors such as bone mineral density and body mass index [3]. The negative effects from sports injury can be especially problematic for young girls as they have shown greater rates of injury than boys (e.g. 14% higher injury rate, in youth female compared to youth male soccer athletes) [14]. In girls, injury rates per 1000 hours exposure range from 2.5-10.6 in soccer, 3.6-4.1 in basketball and 0.5-4.1 in gymnastics [25]. Due to the risk and serious consequences of sport related injury there is a need for preventative measures implemented early in youth, specifically targeted towards females.

In response to the growing number of injuries in youth sport, injury prevention (IP) programs that target a reduction in risk factors and/or injury incidence directly have been developed. Previous research shows that IP programs can reduce overall injury rates in youth by approximately 40% [105]. A common factor in the success of these programs is high adherence [131, 139]. In fact a recent study confirmed that poor adherence to a neuromuscular warm-up program results in limited reduction in injury risk [203]. Programs completed two to three times per week, with multiple components, progressed according to the technical capability of the participants are shown to be the most beneficial [43]. While some have been successful, the majority of IP programs investigated to date have been acute in nature and have lacked individual progression. Additionally, few have been embedded into a school curriculum to maximize adherence and thus the likely benefit of the program. Further research investigating an evidence-based IP program in youth females is needed to better understand the potential for such programs to reduce injury risk in this population. Therefore, the purpose of this study was to examine the effects of an IP program, embedded into the school curriculum, on training and competition injury rates in youth females.

Methods

Participants

One hundred and three girls (mean ± SD; age = 14.0 ± 0.6 y; height = 162.6 ± 5.8 cm; mass = 57.4 ± 9.8 kg) from physical education (PE) classes at a girls' secondary school participated in this study. Fifty-three girls were in the intervention (INT) group and 50 girls were in the control (CON) group. Girls were selected to the INT group based on their level of interest and physical ability. The University Ethics Committee approved the study. Informed parental consent and participant assent was obtained from all girls.

Procedures

Injury data was collected prospectively over three school terms (30 weeks) using an online questionnaire via Google Forms. Participants were familiarized before the study began, then sent an email reminder to complete the questionnaire at the start of their PE class once a week for the duration of the study. Injuries were defined as any physical problem affecting training or competition. The participants reported injuries over the previous week as well as their training and competition (match) exposure. If no response was received within two days, a further email reminder was sent.

Reporting of Injuries

The questionnaire used in this study was a modification of the Oslo Sports Trauma Research Centre (OSTRC) questionnaire [150, 154] and consisted of two parts. Part one included six questions covering: training exposure, game/competition (match) exposure and the impact of any injuries on sports participation, training volume, sports performance and the extent of any symptoms. If a participant reported an injury, they then completed part two of the questionnaire, which asked about the anatomical location of the injury and how and when the injury occurred. If the participant had more than one injury, the questionnaire repeated itself, allowing for registration of additional injuries.

Injury Prevention Program

Due to the nature of school terms in New Zealand, the IP program was divided into three phases lasting eight, nine and six weeks separated by two-week school holidays between terms. Each phase of the IP program was divided into two or three mesocycles lasting three or four weeks, with a focus on movement skill via plyometrics, agility, lower body strength, core stability and balance. The first phase of the program was a 10 minute session incorporating body-weight exercises. The second phase was a 20 minute session including light resistance exercises. Following the completion of these sessions, participants participated in their regular PE class for the remainder of the class period. The third and final phase of the IP program lasted for the entire PE class (40 minutes) and incorporated moderate to high resistance exercises. Proper technique, movement quality and landing mechanics were emphasized throughout the IP program. Each IP session was run by the primary researcher who was a certified strength and conditioning specialist and had a PE teacher present throughout the intervention period.

Statistical Analysis

An independent samples t-test was conducted to compare descriptive characteristics between the INT and CON group. Injury rates and corresponding 95% confidence intervals were calculated per 1000 hours of training and competition exposure. The injury rates were compared between the two groups (as injury rate ratios [IRR]) by means of Poisson regression analysis using SPSS (version 25; SPSS Inc, Chicago, IL). Statistical significance was set at $p < 0.05$.

Results

The overall response rate to the questionnaire was 92% and the overall adherence to the IP program was 82%. Results from the independent samples t-test indicated no significant difference in any of the descriptive characteristics between groups (Table 7.1). However, a significance difference was found in weekly training and competition hours with the INT group reporting greater sports participation than the CON group (Table 7.1). The rate of all injuries per 1000 hours was 15.1 in the CON group and 17.9 in the INT group (Table 7.2). There was no significant difference in any of the injury rates between the two groups. Injury rates in competition were higher than in training. All injury rates and the comparison between groups expressed as rate ratios can be found in Table 7.2. The most common injuries were to the lower extremity with the knee, ankle and thigh being the top three injured areas (Table 7.3).

Table 7.1: Descriptive characteristics of participants and weekly sport exposure hours.

Participant characteristics	Overall (n = 103)	Intervention (n = 53)	Control (n = 50)	P
	Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)	14.0 ± 0.58	13.9 ± 0.6	14.1 ± 0.5	0.18
Height (cm)	162.6 ± 5.8	163.6 ± 5.7	161.6 ± 5.8	0.71
Body mass (kg)	57.4 ± 9.8	57.6 ± 10.3	57.2 ± 9.2	0.83
Maturity offset (years from PHV)	1.8 ± 0.5	1.8 ± 0.6	1.7 ± 0.5	0.64
Weekly training hours	3.20 ± 4.21	4.15 ± 4.78	2.19 ± 3.22	<0.001*
Weekly competition hours	0.66 ± 1.28	0.77 ± 1.42	0.55 ± 1.10	<0.001*

*significant difference between intervention and control.

Table 7.2: Effect of the injury prevention program on injury risk.

Variable	Intervention (n = 53)		Control (n = 50)		Rate ratio (95% CI)	P
	n	Incidence x 1000 hrs (95% CI)	n	Incidence x 1000 hrs (95% CI)		
All injuries	138	17.9 (15.0-21.1)	60	15.1 (11.5-19.4)	1.19 (0.87-1.63)	0.27
Training injuries	89	13.7 (11.0-16.9)	30	9.5 (6.4-13.6)	1.44 (0.94-2.26)	0.08
Competition injuries	49	40.1 (29.7-53.0)	30	36.3 (24.5-51.9)	1.10 (0.69-1.80)	0.67
Lower extremity injuries	89	11.5 (9.3-14.2)	35	8.8 (6.1-12.2)	1.31 (0.88-2.00)	0.17

Table 7.3: Injury by body area.

Injury location	Frequency (percent)
Knee	43 (21.7%)
Ankle	30 (15.2%)
Thigh	21 (10.6%)
Lower leg	15 (7.6%)
Foot/toes	15 (7.6%)
Lumbar spine	11 (5.6%)
Thoracic spine	11 (5.6%)
Hand/fingers	11 (5.6%)
Hip/groin	9 (4.5%)
Shoulder	8 (4.0%)
Wrist	5 (2.5%)
Chest/ribs	4 (2.0%)
Pelvis/buttock	3 (1.5%)
Abdomen	3 (1.5%)
Elbow	2 (1.0%)
Neck	2 (1.0%)
Forearm	2 (1.0%)
Head/face	2 (1.0%)
Upper arm	1 (0.5%)

Discussion

The main finding of this study is that the IP program did not significantly reduce injury rates in secondary school youth females. This is in spite of the IP program being integrated into the school curriculum which resulted in excellent adherence to the program and allowed for individual progression. Previous research has found similar results to the current study with no reduction in injury rates following an IP program in youth female soccer, basketball and volleyball athletes [127, 132]. In contrast, most research on IP programs targeted towards reducing injury rates have found a significantly reduced rate following an IP program [112, 119, 120, 123-125]. For instance, youth female soccer athletes completed a 20 minute IP program twice per week for the entire season and found a significant decrease in ACL injury rate in the INT group compared to the CON group (0.05 vs 0.47 injuries per 1000 hours) [125]. The contrasting results from our study and those that reduced injury rates may be due to the difference in injury definition (all physical problem versus time-loss). This study is the only one to utilize an all injury definition which captured both overuse and acute injuries, whereas a time-loss definition would capture mainly acute injuries. Thus, it is difficult to compare the effects of this IP program to others.

Rates of injury in both groups found here were much higher than those reported in previous studies that have used a time-loss definition of injury where rates in youth males and females range from 2.3-4.8 injuries per 1000 hours of sports participation [156-158]. For example, a higher rate (8.6 injuries per 1000 hours of sport participation) was found in studies of female soccer, basketball and gymnastic athletes that also used the OSTRC questionnaire [28]. It has been suggested that the injury definition used in the current study (any physical problem) is more valid because it can identify 10 times as many injuries as a time-loss method [40]. As many athletes continue to train and play despite having an injury, we suggest that an all injury definition rather than a time-loss or medical definition of injury represents a more valid indication of injury rates in youth females.

The injury rates did not significantly differ between groups in the current study. However, the IP program may have helped in keeping the incidence in the INT group similar to that of the CON group. The participants in the INT group were competing at a much higher level of sport than those in the CON group and thus they may have been exposed to higher risk due to increased intensity of competition. In fact, previous research has demonstrated this in female youth gymnastic athletes as those competing at a higher level (seven through nine) had a rate ratio of 1.47 times greater than those competing at a lower level (four through six) [204].

For both groups, injury risk in competition was much higher than training. This is similar to previous studies in male adult and youth soccer, female adult soccer and male and female youth basketball athletes that have reported a higher risk of injury in competition than training [205-207]. For instance, the injury rate of 16 injuries per 1000 hours of competition was significantly higher than the injury rate of two injuries per 1000 hours of training in female basketball athletes [206]. It is suggested that the higher injury risk in competition is due to the higher intensity level and maximum effort during competition versus training. Given the lack of studies on youth females our findings confirm that this difference between competition and training injury rates also exists in this at-risk group.

The most commonly injured body locations from this study is in agreement with previous research. Specifically, the knee, ankle and thigh were the top locations, which is consistent with previous research showing the ankle, knee and thigh to be the most common in youth female soccer, basketball and gymnastic athletes [37]. Additional research has shown the ankle and knee to be the most common injured areas in youth females [36]. Accordingly, these results corroborate the need for IP programs to target the lower extremity in youth females.

Conclusion

The results from the current study show high injury rates in youth females. Similar to previous research, injury rates in competition are higher than in training. Although the IP program did not reduce injury rates, it may be protective against increased injury risk for youth females competing at higher levels of competition. Future research should aim to include groups of a similar activity level to truly compare the effects of an IP program on injury risk.

Chapter 8 : Discussion and Conclusion

The overall purpose of this thesis was to provide novel insights into the benefits and implications of an IP program embedded into the school curriculum twice per week on injury risk factors, injury rates and athletic performance measures in youth females. To achieve the purpose, it was necessary to first determine what the risk factors for injury are (chapter 2) and what has made previous IP programs successful (chapter 3) in order to inform the development of the IP program. A review of literature showed that lower extremity biomechanical and neuromuscular risk factors are of particular importance (chapter 2). Specifically, landing or cutting in a position of increased hip flexion, adduction and/or internal rotation, increased knee extension, abduction and/or internal rotation, deficits in knee and hip musculature strength, balance and trunk proprioception have all been linked to increased injury risk in females. Chapter 3 highlighted that independent IP training programs with a high session attendance, a duration greater than 20 minutes, and frequency of two to three times per week have shown the greatest benefit in youth females. Additionally, programs with multiple components (plyometrics, agility, strength, core stability and balance) progressed according to the technical competency of the participants are the most beneficial. Given the knowledge from the literature reviews on risk factors and existing IP programs, an IP program was developed for the target population.

The prospective reporting of injuries throughout the study period provided novel insights into the specific sport and PE injuries as well as if an association between injury and phase of the menstrual cycle existed in youth females (chapter 4). Using a recently developed "all physical problem" definition, the results showed that injury rates in youth females may be higher than previously reported using time-loss definitions. They also confirmed the lower extremity as the most common injury location and established the need for an IP program in this population. Based on the substantial evidence showing lower extremity injury as most common and that strength is a risk factor for injury in females (chapter 2) the relationships between maximum strength and measures of athletic performance and movement skill in adolescent females were investigated (chapter 5). The results illustrated that strong girls demonstrated faster sprint times, greater jump height and better movement skill than weak girls. Thus, coaches and practitioners working with youth females should emphasize relative strength to improve speed and jump performance, as well as movement skill.

The effects of an IP program integrated into the school curriculum on injury risk factors and athletic performance measures in year nine and ten secondary school girls were examined (chapter 6). This IP program was done twice per week for 23 weeks and focused on plyometrics, agility, lower extremity strength, core stability and balance. The successful integration of the program into the school curriculum resulted in high program adherence (82%) and provides evidence this type of program can be implemented in a real-world setting, such as a school. Movement skill and balance improved after the IP program in the INT group, whereas relative strength improved in the CON group. Practitioners implementing this program should ensure good adherence, individual progression and a focus on movement technique.

The effects of the IP program (from chapter 6) on injury risk in youth females was also examined in chapter 7. Similar to chapter 4, higher injury rates were shown than those reported in previous youth research. This result is most likely due to the injury definition used. Specifically, we utilized an all physical problem definition, compared to time loss injuries, as is has been shown to better reflect the true injury burden. When injury rates were compared between groups, no significant difference was observed. Although the IP program did not reduce injury rates, it may be protective against increased injury risk for youth females competing at higher levels of competition. The participants in the INT group were competing at a higher level of sport than those in the CON group and therefore may have been exposed to higher risk due to increased intensity of competition.

Figure 8.1 summarizes the key findings from this thesis. The findings suggest that youth females engaging in a school curriculum based IP program can make significant improvements in movement skill and balance. The program may also be able to reduce the risk of injury for youth females competing at higher levels of competition where injury risk has been reported to be greater. Furthermore, based on the use of a novel (and likely more accurate) injury definition in youth females this thesis suggests injury rates in this group are higher than previously reported and confirms that the lower extremity is the most commonly injured area of the body. Additionally, the thesis provides a novel perspective on the importance of relative strength for movement skill development and athletic performance and further supports the implementation of IP programs that target these factors. This thesis is also the first to look at the association between injuries and the menstrual cycle in youth females, providing preliminary evidence that injury is not linked to a certain phase of the menstrual cycle in this group.

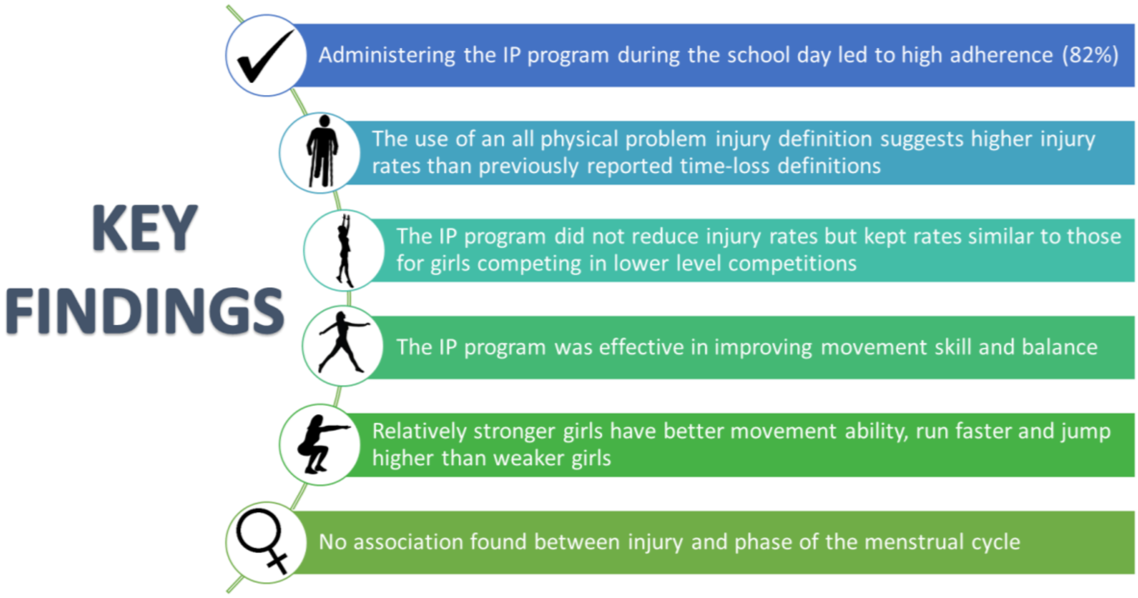

Figure 8.1: Key findings from the thesis.

Practical Applications

Based on the findings of this thesis, the following practical applications may assist practitioners, coaches, teachers and researchers with the implementation of an IP program into the school curriculum:

1. Training programs that focus on hip and knee control during functional tasks (e.g. plyometric and agility exercises), lower extremity strength, core strength and balance are likely to be most successful.

2. Prescribing exercises and activities specific to the skill level of the individual will be most beneficial. Accurately programming for the skill level can be accomplished by starting with body weight exercises that focus on correct positions of the body. Only when the athlete has shown proficient technique, should the volume and intensity of the movement be increased.

3. Allow for progressions to the exercises so that the intensity (resistance, speed and complexity) of movements can be advanced to mimic real-time sporting actions.

4. Emphasize the development of relative strength in order to improve performance and movement skill.

5. If monitoring of injury is a goal of an IP program then a survey tool based on an all physical problem injury definition is likely to be the most valid.

Limitations

There were several limitations of this thesis due to the unique integration within the school curriculum which have been outlined below.

- Due to the thesis being conducted in the PE curriculum, the intervention and control groups were not randomized. Instead, a year nine class was created with class selection based on interest and an existing sports-focused year 10 class was used. Due to the non-randomized nature, the intervention group, who were more athletic, outperformed the control group in all tests.

- Limited time in class, as well as a high number of participants, made data collection challenging. Accordingly, an IMTP was chosen to assess lower extremity strength as it is a practical, time-efficient test. A more specific, isokinetic measure of strength was considered, but unrealistic to complete logistically. Although hamstring strength may have improved throughout the duration of the IP program, without directly measuring it cannot be confirmed.

- A focus on exercises to reduce injury risk may have come at the cost of improving athletic performance. Specifically, due to the poor level of movement competency of the participants, the IP program focused on proper movement patterns instead of sprint mechanics, all-out speed or jumping as high and powerfully as possible. Therefore, the participants in this research did not improve their sprint and jump performance.

- Maturational status was measured with the intent to investigate any associations with injury risk or athletic performance. However, almost all (98 out of 104) girls were post-PHV, so we could not investigate this or see how the IP program influenced different maturation groups. As this research was done with the two youngest year levels of a girls' secondary school, there was no way to capture all three maturational groups.

Future Research

The limitations presented in the above section can help inform future research directions on how IP programs implemented into a school setting can influence injury risk and athletic performance in youth females. The following are recommended for future research:

- Use of more specific measures to better evaluate the impact of the program on strength.
- If improving athletic performance is another goal of an IP program, then once proper movement mechanics are established, progressing to sport specific speeds is recommended.
- As this is the only study to examine if more injuries occur during a certain phase of the menstrual cycle in youth females, more research is needed in this area.
- In order to fully capture the extent of injuries, an all injury definition should be used instead of a time-loss definition of injury.
- As the participants in this thesis were all post-PHV, including younger girls in order to fully understand the influence of IP programs on all maturational groups is recommended.
- Finally, investigating the effects of an IP program in both males and females across maturation status will help inform the development of sex specific programs and be beneficial for those who work with both sexes.

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Appendices

Appendix I. Conference Abstract Presentations

1. **Sommerfield, L.M.**, Whatman, C.S., Harrison, C.B., Maulder, P.S. and Borotkanics, R.J. *The effects of a school based injury prevention program on injury risk in youth females.* Poster presentation. ASCA International Conference on Applied Strength and Conditioning, Gold Coast, Australia, November 2019.

2. **Sommerfield, L.M.**, Harrison, C.B., and Whatman, C.S. *Relationship between maturation and performance measures in youth females.* Oral presentation. International Conference of Strength Training, Perth, Australia, December 2018.

Appendix II. Questionnaire from Chapters 4 and 7

Physical Problem Report Questionnaire

*Physical problem = injury, aches, pains, stiffness, swelling, etc. Does NOT include colds or sickness.

Question 1- Training Exposure

State in numbers, how many hours you have participated in your sport training during the past week?

Question 2- Match Exposure

State in numbers, how many minutes you have participated in your sport matches during the past week?

Question 3

Have you had any difficulties participating in normal training and competition due to physical problems during the past week?

☐ Full participation without physical problems

☐ Full participation, but with physical problems

☐ Reduced participation due to physical problems

☐ Cannot participate due to physical problems

Question 4

To what extent have you reduced your training volume due to physical problems during the past week?

☐ No reduction

☐ To a minor extent

☐ To a moderate extent

☐ To a major extent

☐ Cannot participate at all

Question 5

To what extent have physical problems affected your performance during the past week?

☐ No effect

☐ To a minor extent

☐ To a moderate extent

☐ To a major extent

☐ Cannot participate at all

Question 6

To what extent have you experienced symptoms during the past week?

☐ No symptoms

☐ To a mild extent

☐ To a moderate extent

☐ To a severe extent

Question 7- Physical Problem Area

Please select the location of your physical problem. If the physical problem involves several locations please select the main area. If you have multiple physical problems please complete a separate registration for each one.

☐ Head/face

☐ Neck

☐ Shoulder (including clavicle)

☐ Upper Arm

☐ Elbow

☐ Forearm

☐ Wrist

☐ Hand/fingers

☐ Chest/ribs

☐ Abdomen

☐ Thoracic spine (upper & mid back)

☐ Lumbar spine (low back)

☐ Pelvis and buttock

☐ Hip and groin

☐ Thigh

☐ Knee

☐ Lower leg

☐ Ankle

☐ Foot/toes

☐ Other

Question 8

This physical problem involved:

☐ Sudden onset & contact with another person or equipment

☐ Sudden onset & NO contact with another person or equipment

☐ Gradual onset/overuse

☐ Unknown

Question 9

Physical problems occurred during which of the following:

☐ Practice/sport specific training

☐ Game/competition

☐ Physical education class

☐ Active transport (e.g., biking to school)

☐ Other

Question 10- Time Loss

Please state the number of days over the past 7-day period that you have had to completely miss training or competition due to this physical problem?

☐ 0

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

Question 11- Reporting

Is this the first time you have registered this physical problem through this monitoring system?

☐ Yes, this is the first time

☐ No, I have reported the same problem in one of the previous four weeks

☐ No, I have reported the same problem previously, but it was more than four weeks ago

Question 12- Menstrual Cycle

What day are you in your menstrual cycle according to the FITrWoman or My Calendar App?

____

Appendix III. Ethical approval for Chapters 4-7

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

31 July 2018

Craig Harrison
Faculty of Health and Environmental Sciences

Dear Craig

Ethics Application: **17/102 Assessing injury incidence in adolescent female athletes**

On 27 June 2017 you were advised that your ethics application was approved.

I would like to remind you, that it was a condition of this approval that you submit to AUTEC the following:

- A brief annual progress report using the EA2 Research Progress Report / Amendment Form, available at http://www.aut.ac.nz/research/researchethics/forms, or
- A brief Completion Report about the project using the EA3 from, which is available online through http://www.aut.ac.nz/research/researchethics/forms. This report is to be submitted either when the approval expires on 27 June 2020 or when the project is completed;

It is also a condition of approval that AUTEC is notified if the research did not proceed or any adverse events occurring during the research. If there has been any alteration to the research, (including changes to any documents provided to participants) then AUTEC approval must be sought using the EA2 form.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please contact us at ethics@aut.ac.nz.

Yours sincerely

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: lsommerfield14@gmail.com; chris.whatman@aut.ac.nz

AUTEC Secretariat

Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

28 February 2018

Craig Harrison
Faculty of Health and Environmental Sciences

Dear Craig

Re Ethics Application: **18/29 The effect of a school based injury prevention programme on lower extremity injury risk and performance in youth females**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 27 February 2021.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: lsommerfield14@gmail.com; chris.whatman@aut.ac.nz; themaulders@xtra.co.nz

Appendix IV. Participant and Parent/Guardian Information sheets for Chapters 4-7

Participant Information Sheet

Physical Problem Questionnaire

Date Information Sheet Produced:

13 March 2018

Project Title

Assessing injury incidence in adolescent female athletes

An Invitation

My name is Lesley Sommerfield, I am a PhD student at AUT as well as the Athletic Development Coach at SHGC and I would like to invite you to participate in this study. The research is being conducted as part of my PhD. Participation in this research is entirely voluntary and you are able to withdraw from the study at any time. Your involvement in this study will not impact your selection into future sports teams or academic classes.

What is the purpose of this research?

The incidence of sports-related injury in young female athletes is higher than ever before, a likely result of increased training and competition loads together with underdeveloped athletic competencies, such as strength and fundamental movement skill. Therefore, this research is being conducted to understand what physical problems (injury, aches, pains, stiffness, swelling, etc) occur most frequently in adolescent female athletes. The findings of this injury surveillance will allow a training programme to be developed to meet the needs of the population.

The information gained from this research will be presented in a way so that your name and contact details will remain confidential. The information from this research will be anonymous when presented at an international sports science conference, submitted to a sports science journal for publishing, and when included in my PhD thesis.

How was I identified and why am I being invited to participate in this research?

You are identified as a potential participant for this research as you fit into the following categories:

- Between 12 and 18 years of age
- You are female
- You are a student in a year 9 or 10 physical education class at SHGC

How do I agree to participate in this research?

If you would like to participate in this study your guardian will need to fill out and sign a Guardian Consent Form (see attached) and you will need to fill out and sign an Assent Form (see attached).

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

The research involves examining how time spent in training and competition is influenced by physical problems (injuries) as well as what types of physical problems (injuries) are present in adolescent female student-athletes. If you choose to participate in this research you will be required to complete a physical problem (injury) questionnaire once per week for three school terms. The participants are expected to use a personal mobile device to respond to the questionnaire which is available via Google Forms. This will be done during PE curriculum time with your PE teacher or Miss Sommerfield.

What are the discomforts and risks?

It is not expected that you will experience discomfort or risk beyond that of participating in your normal PE class.

What are the benefits?

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

- Being made aware of your physical problems and how they're affecting training/competition
- Results will determine what specific physical problems to focus on for an injury prevention programme

The findings of the proposed research will be valuable for sport coaches and athletes as well as adolescent athletic development coaches and researchers.

Finally, this research will benefit myself, as this study will be included in my PhD thesis.

How will my privacy be protected?

All of the data from this study will be de-identified. That means that your name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or guardian. I will keep all of your data confidential and any data published or used for presentations will be anonymous.

What are the costs of participating in this research?

The questionnaire will take approximately 1-5 minutes to complete each week done for terms 2, 3 and 4.

What opportunity do I have to consider this invitation?

You have 2 weeks to decide whether or not you would like to participate in this study.

Will I receive feedback on the results of this research?

You will receive feedback for both instantaneous results of each weekly questionnaire and a summary of your results at the end of the data collection. If you would like any additional information, please contact myself.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Dr Craig Harrison*

Email: craig@athletedevelopment.org.nz

Phone: + 64 27 2265181

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Lesley Sommerfield

Email: lsommerfield14@gmail.com

Project Supervisor Contact Details:

Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: *+ 64 27 2265181*

Approved by the Auckland University of Technology Ethics Committee on 12 June 2017, AUTEC Reference number 17/102.

Parent/Guardian Information Sheet

Physical Problem Questionnaire

Date Information Sheet Produced:

13 March 2018

Project Title

Assessing injury incidence in adolescent female athletes

An Invitation

My name is Lesley Sommerfield, I am a PhD student at AUT as well as the Athletic Development Coach at SHGC and I would like to invite your child to participate in this study. The research is being conducted as part of my PhD. Participation in this research is entirely voluntary and your child is able to withdraw from the study at any time. Your child's involvement in this study will not impact her selection into future sports teams or academic classes.

What is the purpose of this research?

The incidence of sports-related injury in young female athletes is higher than ever before, a likely result of increased training and competition loads together with underdeveloped athletic competencies, such as strength and fundamental movement skill. Therefore, this research is being conducted to understand what physical problems (injury, aches, pains, stiffness, swelling, etc) occur most frequently in adolescent female athletes. The findings of this injury surveillance will allow a training programme to be developed to meet the needs of the population.

The information gained from this research will be presented in a way so that your child's name and contact details will remain confidential. The information from this research will be anonymous when presented at an international sports science conference, submitted to a sports science journal for publishing, and when included in my PhD thesis.

How was your child identified and why is she being invited to participate in this research?

Your child is identified as a potential participant for this research as she fits into the following categories:

- Between 12 and 18 years of age
- She is female
- She is a student in a year 9 or 10 physical education class at SHGC

How does my child agree to participate in this research?

If your child would like to participate in this study you will need to fill out and sign a Guardian Consent Form (see attached) and your child will need to fill out and sign an Assent Form (see attached).

Your child's participation in this research is voluntary (it is her choice) and whether or not she chooses to participate will neither advantage nor disadvantage her. She is able to withdraw from the study at any time. If she chooses to withdraw from the study, then she will be offered the choice between having any data that is identifiable as belonging to her removed or allowing it to continue to be used. However, once the findings have been produced, removal of her data may not be possible.

What will happen in this research?

The research involves examining how time spent in training and competition is influenced by physical problems as well as what types of physical problems are present in adolescent female student-athletes. If your child chooses to participate in this research she will be required to complete a physical problem questionnaire once per week for three school terms. The participants are expected to use a personal mobile device to respond to the questionnaire which is available via Google Forms. This will be done during PE curriculum time with their PE teacher or Miss Sommerfield.

What are the discomforts and risks?

It is not expected that your child will experience discomfort or risk beyond that of participating in her normal PE class.

What are the benefits?

The benefits for your child being a part of this study include:

- Being made aware of her physical problems and how they're affecting training/competition

- Results will determine what specific physical problems to focus on for an injury prevention programme

The findings of the proposed research will be valuable for sport coaches and athletes as well as adolescent athletic development coaches and researchers.

Finally, this research will benefit myself, as this study will be included in my PhD thesis.

How will my child's privacy be protected?

All of the data from this study will be de-identified. That means that your child's name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or your child. I will keep all of your data confidential and any data published or used for presentations will be anonymous.

What are the costs of participating in this research?

The questionnaire will take approximately 1-5 minutes to complete each week done for terms 2, 3 and 4.

What opportunity do I have to consider this invitation?

You have 2 weeks to decide whether or not you would like your child to participate in this study.

Will I receive feedback on the results of this research?

You will receive feedback for both instantaneous results of each weekly questionnaire and a summary of your child's results at the end of the data collection. If you would like any additional information, please contact myself.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Dr Craig Harrison*

Email: craig@athletedevelopment.org.nz

Phone: + 64 27 2265181

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Lesley Sommerfield

Email: lsommerfield14@gmail.com

Project Supervisor Contact Details:

Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: *+ 64 27 2265181*

Approved by the Auckland University of Technology Ethics Committee on 12 June 2017, AUTEC Reference number 17/102.

Participant Information Sheet

Injury Prevention Programme

Date Information Sheet Produced:

13 March 2018

Project Title

The role of an injury prevention programme in youth females

An Invitation

Hi-my name is Lesley Sommerfield, I am a PhD student at AUT as well as the Athletic Development Coach at SHGC and I would like to invite you to participate in this study. Participation in this research is entirely voluntary and you are able to withdraw from the study at any time. Your involvement in this study will not impact your selection into future sports teams or classes at SHGC. This research is being done as part of my PhD and I want to find out how an injury prevention programme affects injury risk and athletic performance. Will you help?

What is the purpose of this research?

Sport and increased levels of physical activity in youth are linked with high incidence of injuries. Childhood and adolescence is an important time to learn and develop correct movement patterns and optimal levels of physical conditioning to reduce injury risk. This is particularly true for girls, who are at an increased risk of injury compared to boys. One reason for this is boys see an increase in strength and power during puberty while girls do not. There is growing evidence that risk factors for injury in youth can be reduced and athletic performance improved by an appropriate injury prevention programme. Most programmes, however, have been short in nature and have not been in the school curriculum. As so many youth are involved in multiple extracurricular activities, having a programme based in the school will allow for more girls to be involved with and able to follow the full programme. Therefore, this research is being conducted to examine the effect of an evidence based injury prevention programme integrated into the school curriculum on injury risk factors and athletic performance in youth females.

The information gained from this research will be presented in a way so that your name and contact details will remain confidential. The information from this research will be anonymous when presented at an international sports science conference, submitted to a sports science journal for publishing, and when included in my PhD thesis.

How was I identified and why am I being invited to participate in this research?

You are identified as a potential participant for this research as you fit into the following categories:

- Between 12 and 15 years of age
- You are a student in a year 9 or 10 physical education class at SHGC
- You are injury free for the last 6 months and/or are fully participating in training and competition for sports

How do I agree to participate in this research?

You will receive this document with an attached Assent and Consent Form. If you would like to participate in this study your guardian will need to fill out and sign a Guardian Consent Form (see attached) and you will need to fill out and sign an Assent Form (see attached).

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

This research involves examining how risk factors for injury and athletic performance are influenced by time spent in an injury prevention programme integrated into the school curriculum. If you chose to participate in this research you will be required to participate in an injury prevention programme twice per week during advanced physical education class time for three school terms.

The programme will progress in duration as well as difficulty of exercises. The first term will be a 10-minute programme consisting of body weight exercises. The second term will be a 20-minute programme consisting of exercises with minimal equipment (eg. mats, bands, medicine balls, etc.). The final term will be for the full class period (~40 minutes) and will use equipment in the Fitness Centre (eg. barbells, dumbbells, etc.). The control group of physical education students will not perform the trainings but will participate in their normal physical education class. They will however be participating in the data collection sessions. If you choose to not participant in this research, you will still be doing the injury prevention programme and tests but your data will not be used.

Data collection will occur at the beginning of Term 2 and at the end of Terms 2, 3 and 4. The tests included will involve movement patterns (jumps, squats-filmed with digital cameras), vertical jumping (double and single leg), sprinting, lower body strength and a balance assessment. The tests that are filmed will only be viewed by me. If a photograph or video is used for a presentation or publication, your face will not be visible. I will then analyse the data to determine effectiveness of the injury prevention programme compared to a typical amount of improvement due to maturity from the control group. The findings may be used for publications and presentations.

What are the discomforts and risks?

It is not anticipated that you will experience discomfort that would be greater than that occurring in a normal physical education class.

You will be exposed to a small amount of physical risk of injury as you will be performing some resistance training. You may also be exposed to a small amount of physical risk or injury as you will be performing maximal pulling efforts against a fixed object.

How will these discomforts and risks be alleviated?

Risk will be reduced as much as possible by implementing a suitable warm-up and cool-down before and after each testing session, abstaining from high intensity training in the 24 hours prior to each testing occasion, and arriving to each testing session well hydrated and having eaten at least 90 minutes prior to the start. You will also be sufficiently familiarized with all physical movements and tests.

What are the benefits?

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

- Being made aware of your potential risk for injury
- Being made aware of your ability to accelerate, sprint and jump

The findings of the proposed research will be valuable for sport coaches and athletes as well as adolescent athletic development coaches, teachers and researchers.

Finally, this research will benefit myself, as this study will be included in my PhD thesis and I will gain skills in coaching, teaching and collecting data.

How will my privacy be protected?

All of the data from this study will be de-identified. That means that your name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or guardian. I will keep all of your data confidential and any data published or used for presentations will be anonymous.

What are the costs of participating in this research?

Since this research will be during curriculum time, no additional time will be needed. However, some data collection days may require additional time outside of curriculum. This will be done at either interval or lunch time to not interrupt any other classes.

What opportunity do I have to consider this invitation?

You have 2 weeks to decide whether or not you would like to participate in this study.

Will I receive feedback on the results of this research?

You will receive feedback and a summary of your results at the end of the data collection. If you would like any additional information, please contact myself.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: + 64 27 2265181

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Lesley Sommerfield

Email: lsommerfield14@gmail.com

Project Supervisor Contact Details:

Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: *+ 64 27 2265181*

Approved by the Auckland University of Technology Ethics Committee on *28 February 2018*, AUTEC Reference number *18/29*.

Parent/Guardian Information Sheet

Injury Prevention Programme

Date Information Sheet Produced:

13 March 2018

Project Title

The role of an injury prevention programme in youth females

An Invitation

My name is Lesley Sommerfield, I am a PhD student at AUT as well as the Athletic Development Coach at SHGC and I would like to invite your child to participate in this study. Participation in this research is entirely voluntary and your child is able to withdraw from the study at any time. Your child's involvement in this study will not impact her selection into future sports teams or classes at SHGC. This research is being done as part of my PhD and I want to find out how an injury prevention programme affects injury risk and athletic performance.

What is the purpose of this research?

Sport and increased levels of physical activity in youth are linked with high incidence of injuries. Childhood and adolescence is an important time to learn and develop correct movement patterns and optimal levels of physical conditioning to reduce injury risk. This is particularly true for girls, who are at an increased risk of injury compared to boys. One reason for this is boys see an increase in strength and power during puberty while girls do not. There is growing evidence that risk factors for injury in youth can be reduced and athletic performance improved by an appropriate injury prevention programme. Most programmes, however, have been short in nature and have not been in the school curriculum. As so many youth are involved in multiple extracurricular activities, having a programme based in the school will allow for more girls to be involved with and able to follow the full programme. Therefore, this research is being conducted to examine the effect of an evidence based injury prevention programme integrated into the school curriculum on injury risk factors and athletic performance in youth females.

The information gained from this research will be presented in a way so that your child's name and contact details will remain confidential. The information from this research will be anonymous when presented at an international sports science conference, submitted to a sports science journal for publishing, and when included in my PhD thesis.

How was your child identified and why is she being invited to participate in this research?

Your child is identified as a potential participant for this research as you fit into the following categories:

- Between 12 and 15 years of age
- She is a student in a year 9 or 10 physical education class at SHGC
- She is injury free for the last 6 months and/or has fully participated in training and competition for sports

How does my child agree to participate in this research?

You will receive this document with an attached Assent and Consent Form. If your child and would like to participate in this study you will need to fill out and sign a Guardian Consent Form (see attached) and your child will need to fill out and sign an Assent Form (see attached).

Your child's participation in this research is voluntary (it is her choice) and whether or not she chooses to participate will neither advantage nor disadvantage her. She is able to withdraw from the study at any time. If she chooses to withdraw from the study, then she will be offered the choice between having any data that is identifiable as belonging to her removed or allowing it to continue to be used. However, once the findings have been produced, removal of her data may not be possible.

What will happen in this research?

This research involves examining how risk factors for injury and athletic performance are influenced by time spent in an injury prevention programme integrated into the school curriculum. If your child chooses to participate in this research she will be required to participate in an injury prevention programme twice per week during advanced physical education class time for three school terms.

The programme will progress in duration as well as difficulty of exercises. The first term will be a 10-minute programme consisting of body weight exercises. The second term will be a 20-minute programme consisting of exercises with minimal equipment (eg. mats, bands, medicine balls, etc.). The final term will be for the full class period (~40 minutes) and will use equipment in the Fitness Centre (eg. barbells, dumbbells, etc.). The control group of physical education students will not perform the trainings but will participate in their normal physical education class. They will however be participating in the data collection sessions. If your child chooses to not participant in this research, she will still be doing the injury prevention programme and tests but your child's data will not be used.

Data collection will occur at the beginning of Term 2 and at the end of Terms 2, 3 and 4. The tests included will involve movement patterns (jumps, squats-filmed with digital cameras), vertical jumping (double and single leg), sprinting, lower body strength and a balance assessment. The tests that are filmed will only be viewed by me. If a photograph or video is used for a presentation or publication, your child's face will not be visible. I will then analyse the data to determine effectiveness of the injury prevention programme compared to a typical amount of improvement due to maturity from the control group. The findings may be used for publications and presentations.

What are the discomforts and risks?

It is not anticipated that your child will experience discomfort that would be greater than that occurring in a normal physical education class.

Your child will be exposed to a small amount of physical risk of injury as she will be performing some resistance training. Your child may also be exposed to a small amount of physical risk or injury as she will be performing maximal pulling efforts against a fixed object.

How will these discomforts and risks be alleviated?

Risk will be mitigated as much as possible by implementing a suitable warm-up and cool-down before and after each testing session, having your child abstain from high intensity training in the 24 hours prior to each testing occasion, and having your child arrive to each testing session well hydrated and having eaten at least 90 minutes prior to the start. Your child will also be sufficiently familiarized with all physical movements and tests.

What are the benefits?

The benefits for your child being a part of this study include:

- Being made aware of their potential risk for injury
- Being made aware of their ability to accelerate, sprint and jump

The findings of the proposed research will be valuable for sport coaches and athletes as well as adolescent athletic development coaches, teachers and researchers.

Finally, this research will benefit myself, as this study will be included in my PhD thesis and I will gain skills in coaching, teaching and collecting data.

How will my child's privacy be protected?

All of the data from this study will be de-identified. That means that your child's name or contact information will not be available outside of the research database. The data from this research will be made available for approved researchers without any additional consent beyond that given by yourself or guardian. I will keep all of your child's data confidential and any data published or used for presentations will be anonymous.

What are the costs of participating in this research?

Since this research will be during curriculum time, no additional time will be needed. However, some data collection days may require additional time outside of curriculum. This will be done at either interval or lunch time to not interrupt any other classes.

What opportunity do I have to consider this invitation?

You have 2 weeks to decide whether or not you would like your child to participate in this study.

Will I receive feedback on the results of this research?

You will receive feedback and a summary of your child's results at the end of the data collection. If you would like any additional information, please contact myself.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: + 64 27 2265181

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Lesley Sommerfield

Email: lsommerfield14@gmail.com

Project Supervisor Contact Details:

Dr Craig Harrison

Email: craig@athletedevelopment.org.nz

Phone: *+ 64 27 2265181*

Approved by the Auckland University of Technology Ethics Committee on *28 February 2018*, AUTEC Reference number *18/29*.

Consent Form

Project title: ***Assessing injury incidence in adolescent female athletes***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Lesley Sommerfield***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 13 March 2018.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I agree to take part in this research.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 12 June 2017 AUTEC Reference number 17/102

Note: The Participant should retain a copy of this form.

Parent/Guardian Consent Form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Project title: ***Assessing injury incidence in adolescent female athletes***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Lesley Sommerfield***

○ I have read and understood the information provided about this research project in the Information Sheet dated 13 March 2018.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that my child taking part in this study is voluntary (their choice) and that I may withdraw my child/children from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw my child/children from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.

○ I agree to my child/children taking part in this research.

○ Although I might agree for my child to participate I accept that they have the right to decline participation.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child/children's name/s : ....

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Parent/Guardian's signature: ....

Parent/Guardian's name: ....

Parent/Guardian's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 12 June 2017 AUTEC Reference number 17/102

Note: The Participant should retain a copy of this form.

Assent Form

Project title:	***The role of an injury prevention programme in youth females***
Project Supervisor:	***Dr Craig Harrison***
Researcher:	***Lesley Sommerfield***

- ○ I have read and understood the sheet telling me what will happen in this study and why it is important.
- ○ I have been able to ask questions and to have them answered.
- ○ I understand that I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ○ If I stop being part of the study, I understand that then I will be offered the choice between having any information that that other people can know is about me removed or letting the researcher keep using it. I also understand that sometimes, if the results of the research have been written, some information about me may not be able to be removed.
- ○ I am not suffering from any illness or injury that impairs my physical performance.
- ○ I agree to take part in this research.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 28 February 2018 AUTEC Reference number 18/29

Note: The Participant should retain a copy of this form.

Parent/Guardian Consent Form

Project title: ***The role of an injury prevention programme in youth females***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Lesley Sommerfield***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 13 March 2018.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that my child taking part in this study is voluntary (their choice) and that I may withdraw my child/children from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw my child/children from the study then I will be offered the choice between having any data that is identifiable as belonging to my child/children removed or allowing it to continue to be used. However, once the findings have been produced, removal of our data may not be possible.
- ○ My child is not suffering from any illness or injury that impairs her physical performance.
- ○ I agree to my child/children taking part in this research.
- ○ Although I might agree for my child to participate I accept that they have the right to decline participation.
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child/children's name/s : ....

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Parent/Guardian's signature : ....

Parent/Guardian's name: ....

Parent/Guardian's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 28 February 2018 AUTEC Reference number 18/29

Note: The Participant should retain a copy of this form.

Assent Form

Project title: ***The role of an injury prevention programme in youth females***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Lesley Sommerfield***

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered

○ I understand that I will be part of a control group and will not receive the intervention training.

○ I understand that I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that then I will be offered the choice between having any information that that other people can know is about me removed or letting the researcher keep using it. I also understand that sometimes, if the results of the research have been written, some information about me may not be able to be removed.

○ I am not suffering from any illness or injury that impairs my physical performance.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 28 February 2018 AUTEC Reference number 18/29

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Parent/Guardian Consent Form

Project title: ***The role of an injury prevention programme in youth females***

Project Supervisor: ***Dr Craig Harrison***

Researcher: ***Lesley Sommerfield***

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- ○ I understand that my child taking part in this study is voluntary (their choice) and that I may withdraw my child/children from the study at any time without being disadvantaged in any way.
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- ○ I agree to my child/children taking part in this research.
- ○ Although I might agree for my child to participate I accept that they have the right to decline participation
- ○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child/children's name/s : ....

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Parent/Guardian's signature: ....

Parent/Guardian's name: ....

Parent/Guardian's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 28 February 2018 AUTEC Reference number 18/29

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