The Effect of a Neuromuscular Warm-up on Physical Performance in Youth Field Hockey Players with Two Footwear Conditions

by

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“The most important thing is to try and inspire people
so that they can be great in whatever they want to do.”
– Kobe Bryant, 24

SUMMARY

Background:

The FIFA 11+ warm-up program has consistently been shown to decrease injury rates, reduce injury risk factors, and enhance performance in various youth club sport populations, with bias towards football. Limited research addresses the 11+ as a suitable program for other field-based team sports and whether the program can be successfully implemented in a school sport environment. The first aim of this study was to assess the influence of the FIFA 11+ warm-up program on various physical performance measurement in female youth field hockey players. The second aim was to assess whether adaptations differ when performing the intervention barefoot as compared to shod. Field hockey players ($n = 40$; 16.2 ± 1.23 years) from three teams from a South African high school were recruited and randomly assigned to either a barefoot or shod intervention group. A testing battery consisting of five physical performance tests, namely Y-Balance, Single-leg hop, Counter-movement Jump, Sprint, and Illinois Agility, was conducted before and after a nine-week intervention utilizing the 11+ twice a week, 20 min per session. Mixed model ANOVA's were conducted with the full data set of 34 participant with the participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects. Both groups significantly improved ($p < 0.05$) their performance pre- to post intervention in all tests. No statistically significant differences ($p > 0.05$) were found between the two groups with mostly small effect sizes ($ES \geq 0.2$). The FIFA 11+ is a suitable program for female youth field hockey players in a school sport environment to contribute to the development of physical performance and decrease injury risk factors. Performing the warm-up program barefoot or shod appeared to be equally effective to improve physical performance in this population.

Keywords:

Team sport, adolescents, performance, injury, barefoot, warm-up, FIFA 11+

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OVERVIEW

The thesis is presented in research article format, with one submitted article as required. The research article (Chapter Four) was prepared according to the guidelines of the Journal of Sports Sciences and submitted to the Journal for review (Appendix 14). The submitted article reports on the results pertaining to research question two of the study. A second article was prepared to keep to the article format for presenting results for the first research question. Consequently, the referencing styles used in Chapter Four will differ to that of the remaining chapters.

Chapter One: Introduction. This chapter contains the introduction and problem statement as well as the aims of the study and the hypotheses. The Harvard method of referencing was used.

Chapter Two: Theoretical Background. The purpose of this chapter was, firstly, to summarise the existing literature relating to the broader youth team sport context and rising rates of injuries in the South African context. Secondly, to provide insight how intervention-based neuromuscular training (warm-ups) can decrease injury rates, improve injury risk factors, and enhance performance. Thirdly, to provide rationale for the chosen measurements to assess physical performance, namely balance, functional jump performance, lower-limb power, acceleration and speed, and agility. Lastly, to provide explanation how the novelty of implementing the intervention barefoot assists the scope of neuromuscular training and warm-ups in literature and practice.

Chapter Three: Methodology. This chapter explains the sample size, study design, ethics, methods for data collection, and statistical analysis.

Chapter Four: Results and Discussion. Research article one – The Influence of the "FIFA 11+" Warm-up Program on Physical Performance in Youth Field Hockey Players. The focus of the article was to determine whether a nine-week neuromuscular warm-up program can be successfully implemented in an ecologically valid environment to affect physical performance in female youth field hockey players.

Research article two – Changes in Physical Performance after a nine-week Neuromuscular Warm-up Program performed Shod or Barefoot in Youth Field Hockey Players: A Randomized Controlled Trial. This article reports on the comparison in physical performance adaptations following a nine-week neuromuscular warm-up program in shod and barefoot conditions in youth field hockey players.

Chapter Five: Conclusion. This chapter includes the conclusion of the study, practical applications of the results, limitations of the study, recommendations for research in a similar environment and suggestions for future research.

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CHAPTER ONE

INTRODUCTION

A. INTRODUCTION

School sport is a large platform for learners to participate in organized team sports (McKay, Cumming, and Blake, 2019; Lombard, 2018). This is true in particular for countries whose sport culture emphasizes and incentivizes a competitive- and achievement-oriented sport environment from youth- to elite sport settings (Jacobs et al., 2019). Most team sports are characterized by repeated intermitted high-intensity and multidirectional actions that require large amounts of explosive strength, change-of-direction ability, acceleration, and deceleration, as well as contact with other players (Lombard et al., 2021). Due to the nature of these sport-specific high intensity movements, injuries to the lower-limbs are common and come at a large personal-, financial-, and societal burden (Cumps et al., 2008). Unsurprisingly, concerning rates of injury have been frequently reported in popular South African youth team sports, such as field hockey (Ellapen, Bowyer and Van Heerden, 2014; Ellapen et al., 2009) and rugby (Brown et al., 2015, 2018; Burger et al., 2014, 2017; Constantinou, 2016; Mc Fie et al., 2016; Sewry et al., 2019; Tee et al., 2017).

It is commonly accepted and supported in academic literature that integrative neuromuscular training (INMT) reduces injury rates (Steffen et al., 2008; 2013), improves specific injury risk factors (such as impaired balance) (Hübscher et al., 2010), and enhances sport-specific performance metrics (such as speed and agility) (Fort-Vanmeerhaeghe et al., 2016; Markovic & Mikulic, 2010; Rameshkannan & Chittibabu, 2014) in athletes of all ages and performance levels. Neuromuscular warm-ups, that follow the principles of multicomponent exercise selection, have been designed as an effective, cost- and time-saving alternative to replace traditional warm-ups without the need for additional strength and conditioning programs and only require minimal and readily available equipment, such as cones (LaBella et al., 2011; Soligard et al., 2009). Neuromuscular warm-ups, such as the FIFA-endorsed ‘FIFA 11+’ (advertised as ‘injury prevention programs’), have been widely researched and shown to decrease injury and enhance performance in (youth) team sport athletes in mainly Western club sport environments (Ayala et al., 2017; Longo et al., 2012; Owoeye et al., 2014; Soligard et al., 2009; Steffen et al., 2008, 2013). The effectiveness of such programs, especially those that do not require additional resources, equipment, or qualified personnel, is of importance for the application in ecologically valid environments (LaBella et al., 2011). In the current context, ecological validity refers to how well the results of studies, e.g., injury prevention neuromuscular training interventions, can be applied in a real-world school sport environment to achieve its desired effects of injury risk reduction and performance enhancement.

Performance- and injury risk factors can be assessed through a variety of physical performance tests. The chosen physical performance tests for the current study are balance, functional jumping, vertical jump, acceleration and speed, and agility. The rationale for the selection of these tests is discussed in Chapter Two and are in line with other performance studies. The tests were conducted one week prior and one week immediately after a nice-week neuromuscular warm-up intervention, which utilized the FIFA 11+ program, with a sample of 34 female youth field hockey players from one high school.

Current training trends and geographical (country-specific) habits of the population that is studied should be considered in the design of appropriate training interventions. Based on research by Hollander et al. (2017; 2016), most South African children and adolescents have been classified as habitually barefoot. The sample of this study is classified almost entirely as growing up habitually barefoot (34 out of 31 participants). Growing up barefoot has significant effects on the development of foot morphology, including an increase in foot arch angles, and motor performance (Hollander et al., 2016, 2017). A cross-sectional study by Zech and colleagues (2018) showed that footwear habits impacted motor skill development in youth and adolescent children. Particularly jumping and balance skills appeared to have been positively influenced by regular barefoot physical activity in 6- to 10-year-olds. The performance-, physiological-, and biomechanical adaptations to barefoot running compared to shod have become a growing field of interest in academic literature (da Silva Azevedo et al., 2016; Lieberman et al., 2010; Perkins et al., 2014). There is currently both support as well as possible contra-indications for barefoot running when compared to shod (wearing of shoes), with overall inconclusive evidence for long-term effects due to a lack of prospective studies (Hannigan & Pollard, 2019; Hollander et al., 2019;

Lieberman et al., 2010; Nigg, 2009; Nigg & Enders, 2013; Warne & Gruber, 2017). Some evidence indicates that balance and agility training performed barefoot may lead to superior performance adaptations in female university netball players due to intrinsic neuromuscular adaptation surrounding the ankle joint and foot (de Villiers & Venter, 2014). These findings are of interest to determine the (potential superior) usefulness of barefoot training when compared to shod, especially in a population that is already classified as predominantly habitually barefoot (South Africa).

B. PROBLEM STATEMENT & SIGNIFICANT OF THE STUDY

Firstly, there is currently a lack of intervention-based research to enhance physical performance and subsequently addresses the multicomponent burden of injury risk in the South African youth sport context. Neuromuscular training programs, such as the 'FIFA 11+', have a large body of research, suggesting injury reducing- and performance enhancing benefits in mainly Western club sport environments (Ayala et al., 2017; Longo et al., 2012; Owoeye et al., 2014; Soligard et al., 2009; Steffen et al., 2008, 2013). Further, the 'FIFA 11+' requires minimal equipment (cones) and has readily available- and extensive educational material. This presents an opportunity to determine whether such programs can be successfully applied in a youth team sport environment that attracts high rates of participation (i.e., at a school) and influence physical performance. A successful implementation may allow the program to be recommended to coaches of varying levels of education, in various field-based team sports and in different socio-economic environments to be inclusive of the South African context.

Secondly, it remains unclear how barefoot training might affect measures of physical performance of (habitually barefoot) youth team sport athletes due to the limited and contested available evidence. The novelty of the current study is the implementation of the warm-up intervention in barefoot conditions. No previous research on physical improvements following a neuromuscular warm-up in youth team sport athlete has assessed possible different adaptations when performed barefoot when compared to shod. Barefoot habits need to be considered in conducting interventions in populations that are classified as either habitually barefoot or shod, so that findings can be contextualized, and recommendations made with caution.

The following section presents the research questions, hypotheses, aims, and objectives of the current study.

C. RESEARCH QUESTIONS, HYPOTHESES, AIMS, AND OBJECTIVES

Research Questions

Research questions one:

Can a nine-week neuromuscular warm-up program be successfully implemented in an ecologically valid environment to affect physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, in female youth field hockey players?

Research question two:

Does performing the warm-up intervention barefoot, as compared to shod, lead to different adaptations in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility in predominantly habitually barefoot female adolescent field hockey players?

Hypotheses

Research hypothesis one:

It is hypothesized that a nine-week neuromuscular warm-up program could be successfully implemented with high adherence and improvement in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, in female youth field hockey players in a school setting.

Research hypothesis two:

It is hypothesized that there will be a difference in physical performance, as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, between barefoot and shod conditions in predominantly habitually barefoot female youth field hockey players with the barefoot condition showing superior results compared to shod.

Research Aims

The first aim of the study was to determine whether a nine-week neuromuscular warm-up program could be successfully implemented with high adherence and improvement in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, in female youth field hockey players in a school setting.

The second aim of the study was to compare the effect of two different footwear conditions (shod and barefoot) of a nine-week neuromuscular warm-up intervention on physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, in predominantly habitually barefoot female adolescent field hockey players.

Objectives

The objectives for the study were to determine:

1) Adherence to a nine-week warm-up program intervention for each session in a school setting by documenting attendance.

2) Adaptations in physical performance, pre- and post a nine-week neuromuscular warm-up intervention performed in either barefoot- or shod conditions, by assessing:

2.1) Balance / dynamic postural stability

as measured by the Star Excursion Balance Test (adapted Y-Test) by assessing:

- the reach distance of each foot in the anterior, posteromedial, and posterolateral directions
- the right-left discrepancies in the anterior reach direction to determine lower-limb asymmetry.

2.2) Functional jump performance

as measured by the Single-leg Hop test for distance by:

- having the athletes perform three single-leg jumps for distance on each leg, with the furthest distance as the score
- assessing right-left differences in jump distance to determine lower-limb asymmetry.

2.3) Vertical jump

as measured by the counter-movement jump height with the best attempt out of three attempts as the score.

2.4) Acceleration and speed

as measured by a 40-m sprint test with a split time at 10-m, with the fastest of two attempts as the score.

2.5) Agility

as measured by the Illinois Agility course, with the fastest of two attempts as the score.

D. VARIABLES

The variables of the study are presented in Table 1.1.

Table 1.1. Variables of the current study.

Independent	1. Barefoot intervention group utilizing the integrative neuromuscular training (INMT) warm-up 2. Shod intervention group utilizing the INMT warm-up
Dependent	1. Adherence to program 2. Balance / dynamic postural stability 3. Functional jump performance 4. Vertical jump 5. Acceleration and speed 6. Agility
Categorical	1. Age 2. Height 3. Highest level of participation (u19A, u19B, u16A) 4. Barefoot habits
Confounding	1. Adherence to program 2. Covid-19 resurgence and school sport shut-down
Control	No passive control group

E. ASSUMPTIONS

Certain assumptions regarding the participants were made at the start and during the study. It was assumed that participants were motivated to take part in the study, and that they would perform the performance tests and the intervention exercises to the best of their ability. It was also assumed that the coaches were motivated to implement the program and gave adequate exercise instructions and assistance to safely conduct the intervention sessions. Further, it was assumed that participants were honest about their footwear habits, as well as not being injured. Finally, the participants were verbally instructed to refrain from exercise 24-hours prior to testing and it was assumed that the participants followed these guidelines.

Regarding data collection, it was assumed that the equipment produced reliable and valid data during the different testing days. The researchers ensured that all equipment worked properly, prior to the start of the testing protocol. The calibration of the speed gates was conducted by qualified sport scientist from Maties Sport who operated the equipment throughout testing. The researchers did their best to ensure similar circumstances during the testing days, to make sure all the testing were conducted in a similar way, data were recorded properly and that all participants had a similar experience during pre- and post-testing.

CHAPTER TWO
THEORETICAL CONTEXT

A. INTRODUCTION

Competitive school sport participation is a large platform for learners to attend and compete in organized team sports with large training volumes and increasingly congested competition schedules (McKay, Cumming, and Blake, 2019; Lombard, 2018). As a result, there is growing concern in academic literature about increasingly high injury rates in youth athletes, specifically in a competitive school sport system such as in South Africa (DiFiori et al., 2014; Jones et al., 2019). Evidence-based injury-prevention interventions in South African youth sport literature are scarce and largely biased towards injury rates in popular male sports, such as rugby (Brown et al., 2015, 2018; Burger et al., 2014, 2017; Constantinou, 2016; Mc Fie et al., 2016; Sewry et al., 2019; Tee et al., 2017). Scholarly attention exists internationally, and several intervention programs have been proposed that aim to decrease injury risk and enhance performance in youth sport and school sport environments (Emery et al., 2015). Neuromuscular training interventions seem to be part of the answer, for reasons such as improved neuromuscular control and the development of basic- and sport-specific movement patterns to adequately prepare youth athletes for the demands of their sport (Fort-Vanmeehrhaeghe 2016, Markovic & Mikulic 2010, Meyer 2011, Rameshkannan & Chittibabu 2014). This chapter provides relevant and recent literature (≥ 2010) pertaining to the aims of this study. Firstly, the context of South African youth sport participation, injury risk factors and physical performance will be provided. This knowledge provides the foundation for the design of the current study and the need to implement injury-prevention programs that target the high prevalence of injury risk in youth sport in the country. Secondly, relevant literature will be discussed which provides support for the effectiveness of integrative neuromuscular training to (1) decrease injury prevalence (2) decrease specific injury risk factors, and (3) improve performance factors in youth team sport. This is of importance to inform this study and other researchers of similar program design and exercise selection for future interventions with the focus on programs' application in ecologically valid environments at minimal extra cost for a broad scale adoption. It is important to note that this study does not assess injury rates over a season, due to constraints in time and data collection procedures. Rather, the focus of this study will be on the assessment of modifiable neuromuscular performance- and injury risk factors, such as balance, dynamic postural stability, speed, and power. Lastly, it will be discussed how the effectiveness of integrative neuromuscular programs could be enhanced through the inclusion of barefoot activities in their protocols. This addition provides the novelty of the current study, as, to our knowledge, there are no other studies that examine the effects of barefoot neuromuscular training compared to shod in youth team sport. The next section discusses the specific literature pertaining to youth sport participation in South Africa and the growing need for intervention-based research to address injury risk factors in the youth population. The chapter will guide the reader to contextualize how integrative neuromuscular training interventions may address identifiable injury risk- and physical performance through selected physical performance testing.

B. YOUTH SPORT

Youth sport participation is popular and increasingly growing globally with competitive high school sport systems in many countries (McKay, Cumming, and Blake, 2019). High school sport is often considered a jumping board for a potential university-, professional- and club sport career. Defining youth sport poses many challenges. The chronological age for the onset of youth varies between societies and one exact age span to define youth is difficult to find (Green, 2010). Typical synonyms for “youth” would be “teenager” and “adolescent”, with youth being defined as “a life-stage that can be broadly mapped onto the middle-to-late teenage years”, roughly starting at the age of 15 years (Green, 2010, p. 17). A broader age rage under which youth (or adolescent) sport research can be classified is 12 to 18 years old for girls and 14 to 18 years old for boys (Lloyd et al., 2015).

South Africa’s Department of Sport and Recreation (2021) promotes competitive school sport on intra-school-, inter-school-, district-, provincial-, and national-level. On tertiary education level, the televised tournament ‘Varsity Cup’ attracts thousands of spectators and viewers annually in South Africa’s most popular (mainly team-) sports, such as rugby, netball, athletics, field hockey, and football (*Varsity Sports SA*, 2021). Becoming a competitive student-athlete is highly incentivised with prominent driving factors such as scouting by professional teams, performance-related awards, television appearances, study opportunities, family- and peer popularity, and building close interpersonal relationships (Toriola et al., 2021). High school athletes who excel can be recruited directly from schools on bursary opportunities to attend universities or colleges and compete on both the provincial and national stages. Performing well in sport at school level could, therefore, also provide a route to a tertiary institution which might not have been accessible otherwise (Hextrum, 2018).

Despite university sport's popularity and prestige, South African high schools remain the largest platform for young people to be exposed to a variety of sports and opportunities to compete. It is not uncommon for high school learners to be involved in multiple sports year-around, leading to large training volumes and increasingly congested competition schedules (Lombard, 2018). These accumulative physical demands are accentuated by simultaneous participation in high school- and club sport (Post et al., 2017). Due to the associated injury risks of large training volumes, age-appropriate strength and conditioning initiatives started to emerge, advocating to develop physical competencies, decrease risk of burn-out and injuries, and develop future professional athletes (Lombard, 2018). The fact that there is a need for such targeted approaches in adolescent years highlights the trend of ever-increasing competitiveness in South African high school sport. This sentiment is mirrored by growing media attraction and coverage that high school sport receives. The South African-based Pan-African television network *SuperSport* has recently launched a 'SuperSport Schools' channel to "expose young talent by broadcasting as many schools sporting fixtures as possible" and contribute to produce a 'winning sporting nation' (SuperSport, 2021). Although the government's National Sports and Recreation Plan's first strategic objective in 'building an active and winning nation' is "to improve the health and well-being of the nation by providing mass participation opportunities through active recreation" (Ministry of Sports and Recreation, 2011, p. 18), South Africa's youth sport participation may be driven by a performance- and competition-oriented culture (Jacobs et al., 2019). A Finnish study involving young athletes (n = 1962; 553 girls; 1409 boys) from football, ice hockey, and basketball (n = 293) showed that "beating others", served as an important motive for these young athletes to maintain participation in sport (Rottensteiner et al., 2015, p. 442).

Youth sport from a performance and competitive perspective has not been a prominent topic within research in South Africa. It would seem that, where research on training- and competition-related topics are performed, a bias towards certain sports and populations may exist. Men’s youth rugby is a dominant field of interest in South African academic literature, with particular focus on youth injury prevalence from community- to youth rugby union settings. Significant scholarly attention is directed towards (tackle-related) injury incidences and associated multi-component burden (Brown et al., 2015, 2018; Burger et al., 2014, 2017; Constantinou, 2016; Mc Fie et al., 2016; Sewry et al., 2019; Tee et al., 2017). Another growing area within performance-focused research in South African field hockey is sport psychology and mental skills training in both male and female populations (Eloff et al., 2011; Kruger, 2010; Tinkler et al., 2020). However, the existing literature focuses on tertiary education-level athletes and not on adolescent sport. In school-level netball, psychosocial profiles of South African school netball players have been assessed (Joosub & Niekerk, 2016). There is, therefore, a growing need to research interventions that can provide practical guidelines for coaches in various youth (school) sport environments to fill the gap of academic- and solution-oriented literature.

A few deductions can be made based on the outlined development of competitive youth sport and the provided brief overview of the current state of youth sport literature in South Africa. Firstly, the overall limited existing performance-focused literature does not match the popular and ever-growing competitive youth sport culture in South Africa. Secondly, the existing literature is heavily biased towards male youth rugby and neglects female populations as well as other popular sports (Brown et al., 2018; Durandt et al., 2015; Hendricks et al., 2017). Thirdly, most research addresses the high prevalence of injuries in South African youth sport and provides some insight on the associated injury risks and mechanisms yet does not provide a solution-based perspective on the issue (Burger et al., 2017; Mc Fie et al., 2016; Sewry et al., 2019; Tee et al., 2017).

There is scarcity in South African studies that address possible interventions to reduce injury risk and enhance performance in youth athletes. Overall, this creates the necessity to dedicate more research efforts towards youth sport populations in general and female adolescent athletes at large in ecologically valid environments, such as high schools, that see a large percentage of their learners participating in organized school sports. Reports of the high prevalence of injuries in South African youth athletes should be followed by intervention-based research, aimed at addressing injury risk factors and potentially reducing them. The present study should add to the current lack of research on youth sport in South Africa.

C. INJURIES IN YOUTH SPORT

Injury Rates

Addressing high rates of sport injuries is paramount, as they have, apart from hampered performance and teams' success, large individual- and societal costs (Cumps et al., 2008). These costs are accentuated by the lack of accessibility of socio-economic resources and injury treatment options, as well as the nature of sports, such as collisions in rugby and hockey (Brown et al., 2015; Burger et al., 2017; Eirale et al., 2013; Hägglund et al., 2013; Van Mechelen, 1997). Before addressing prevalent injury risk factors, such as impaired balance, it is important to determine the extent of injury burden in South Africa. Tee and colleagues (2017) revealed that injury incidence (52-105 injuries/1000 training hours) in South African high school rugby was alarmingly higher than expected and comparable with the incidence in men's senior professional rugby (81 injuries/1000 h), as well as higher compared to similar population groups in England, Ireland, and Scotland. A possible explanation for this may be the perceived higher level of physicality from rucks and mauls in rugby union game rules, which is commonly played in South Africa, compared to rugby league rules, which are more commonly played in Europe. Such comparisons must be interpreted with caution due to significant heterogeneity in the definitions of injuries in different studies (Kirkwood et al., 2015). Female youth populations, as well as other popular sports, such as field hockey, netball, and football, have not received similar attention in performance-focused South African youth research literature. There is limited literature in female youth field hockey, which, comparable to the outlined trend in male youth rugby research, highlights the high prevalence of musculoskeletal injuries.

Ellapen, Bowyer and Van Heerden (2014) reported that 94 out of 148 (64%) 13-18-year-old female adolescent field hockey players in KwaZulu-Natal (KZN), South Africa, sustained acute musculoskeletal injuries across one season, which prevented sporting activities of at least 24-hours. Chronic, persistent pain was reported by 137 players, predominantly in the hip and lower back area, which is likely due to a prolonged semi-crouched running position with ball and stick (Ellapen, Bowyer and Van Heerden, 2014). Acute lower-limb injuries were primarily sustained during direct physical trauma and collision with other players (63%) or rapid rotational movements (27%), with the most affected areas being the knee (23%), lower back (18%) and ankle (15%) (Ellapen, Bowyer and Van Heerden, 2014). Rapid rotational movements were also the primary cause (64,4%) for a high prevalence of inversion ankle sprains, reported in 53 16-18-year-old male adolescent field hockey players in KZN (Ellapen et al., 2009).

Four steps in the development of holistic programs to reduce and manage injury risk factors and the associated injury burden have been identified (van Mechelen, Hlobil and Kemper, 1992). *Determining the extent of the injury problem* is regarded as the first step. As previously highlighted, Ellapen, Bowyer and van Heerden (2014) described that in the South African context most injuries sustained in female youth field hockey are to the knee, lower back, and ankle, in both contact- and non-contact scenarios. This is in line with broader international research in high school-, university-, and national-level female hockey athletes (Barboza et al., 2018; Murtaugh, 2001).

Injury Risk Factors

The second step in the holistic approach is the *identification of specific intrinsic and extrinsic injury risk factors and mechanisms* that may predispose athletes to a greater risk for injuries in a particular sport (Van Mechelen, 1997; van Mechelen et al., 1992). Extrinsic risk factors are those considered ‘outside’ of the athlete, such as the level of competition and playing surface (Murphy et al., 2003). It is generally understood that the higher the level of competition and the greater the training and competition exposure (volume), the higher the risk of injury, which are not influenced by performance enhancement (Windt & Gabbett, 2017). Intrinsic factors are inherent or acquired characteristics, such as age, sex, fitness status, or previous injury history, that may predispose athletes to a greater injury risk (Murphy et al., 2003). For example, it has been well established that female athletes are at a significantly greater risk to sustain ACL injuries than males, mainly due to intrinsic anatomical differences (Consensus Statement, 2016; Montalvo et al., 2019; Sutton & Bullock, 2013). Kinetic and kinematic mechanisms for heightened ACL injury risk include faulty landing technique with abnormal knee valgus and external tibial rotation (foot turned outward) upon landing.

Collings and colleagues' (2021) systematic review examined existing literature to identify primary risk factors for lower limb injuries in female team- and field sports based on outcomes from physical tests. Lower limb injury risk factors included a greater star excursion balance test (SEBT) anterior reach distance and smaller single-leg hop distance (Collings et al., 2021). Ankle injury risk factors included a smaller SEBT anterior reach distance, a greater single-leg hop test distance asymmetry and slower agility course time (Collings et al., 2021). Functional ankle instability following an acute ankle sprain was reported by 32-47% of participants, making them more susceptible to subsequent ankle injuries (Wright et al., 2016). These findings highlight the importance of balance, postural stability, single-limb power, and between-limb hop distance symmetries in injury risk management. A comprehensive assessment plan and testing battery that assesses these physical qualities and competencies may be valuable tools for coaches and medical personnel to identify at-risk athletes and monitor their progression over time.

Solution-focused Interventions

The third step in the *development of program*s to reduce risk of injury is to create *suitable interventions* that address the identified risk factors. The high injury burden in South African (school) rugby has led to the development and implementation of safety initiatives, such as the BokSmart program. BokSmart, launched in 2009, was developed by the national governing body, Rugby South Africa, and includes accredited training courses with video- and reading material, and the exercise-based injury prevention intervention Safe Six (Rugby South Africa, 2021). BokSmart safety protocols are widely accepted standards across the country and are even required to attain coaching and referee licenses (South African Rugby Union, 2011). Such safety measures are only one part of necessary protocols to ensure safe youth sport participation in schools. In their study involving 16-18-year-old male adolescent field hockey players, Ellapen et al. (2009) suggested that the lack of supplementary resistance training, aimed at increasing strength in ankle musculature, may have predisposed youth athletes to greater ankle injury risk. Overall injury management remains of concern, as it was found that many South African schools are still lacking behind in crucial safety areas such as appropriate supervision of inexperienced coaches, safe sport facilities and equipment, as well as medical care, screening, and keeping of records (Singh and Surujlal, 2010). Finally, the fourth step is to *implement holistic programs and measure their effectiveness.*

D. INTEGRATIVE NEUROMUSCULAR TRAINING IN TEAM SPORTS

Integrative neuromuscular training (INMT) has been widely accepted as an effective method to manage and reduce injury risk factors, as well as develop physical competencies in athletes of all ages (Hübscher et al., 2010). It is defined as a systematic and progressive training program that incorporates general (fundamental) and sport-specific strength and conditioning activities “that are designed to enhance health and skill-related components of physical fitness” (Myer et al., 2011, p. 158). Fort-Vanmeerhaeghe et al. (2016b) classified the components of INMT into two categories. The first category comprises of activities that include strength, plyometrics, agility, speed coordination, and dynamic stability, with the goal to develop fundamental movement skills (Fort-Vanmeerhaeghe et al., 2016b). The second category includes sport-specific movement skills to improve skill-related components of physical fitness to prepare athletes for the demands of their sports. Plyometrics and agility training in particular are prevalent training components in a majority of individual- and team-sports. Drills are performed at high velocities and have shown to lead to musculoskeletal adaptations that enhance lower-limb power, and a wide range of performance measures, such as jumping, sprinting, and change of direction speed (Markovic & Mikulic, 2010; Rameshkannan & Chittibabu, 2014). Dynamic stability training (the ability to maintain balance during dynamic jump-landing actions) is suggested to be a major contributor in reducing injury risk in youth sport because of sensorimotor improvements that enhance joint dynamic stability (Fort-Vanmeerhaeghe et al., 2016a). A consensus is that progressive INMT, with focus on movement education, motor skill learning, and guided under appropriate supervision, is safe and advisable for children to start as early as middle childhood (preadolescent, 7 to 10 years) and continuation through adolescent years (Lloyd et al., 2014; Myer et al., 2011). It is important to understand in which way INMT can benefit (youth) athletes in their sport’s performance and address possible injury risk factors for safe and lifelong participation.

Reducing Injury Rates

Systematic reviews show overall positive injury risk reduction through INMT (Caldemeyer et al., 2020; Stevenson et al., 2015). Hübscher and colleagues (2010) reported a reduction of 39% in lower-limb injuries in general, 54% in acute knee injuries, and 50% in acute ankle sprains in adolescent and young adult athletes in pivoting sports, compiled from seven high-quality randomized controlled studies. Interestingly, it was acknowledged that not enough evidence could be gathered regarding the underlying mechanisms of INMT interventions (e.g., balance improvements) that resulted in these protective effects (Hübscher et al., 2010). This leaves room to explore the effects of specific measurement outcomes in INMT training interventions, such as balance and proprioception, on reducing the risk of injury in team sport settings.

In reviewing high-quality INMT interventions aimed at reducing injuries in youth team sports, Emery and colleagues (2015, p. 3) found a "substantial overall protective effect for the reduction of lower extremity injuries and suggest a potential reduction of knee injuries". Most of the included studies followed a multimodal approach with components of balance, agility, and strength. INMT injury prevention programs may result in injury reduction of up to 46% in youth sports (football, basketball, and handball), with the recommendation to incorporate multimodal programs that include jumping and plyometrics (Rössler et al., 2014). This is in line with findings that lower-limb injury risk factors are modifiable with injury prevention programs aimed at improving strength, balance, coordination, and posture, and have negligible effects on endurance and speed (Hanlon et al., 2020).

It has further been suggested that the use of stretching alone to reduce injuries cannot be supported and recommended (Lauersen et al., 2014). In contrast, the researchers found that multimodal programs (i.e., INMT), proprioception, and strength training showed increasing effects across various sports with multifaceted training resulting in the greatest overall protective effects (Lauersen et al., 2014). Additionally, strength programs alone reduced sports injuries to less than one-third, and over-use injuries could be halved, indicating effectiveness for various injury patterns (acute and chronic) (Lauersen et al., 2014).

Table 2.1. provides a summary of nine studies on the effectiveness of INMT in reducing injury rates in youth team athletes. There are many programs, but for the context of the current study, studies were included that satisfied the following inclusion criteria:

- Male and female youth participants in the age range of 12 – 18 years, as per the previously discussed definition by Lloyd et al. (2015)
- The athletes participated in team-sports
- The utilized programs were based on multimodal (INMT) training approaches
- Injury incidence was measured directly
- Articles were published between 2010 - 2021

Table 2.1. Summary of studies of Integrative Neuromuscular Training Interventions to reduce injury risk in youth team athletes since 2010.

Reference	**Title**	**Study Design**	**Population & context**	**Components of program**	**Program design**	**Injury variables assessed**	**Results on injury risk**
Emery & Meeuwisse (2010)	"The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial"	C-RCT N = 744 M + F	13 to 18 years Upper competitive under-13 to under-18 Canadian indoor **football** players from 12 clubs (60 teams total)	Strength (lower limb & core) Plyometrics Agility Balance Equipment: balance/wobble boards	Duration: one season (five months) Frequency: depending on practice frequency, 15min warm-up + 10min NM training components + 15min home-based balance	All injuries Acute Lower limb Knee Ankle	↓ all ↓ acute Protective effect, but → lower limb-, knee-, & ankle
Kiani et al. (2010)	"Prevention of Soccer-Related Knee Injuries in Teenaged Girls"	Non-randomized prospective cohort N = 1407 F	13 to 19 years Lower- to upper competitive regional club **football** players	***HarmoKnee*** *program* Strength (lower limb, core) Plyometrics Balance Core stability Muscle activation Equipment: none	Duration: one season (eight months) Frequency: two times / week during pre-season, one time / week during regular season, 20 – 25min warm-up	Knee	↓ any knee ↓ NC knee ↓ severe knee
LaBella et al. (2012)	"Effect of Neuromuscular Warm-up on Injuries in Female Soccer and Basketball Athletes in Urban Public High Schools"	P-RCT N = 1492 F	≤ 16 years Lower- to upper competitive urban public high school **basketball** and **football** players	***KIPP*** *(Knee Injury Prevention) program* Strength (lower limb) Plyometrics Balance Agility Equipment: none	Duration: one season Frequency: depending on practice frequency, 20min warm-up	Overall lower limb Knee Ankle	↓ NC ankle ↓ NC knee ↓ NC ACL ↓ gradual-onset lower limb

Longo et al. (2012)	"The FIFA 11+ Program is Effective in Preventing Injuries in Elite Male Basketball Players"	C-RCT N = 121 M	11 to 19 years Elite male under-12 to under-19 **basketball** league players from one Italian third division club	***FIFA 11+** program* Strength (lower limb & core) Plyometrics Balance Speed Agility Equipment: none	Duration: one season (nine months) Frequency: three to four times / week, 20min warm-up	All injuries Lower limb (trunk, leg, hip, and groin) Knee Ankle	↓ all injuries ↓ training ↓ lower limb (trunk, leg, hip, groin) ↓ acute ↓ severe knee- & ankle → overall match-, knee-, & ankle
Waldén et al. (2012)	"Prevention of acute knee injuries in adolescent female football players"	C- RCT N = 4564 F	12 to 17 years Under-14 to under-18 Swedish club **football** players	***Knäkontroll** program* Plyometrics Core stability Dynamic stability Balance Equipment: none	Duration: one competitive season (seven months) Frequency: two times / week throughout season, 15min warm-up	ACL Knee Severe knee	↓ ACL Protective effect but → severe knee- & any acute knee
Steffen et al. (2013)	"High adherence to a neuromuscular injury prevention program (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players"	C-RCT N = 148 F	13 – 18 years Upper competitive under-16 and under-18 Canadian **football** players	***FIFA 11+** program* Strength (lower limb, core) Plyometrics Balance Speed Agility Equipment: none	Duration: one season (four months) Frequency: two to three times / week, 20min warm-up	Injury incidence Balance (SEBT, single-leg eyes-closed) Triple hop Jumping-over-a-bar	↓ injury incidence ↑ SEBT (5/6 direction) ↑ single-leg eyes-closed balance in supervised group → triple hop → jumping-over-a-bar
Owoeye et al. (2014)	"Efficacy of the FIFA 11+ Warm-Up Programme in Male Youth Football"	C-RCT N = 414 M	14 – 19 years Nigerian **football** players from 20 club teams	***FIFA 11+** program* Strength (lower limb, core) Plyometrics Balance Speed Agility Equipment: none	Duration: one season (six months) Frequency, two times / week, 20min warm-up	Any injury Lower limb	↓ any injury ↓ lower limb

Achenbach et al. (2018)	"Neuromuscular exercises prevent severe knee injury in adolescent team handball players"	Block RCT N = 279 M + F	13 to 18 years Under-16 to under-18 German club **handball** players	Strength (lower limb) Plyometrics Dynamic stability Balance Equipment: none	Duration: one season Frequency: two to three times / week for 15min during pre-season; once a week for 15min during competitive season	Lower- and upper limb Severe knee Ankle	↓ severe knee → ankle → lower- & upper limb
Barber Foss et al. (2018)	"A school-based neuromuscular training program and sport-related injury incidence"	P-RCT N = 474 F	12 to 15 years High school (HS) and middle school (MS) basketball-, **football**-, and **volleyball** players	Strength (trunk- and lower limb) Plyometrics Dynamic stability Balance Equipment: BOSU ball, step, foam pad	Duration: one season Frequency: three times / week, 20 – 25min during pre-season; two times / week, 10 – 15min during competitive season	Knee Ankle	↓ knee (MS volleyball) ↓ knee (HS basketball) → knee (soccer) → ankle

P-RCT = prospective randomized controlled trial; C-RCT = cluster randomized controlled trial; N = population; M = male; F = female; M + F = male and female; ACL = anterior cruciate ligament injury; NC = non-contact; COD = change of direction; ↑ = statistically significant increase in; ↓ = statistically significant decrease in; → = no statistically significant increase/decrease in

In the description of the programs, the researchers of the identified articles in Table 2.1 defined the training components and exercise categories differently (e.g., balance vs dynamic balance vs dynamic stability), or, at times, did not list specific components despite referring to them in the program. The researcher collated the components from the included studies into seven categories. This was done to standardize terminology and group the components to uniformly present them in Table 2.1. The components mentioned in the selected studies are named and described in Table 2.2. The descriptions of the components are derived from the definitions of the National Strength & Conditioning Association (National Strength and Conditioning Association, 2012; Sands, Wurth, and Hewit, 2012).

Table 2.2. Description of primary components of INMT interventions collated from nine studies in Table 2.1.

Component	Description
Strength	Exercises to improve muscular strength (e.g., bridge).
Plyometrics	Exercises that require rapid force production during (repeated) high intensity jumping efforts (e.g., triple hop).
Agility	Exercises that require rapid change of velocity (acceleration and deceleration) or direction manoeuvres during running tasks (e.g., diagonal cutting), also commonly defined as Change of Direction Speed (CODS).
Balance	Static stability exercises that require both or one leg to remain in contact with the ground (e.g., single-leg balance on wobble board).
Dynamic stability (postural control)	Exercises that require control of the body during dynamic actions and achieve appropriate knee alignment (e.g., jump-landing tasks such as skater jumps).
Core stability	Exercises that require bracing of the lumbopelvic region in a continuous manner (e.g., plank)
Speed	Exercises that require maximum sprint efforts across a predefined distance (e.g., 10m sprint/acceleration).

In summary, eight out of the nine studies in Table 2.1 were randomized control trials with large participant samples of 121 to 4564 (mean = 1071). Five out of nine studies included only female- (Kiani et al., 2010; LaBella et al., 2011; Waldén et al., 2012; Steffen et al., 2013; Barber Foss et al., 2018), two studies included only male- (Longo et al., 2012; Owoeye et al., 2014) and two studies included both male- and female youth athletes (Emery and Meeuwisse, 2010; Achenbach et al., 2018). The proportion of research including female youth populations is encouraging, due to the previously mentioned higher injury risk in female populations (Consensus Statement, 2016; Montalvo et al., 2019; Sutton & Bullock, 2013). The age range from all studies was 11 – 19 years old. A bias exists towards football research with five out of nine studies examining only youth football athletes (Emery and Meeuwisse, 2010; Kiani et al., 2010; Waldén et al., 2012; Steffen et al., 2013; Owoeye et al., 2014). One program was implemented with female youth basketball- and football players (LaBella et al., 2012), one study included male and female youth handball players (Achenbach et al., 2018), and another female youth basketball-, football-, and volleyball players (Foss et al., 2018). Where specified, it could be identified that the programs were administered with lower- to upper-competitive performance levels, ranging from mostly regional- to national league club level (Emery and Meeuwisse, 2010; Kiani et al., 2010; Longo et al., 2012; Steffen et al., 2013). Only two out of the nine studies were conducted in school sport environments (Barber Foss et al., 2018; LaBella et al., 2012).

Six out of the nine studies utilized specific injury prevention programs, namely the football-specific ‘FIFA 11+’ in three studies (Longo et al., 2012; Steffen et al., 2013; Owoeye et al., 2014) and ‘HarmoKnee’ in one study (Kiani et al., 2010). The ‘KIPP’ (LaBella et al., 2012), and ‘Knäkontroll’ (Waldén et al., 2012) programs were used in one study respectively. The ‘FIFA 11+’ underwent the most rigorous process of program design and approval, as it was designed by the FIFA Medical Assessment Centre, in collaboration with Oslo Sports Trauma Research Centre and Santa Monica Orthopaedics and Sports Medicine Centre. It is the only program that was designed for- and officially endorsed by a major governing sport body (FIFA), which explains the larger research interest and the bias towards youth football in comparison to other team sports. The program components of the ‘FIFA 11+’ are strength, plyometrics, balance, speed, and agility exercises. The remaining three articles used programs that were adapted from previous studies and the experiences of the researchers (Emery and Meeuwisse, 2010; Achenbach et al., 2018; Foss et al., 2018). Comparisons between specific programs are challenging, as it was often not specified on which grounds certain exercises were included, therefore, leaving room for interpretation and discussion on their effectiveness over other exercises. Despite the mentioned limitations on the (missing) researcher’s rationale for the inclusion of specific exercises, all studies incorporated some exercise variations of strength, plyometrics and balance (or postural stability). This highlights the importance of a holistic approach to injury prevention programs that incorporate both exercises commonly associated with sport-specific conditioning (e.g., plyometrics) and exercises that are specifically targeted to the prevention of injuries (e.g., knee alignment during jump-landing tasks and balance). It is also important to mention that all studies but two (Emery and Meeuwisse, 2010; Barber Foss, 2018) needed no additional- or only readily available equipment (cones). Equipment-free programs are valuable considerations for resource-scarce environments to allow for their implementation regardless of available budget.

It is assumed that training sessions should last for at least 10-20 minutes, performed more than once per week for at least three months to elicit injury reducing benefits (Hübscher et al., 2010). These conditions have been satisfied in all presented studies. All studies were conducted across one season, ranging between four to nine months intervention duration. Each program followed a similar training frequency of two to three times per week and 15 – 25 min session duration, mostly administered as a warm-up program. Emery and Meeuwisse (2010) prescribed an additional 15 min home-based balance program using wobble boards.

Injury incidence was reported in all studies by means of tracking incidence per hour training/playing time across one competitive season (according to the described inclusion criteria). Most research focused on the reduction of knee injuries (seven out of nine studies), followed by the ankle and any lower-limb injuries. Walden et al. (2012) and Achenbach et al. (2018) differentiated between ACL and severe knee injuries in their studies. It is important to note that only Walden et al. (2012) and Achenbach et al. (2018, p. 2) specified their inclusion criteria for the “severe” injury category (≥ 4 weeks, and ≥ 28 days absence from practice, “intraarticular fracture, patella luxation, ACL or collateral rupture, meniscus tear, or cartilage injury”). However, Walden and colleagues (2012) listed ACL (significant decrease) separate from “severe” injuries (no significant decrease), which would be combined using Achenbach et al.’s (2018) classification. Clarifications which specific injuries constitute “lower limb”, “ankle” and “knee” injuries are also unclear and not elaborated upon in the presented literature. This highlights the need for standardization of injury classifications in future research to appropriately measure the effectiveness of INMT interventions, specifically on severe injuries that result in the longest absence from training and largest burden.

INMT interventions in youth sport showed overall positive effects on injury prevention. Three out of the nine studies reported significant decreases in all measured injuries in youth football and basketball players (Kiani et al., 2010; LaBella et al., 2012; Owoeye et al., 2014). A clear trend on severe injuries became apparent across the included studies. Severe non-contact (and ACL) knee injuries decreased significantly in all studies that assessed this injury classification (five out of nine) (Kiani et al., 2010; LaBella et al., 2012; Longo et al., 2012; Waldén et al., 2012; Achenbach et al., 2018). Waldén et al. (2012) found a statistically significant 64% reduction in ACL injuries in female adolescent football players, but no further effects for any other acute knee injury. This study had the largest sample size with 4564 football players and the researchers owed the non-statistically significant decrease in absolute rate difference of injuries to an overall small number of injury events. Mixed results are identified for (unspecified) knee-, ankle- and lower-limb injuries. The expression “protective effect” was used to describe non-significant decreases in certain injuries, which may have been a way for researchers to overstate results when no significant decreases were detected (Emery and Meeuwisse, 2010; Waldén et al., 2012). It is important to mention that all studies in Table 2.2 reported at least one or more significant decreases in specific injury incidence. The clear protective effect on ACL injuries adds to the general support of the implementation of INMT programs.

Interestingly, Longo et al. (2012) reported decreased training-, lower limb-, acute, and severe knee- and ankle- injuries in elite level male youth basketball players, using the ‘FIFA 11+’ program. This result is comparable to the ‘KIPP’ program, which decreased injury risk in both female youth football and basketball athletes (LaBella et al., 2012). As highlighted in the section above, the ‘FIFA 11+’ program was specifically designed for football, whereas the ‘KIPP’ program was designed for general youth team sports. The description ‘football-specific warm-up program’ for the ‘FIFA 11+’ might be overstated, as most exercises included in the program (strength, plyometrics, balance, speed, and agility) are general strength and conditioning exercises that are applicable to the physical development in a variety of sports, and may, hence, be appropriate to recommend to other team sports. Longo et al.'s (2012) findings incentivise further research to be conducted with the 'FIFA 11+' program in sports other than football to assess possible transferability effects and general applicability in various youth team sport environments.

Adherence has been described as a major confounding factor in the effectiveness of INMT interventions to prevent injuries (Steffen et al., 2013). Steffen et al.'s (2013) study showed that a high adherence group (≥ 80% of sessions) reduced overall injury risk by 72% (and 68% decrease in lower-limb injury risk) compared to low adherence. On the other hand, Owoeye et al. (2014) reported a decrease in injury rate by 41% and lower limb injury by 48% despite 74% of the football players only completing 60% (1.6 times per week) of all sessions. This could support the overall effectiveness of the 'FIFA 11+' even with considerably lower attendance compared to Steffen et al. (2013). Steffen et al. (2013) was the only study that assessed injury incidence as well as several physical performance tests. The two balance assessments (SEBT and single-leg eyes-closed balance) both showed significant improvements after the intervention. This provides support to the notion that improved balance and postural stability may be important factors to reduce lower-limb injuries in youth team sport athletes and should be part of any injury prevention program (Collings et al., 2021).

The presented results in Table 2.2 provide support for the implementation of INMT to decrease lower-limb injury incidence in youth team sport in both male and female participants across various performance levels. Gaps exist to explore the effect on team sports other than football and in school setting. Further, there is a need for standardization of specific injury classifications to clarify findings. Despite conflicting evidence on general knee- and ankle injuries, there is consensus that severe injuries, such as ACL injuries, can be decreased in youth team athletes using INMT.

Beneficial intervention programs to reduce injury incidence in youth sports include strength, plyometrics, balance and dynamic stability, and sport-specific agility, during pre-season and in-season (as part of the warm-up), for at least 15 to 20min twice a week. This is in line with Fort-Vanmeerhhaeghe et al.'s (2016b) INMT two-block classification of fundamental movement skills and sport-specific skills. Notably, most interventions did not require any additional equipment, which makes the implementation in various socio-economic backgrounds feasible and of particular interest for countries like South Africa.

As previously stated, addressing high rates of sport injuries in youth sport is of vast interest, as they have, apart from hampered performance and teams' success, large individual- and societal costs. Understanding that INMT programs have shown to decrease lower-limb injury rates is an important step to incentivise coaches and trainers to implement such programs as regular part of their training. Further, determining which INMT programs and their specific components, such as balance, plyometrics and agility, result in superior injury risk reduction can inform subsequent studies, such as this current study, of appropriate program and exercise selection. Reducing injuries may not be sufficient to encourage coaches to implement INMT programs. Coaches generally have short contact time with (youth) athletes and may be hesitant to sacrifice valuable time for additional training modalities that are not directly related to skill training and enhanced performance. Hence, support for physical performance enhancement alongside injury reduction following INMT may persuade coaches to implement such programs. Due to the physical and sport-specific characteristics that are targeted in INMT, such as plyometrics and agility, potential performance enhancing benefits of INMT programs will be discussed in the following section.

Enhancing Physical Performance

As previously explained, an integrative multimodal approach to sport conditioning (i.e., INMT), is aimed at enhancing physical fitness, improve motor competencies and reduce neuromuscular deficits, such as faulty movement patterns, that may predispose athletes to injury (Hübscher et al., 2010; Myer et al., 2011). INMT has been shown to elicit greater performance enhancement (and injury prevention outcomes), compared to isolated resistance training strategies that are aimed at enhancing strength alone (DiStefano et al., 2013; Sañudo et al., 2019). INMT interventions are applied across many age groups, from early adolescent- to trained athlete populations, and in different contexts (e.g., as part of regular training or in addition to regular training) to improve sport-specific performance outcomes, such as strength, balance, lower-limb power, speed, agility, and general movement competency (Asadi et al., 2015; Hopper et al., 2017; Mendiguchia et al., 2015; Panagoulis et al., 2020; Trajković & Bogataj, 2020).

Table 2.3 provides a summary of studies of the effect of INMT to enhance physical performance parameters in youth team athletes. The same exercise category classifications from Table 2.2 were applied to describe the components of the included studies. For the context of the current study, articles were included that satisfied the following inclusion criteria:

- Male and female youth participants in the age range of 12 – 18 years, as per the previously discussed definition by Lloyd et al. (2015)
- The athletes participated in team-sports
- The utilized programs were based on multimodal training approaches
- Neuromuscular performance tests were the measured outcomes (e.g., sprints, balance tests such as the SEBT, etc.)
- Articles were published between 2010 - 2021

Table 2.3. Summary of studies of Integrative Neuromuscular Training Interventions to improve physical performance in youth team athletes since 2010.

Reference	Title	Study Design	Population & context	Components of program	Program design	Physical performance tests	Results on physical performance tests
Filipa et al. (2010)	"Neuromuscular Training Improves Performance on the Star Excursion Balance Test in Young Female Athletes"	RCT N = 20 F	14 – 17 years **Football** players from two club teams	Strength (lower limb, core) Plyometrics Dynamic stability Equipment: BOSU ball, Swiss ball, foam pad	Duration: eight weeks Frequency: two times / week, 50min per session	Balance (SEBT, modified Y)	↑ SEBT (modified Y)
Vescovi & VanHeest (2010)	"Effects of an anterior cruciate ligament injury prevention program on performance in adolescent female soccer players"	RCT N = 31 F	13 to 18 years Experienced American **football** players from four community club teams	***PEP*** *(Prevent Injury Enhance Performance) program* Strength (lower limb) Plyometrics Agility Stretching	Duration: 12 weeks Frequency: three times / week, 15 - 20min warm-up	Sprint (9.1m, 18.2m, 27.3m, 36.6m) Agility (Illinois, pro-agility) Vertical Jump (CMJ)	→ 9.1m & 18.2m sprint small ↑ 27.3m & 36.6m sprint after 6 weeks, reverted after 12 weeks Small ↓ in Illinois & pro-agility tests → CMJ
Barendrecht et al. (2011)	"Neuromuscular Training Improves Knee Kinematics, in Particular Valgus Aligned Adolescent Team Handball Players in Both Sexes	RCT N = 80 M + F	14 – 17 years Under-19 and under-16 Dutch **handball** players	Strength (lower limb) Plyometrics Dynamic stability Balance Coordination Agility Equipment: wobble board/mat	Duration: 10 weeks Frequency: two times / week, 20min added to regular training	Knee kinematics (DJ) Single-leg Hop	↑ knee kinematics in M & F (knee valgus angle, contact time, knee flexion angle) ↑ single-leg hop distance in M & F

Klugman et al. (2011)	"Does an In-Season Only Neuromuscular Training Protocol Reduce Deficits Quantified by the Tuck Jump Assessment?"	RCT N = 49 F	13 – 15 years American high school and junior varsity **football** players	Strength (lower limb) Plyometrics Dynamic stability	Duration: five weeks Frequency: /	Tuck Jump Assessment	→ tuck jump assessment
Lindblom et al. (2012)	"No effect on performance tests from a neuromuscular warm-up programme in youth female football"	C-RCT N = 41 F	12 – 16 years Swedish **football** players from four club teams	***Knäkontroll** program* Plyometrics Core stability Dynamic stability Balance	Duration: 11 weeks Frequency: two times / week, 15min warm-up	Balance (SEBT, modified Y) Vertical jump (CMJ) Triple-Hop Agility (modified Illinois) Sprint (10m, 20m)	→ all tests small ↑ SEBT & Illinois Agility after between-group comparisons
Reis et al. (2013)	"Performance Enhancement Effects of Federation Internationale de Football Association's "The 11+" Injury Prevention Training Program in Youth Futsal Players"	RCT N = 36 M	16 – 18 years Portuguese **futsal** players	***FIFA 11+** program* Strength (lower limb, core) Plyometrics Balance Speed Agility	Duration: 12 weeks Frequency: two times / week, 20min warm-up	Isokinetic strength ratios (quadriceps & hamstrings) Vertical jump (SJ, CMJ) Sprint (5m, 30m) Agility T Skill ability (slalom-dribbling) Balance (single-leg flamingo balance	↑ strength (functional H:Q ratio) ↑ sprint (5m, 30m) ↑ agility ↑ slalom ↑ SJ & CMJ ↑ balance
Steffen et al. (2013)	"High adherence to a neuromuscular injury prevention program (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players"	C-RCT N = 148 F	13 – 18 years Upper competitive under-16 and under-18 Canadian **football** players	***FIFA 11+** program* Strength (lower limb, core) Plyometrics Balance Speed Agility	Duration: one season (18 weeks) Frequency: two to three times / week, 20min warm-up	**Injury incidence** Balance (SEBT, single-leg eyes-closed) Triple hop Jumping-over-a-bar	↓ **injury incidence** ↑ SEBT (5/6 direction) ↑ single-leg eyes-closed balance in supervised group → triple hop → jumping-over-a-bar

Zech et al. (2014)	“Time course and dimensions of postural control changes following neuromuscular training in youth field hockey athletes”	RCT N = 30 M	12 – 17 years Upper competitive German regional **field hockey** players from three club teams	Strength (lower limb, core) Plyometrics Balance Running Agility	Duration: 10 weeks Frequency: two times / week, 20min warm-up	Balance & Dynamic Stability: SEBT (modified Y) BESS TTS Single-leg stance (COP sway)	↑ BESS → SEBT (modified Y) → TTS → COP sway
Heleno et al. (2016)	“Five-week sensory motor training program improves functional performance and postural control in young male soccer players”	RCT N = 22 M	14 – 16 years Elite Brazilian **football** players	Plyometrics Dynamic stability Balance Equipment: Foam pad	Duration: five weeks Frequency: three times / week, 50min per session	Balance & Dynamic Stability: SEBT (modified Y) Figure-of-Eight (F8) Single-leg stance (COP sway) Side hop	↑ SEBT (modified Y) ↑ F8 ↑ side hop ↓ COP sway
Ayala et al. (2017)	“Training effects of the FIFA 11+ and HarmoKnee on several neuromuscular parameters of physical performance measures”	RCT N = 41 M	16 – 17 years Upper competitive Spanish amateur **football** players from two club teams	***FIFA 11+*** *program & **HarmoKnee** program* Strength (lower limb, core) Plyometrics Balance Speed Agility	Duration: four weeks Frequency: three times / week, 20 – 25min warm-up	ROM (hip, knee, and ankle joints) Balance (SEBT, modified Y) Single-leg Hop limb symmetry (single- & triple hop) Sprint (10m, 20m) Vertical Jump (DJ) Agility (Illinois)	*FIFA 11+:* ↑ SEBT (modified Y) ↑ single-leg hop limb symmetry ↑ Sprint ↑ DJ → ROM → Agility (Illinois) *HarmoKnee:* ↑ Sprint ↑ DJ → all other parameters
Ondra et al. (2017)	“Effect of in-season neuromuscular and proprioceptive training on postural stability in male youth basketball players”	RCT N = 21 M	16 – 18 years Elite Czech **basketball** players from one club	Strength (lower- & upper limb, core) Dynamic stability Plyometrics Balance Equipment: BOSU ball, Swiss ball, balance mat, kettlebell	Duration: one season (20 weeks in-season) Frequency: three times / week, 20min before or during practice	Balance (single-leg stance, COP sway)	↓ COP sway

Zarei et al. (2018)	"Long-term effects of the 11+ warm-up injury prevention programme on physical performance in adolescent male football players"	C-RCT N = 82 M	14 – 16 years Upper competitive Iranian **football** players from	***FIFA 11+*** *program* Strength (lower limb, core) Plyometrics Balance Speed Agility	Duration: one season (30 weeks) Frequency: two times / week, 20min warm-up	Agility (Illinois) Dribble skill Sprint (9.1m, 36.6m) Aerobic (Yo-Yo IRT1) Bosco CMJ 15s Vertical Jump (Sargent Jump) Flexibility (sit-and-reach)	↑ vertical jump ↑ Bosco CMJ 15s ↑ Illinois agility Possible ↑ in 9.1m sprint, but not 36.6m → aerobic capacity (Yo-Yo IRT1) → flexibility (sit-and-reach) Possible ↓ dribble skill
Lindblom et al. (2020)	"Performance Effects with Injury Prevention Exercise Programmes in Male Youth Football Players: A Randomised Trial Comparing Two Interventions"	RT N = 47 M	13 – 15 years Swedish **football** players from four club teams	***Knee Control*** *program & **Knee Control+** program* Strength (lower limb, core) Plyometrics Dynamic stability	Duration: eight weeks Frequency: two times / week, 20min warm-up	Vertical jump (DJ, CMJ) Agility (Agility T & 505) Single-leg hop Side hop Sprint (10m, 20m)	→ all parameters in both interventions → effects between interventions ↓ 505 agility in *Knee Control+* group & ↑ in *Knee Control* group
Isla et al. (2021)	"Effects of Neuromuscular Warm-Up Program in Youth Female Soccer Players"	RCT N = 38 F	13 – 14 years Upper competitive Spanish **football** players from one club academy	Strength (lower limb) Plyometrics Agility Equipment: agility ladders, 5kg disc	Duration: 12 weeks Frequency: two to three times / week, 15min warm-up	Balance (SEBT, modified Y) Strength (back squat & hip thrust velocity) Vertical jump (CMJ: unilateral & bilateral, loaded & unloaded)	↑ back squat velocity, → hip thrust velocity ↑ unloaded unilateral & bilateral CMJ, → loaded CMJ ↑ SEBT anterior direction, → posterolateral- and posteromedial directions

RCT = randomized controlled trial; RT = randomized trial; N = population; M = male; F = female; M + F = male and female; ↑ = statistically significant increase in; ↓ = statistically significant decrease in; → = no statistically significant increase/decrease in; COD = change of direction; CMJ = counter-movement jump; SJ = squat jump; DJ = drop jump; SEBT = star excursion balance test; BESS = balance error scoring system; TTS = time to stabilization; COP = centre of pressure; H:Q ratio = hamstring to quadriceps ratio

In summary, all 14 included studies in Table 2.3 were randomized controlled trials of between 20 to 148 participants (mean = 49). Seven studies assessed male adolescents, six assessed female adolescents, and one study assessed both male and female adolescents, with an age range of 12 – 18 years. Similar to the studies presented in Table 2.2, a large bias exists towards youth football research, with 11 out of 14 studies assessing solely football players. The remaining three studies assessed youth handball (Barendrecht et al., 2011), field hockey (Zech et al., 2014), and basketball (Ondra et al., 2017). Where specified, interventions were administered with lower- to upper-competitive and elite-level club sport athletes. Only one out of the 14 studies was conducted in a high school environment (Klugman et al., 2011).

Seven studies utilized specific neuromuscular (injury prevention) programs, namely the 'FIFA 11+' in four studies (Reis et al., 2013; Steffen et al., 2013; Ayala et al., 2017; Zarei et al., 2018), the 'PEP – Prevent Injury Enhance Performance' in one study (Vescovi & VanHeest, 2010), the 'Knäkontroll' in one study (Lindblom et al., 2012), the 'HarmoKnee' in one study (Ayala et al., 2017). The program components of these specific programs have been discussed in Table 2.2. The other seven studies adapted their programs from previous literature or the researchers' experience. Similar to Table 2.2, this makes comparisons to specific programs somewhat difficult, as it was often not specified on which grounds certain exercises were included.

The intervention duration varied between four to twelve weeks, with three studies (Steffen et al., 2013; Ondra et al., 2017; Zarei et al., 2018) lasting one season (18 – 30 weeks). Program duration was between 15 – 25 min with two studies (Filipa et al., 2010; Heleno et al., 2016) lasting 50 min per session. Training frequency ranged from two to three times per week, and the implementation was mostly applied as a replacement for the teams' regular warm-up.

The most commonly measured neuromuscular performance parameters where, firstly, variations of a vertical jump (drop jump, counter-movement jump, squat jump) to assess lower limb power with positive adaptations in five out of eight studies (Vescovi and VanHeest, 2010; Barendrecht et al., 2011; Lindblom, Waldén and Hägglund, 2012, 2020; Reis et al., 2013; Ayala et al., 2017; Zarei et al., 2018; Isla et al., 2021), and secondly, the SEBT (Star Excursion Balance Test) to assess balance and dynamic postural stability with positive adaptations in five out of seven studies (Filipa et al., 2010; Lindblom, Waldén and Hägglund, 2012; Steffen et al., 2013; Zech et al., 2014; Heleno et al., 2016; Ayala et al., 2017; Isla et al., 2021). Variations of agility (COD) tests (Illinois, Agility T, pro agility, 505 agility) to assess agility were measured with positive adaptation in two out of six studies (Vescovi and VanHeest, 2010; Lindblom, Waldén and Hägglund, 2012, 2020; Reis et al., 2013; Ayala et al., 2017; Zarei et al., 2018). Variations of sprint protocols (5 m to 36.6 m) were used to assess speed with positive adaptations in three out of five studies (Vescovi and VanHeest, 2010; Lindblom, Waldén and Hägglund, 2012; Reis et al., 2013; Ayala et al., 2017; Zarei et al., 2018). Balance and dynamic postural stability were sole measurements in four studies (Filipa et al., 2010; Heleno et al., 2016; Ondra et al., 2017; Zech et al., 2014) with test variations of the SEBT, BESS, TTS, and COP sway. The SEBT was modified to the Y-Test (anterior-, posterolateral-, and posteromedial directions) in all but one study (Steffen et al., 2013). It has been previously established, that an individual's reach distance in any direction is highly correlated with the reaching distance in any of the other seven directions in the original eight-direction SEBT (Gribble et al., 2012; Hertel et al., 2006). Therefore, the simplified Y-Test presents a reliable, timesaving and more practical alternative to assess dynamic postural stability in a testing battery to measure performance adaptations.

The majority of studies (10 from 14) showed significant improvements in some or all of the performance tests, indicating strong support for performance enhancement following INMT programs in youth team athletes. Reis and colleagues (2013) implemented a 12-week study with youth futsal players, utilizing the 'FIFA 11+' program. The researchers had the most comprehensive testing battery compared to the other studies and showed improvements in all eight tests (strength, sprint, agility, slalom-dribbling, vertical jump, and balance). Zarei et al. (2018) reported improvements in vertical jump and repeated jump ability (Bosco CMJ 15s), agility (Illinois), with no improvements in aerobic capacity and flexibility. These results are to be expected as the 'FIFA 11+' does not include specific exercises for the improvement of aerobic capacity and flexibility. Zarei et al. (2018) reported a decrease in dribble skill after the interventions. The researchers advised to combine the program with additional football-specific dribble skills to counteract the potential decline in skill performance. As previously mentioned, it is important to mention, that the 'FIFA 11+' program, as well as most other programs in Table 2.3, are designed as warm-up interventions. Hence, their aim is not to primarily improve sport-specific skills, such as dribbling. It is important to keep the aim of the intervention in mind when designing programs and choosing tests to measure their effectiveness. As mentioned in Table 2.2, Steffen et al. (2013) was the only study that assessed both injury incidence and performance adaptations (balance and repeated jump ability) in youth team athletes, utilizing the 'FIFA 11+', with superior adaptations in their high adherence group. Alongside a decreased injury risk, balance measurements improved (SEBT, single-leg eyes-closed balance), with no effect on repeated jump ability (triple hop and jumping-over-a-bar). The balance improvements are congruent with Reis et al. (2013), whilst results on repeated jump ability differed, which may be attributed to the difference in the chosen tests (15s continuous jumping vs. triple hop). Ayala et al. (2017) compared the effects of the 'FIFA 11+' and 'HarmoKnee' on ROM, balance, single-leg symmetry, sprint, vertical jump, and agility. The results showed superior adaptations for the 'FIFA 11+' with significant improvements in the SEBT, single-leg symmetry, sprint (10, 20m), and drop jump, and no effects on ROM and agility (Illinois). The 'HarmoKnee' intervention group only improved in sprint and drop jump measures (Ayala et al., 2017). These results provide support for the (superior) effectiveness of the 'FIFA 11+' program on selected performance factors and is congruent with the equally superior effectiveness to decrease injury risk, as discussed in Table 2.2.

As highlighted, balance and dynamic stability (postural control) improvements have been reported in three 'FIFA 11+' studies (Reis et al., 2013; Steffen et al., 2013; Ayala et al., 2017) and supported by other studies that assessed solely balance and dynamic stability (Filipa et al., 2010; Heleno et al., 2016; Ondra et al., 2017). Particularly Heleno et al. (2016) developed a highly specific sensory-motor training program that specifically targeted balance, dynamic stability, and single-leg jump-landing tasks (postural control) that are found in football (cutting, COD). The tests (SEBT, figure-of-eight, side hop, COP postural sway) had greater similarity to the chosen exercises and resulted in significant improvements after five weeks (Heleno et al., 2016). This program was 50 min in duration, compared to the average duration of 20 min per session in the other programs, which may explain the positive adaptations after a comparably short intervention duration. Nevertheless, this research provides valuable results for program design when the desired outcomes are specific performance parameters (e.g., balance, dynamic stability in athletes with identified deficits) and time is available for longer-duration strength and conditioning training sessions. Apart from performance, results from the mentioned study by Heleno *et al*. (2016) contribute to the notion that specific factors such as balance and dynamic stability are important contributors for the effectiveness of the ‘FIFA 11+’ and other INMT program to decrease injury risk. This is informed by research that showed that poor balance and postural control is significantly correlated with increased risk of injury in numerous sports and can be augmented by (multifaceted) training (Aarts, 2021; Hrysomallis, 2007). Zech et al. (2014) assessed balance and postural control in four separate balance tests in 12- to 17-year-old field hockey players. Interestingly, they only found balance improvements in the highly sensitive BESS test, which is completed on an unstable surface foam pad and eyes closed, and no improvements in the SEBT, time-to-stability (TTS) and COP sway. The researchers argued that balance tests are interrelated but may not assess equal components of postural stability (Zech et al., 2014). The exercise list is unfortunately not provided which does not allow for comparison to the other five studies who included the SEBT and showed positive adaptations (Filipa et al., 2010; Steffen et al., 2013; Heleno et al., 2016; Ayala et al., 2017; Isla et al., 2021).

Single-leg hop distance was used to determine symmetry in three intervention studies with positive adaptations in two (Ayala et al., 2011; Lindblom et al., 2020). Tests to determine lower limb asymmetry may be important to consider in future research, as an asymmetry of >10 cm resulted in a greater risk of lower limb (ankle-) injuries in female field- and court-sports (Collings et al., 2021). Single-leg hop distance improvements were accompanied by improved knee kinematics (knee valgus angle, contact time, knee flexion angle) in both male and female adolescent handball players, which may further decrease the risk of landing-related knee injuries (Barendrecht et al., 2011). Further, the single-leg hop test assesses developments of single-leg power, which is important for any sport that requires explosive intermittent sprinting and cutting actions, such as football, basketball, or field hockey.

The two studies utilizing the ‘PEP’ and ‘Knäkontroll’ program showed no improvements on their respective performance tests (balance, sprint, agility, vertical jump, triple hop, and agility) (Lindblom et al., 2012; Vescovi & VanHeest, 2010). The researchers attributed these results to the lack of intensity in the included exercises (Vescovi & VanHeest, 2010), a lack of player attendance (59.6 +- 14.3%) and low exercise specificity compared to the performance tests that were used (Lindblom et al., 2012).

The program only comprises of core stability, dynamic stability, and balance exercises, and some low-level plyometric exercises, thus limiting the potential performance enhancing benefits, as no additional agility or sprint exercises were included. These are common components of most other discussed programs. As previously discussed, the 'Knäkontroll' program only decreased ACL injuries with no significant effects on other severe knee- or any acute knee injuries (Waldén et al., 2012). Other knee injury prevention programs, such as the, 'FIFA 11+', 'HarmoKnee', or 'KIPP' may be a preferable choice, as they have shown to decrease various lower limb injury risks alongside severe (ACL) injuries (Table 2.2). Both the 'Knee Control' and 'Knee Control+' programs have also failed to report improvements in vertical jump, agility, single-leg hop and sprint performance tests (Lindblom et al., 2020). These programs are available via mobile app and only consist of six standard exercises (one-legged squats, hamstring strengthening, two-legged knee squats, core strength, lunges, and jump/landing) with 30 more progressions and plyometric alternatives in the 'Knee Control+' version. Like the 'PEP' and 'Knäkontroll' programs, the researchers attributed the discrepancy between the program's exercises (controlled strengthening exercises) and performance tests (agility, hopping, sprinting, jump/landing), as well as fatigue towards the end of the season to the non-significant results (Lindblom et al., 2020). It is argued that the programs may be beneficial if injury prevention and not performance enhancement is the goal (Lindblom et al., 2020). However, as demonstrated with programs such as the 'FIFA 11+', INMT programs can achieve both injury prevention and performance enhancement goals and may be considered more appropriate for coaches to implement.

Table 2.3 supports the overall effectiveness of INMT programs on performance enhancement in male and female youth team sport athletes across various competitive performance levels. Mixed results for certain performance factors exist and have been presented in the paragraphs above. Possible reasons are differences in program components design (especially those who have been adapted from previous studies), low compliance, and inappropriate test selection. Studies that reported no improvements in some or all performance tests generally showed discrepancies between the exercise components of the program and the selection of the tests. Testing should reflect the exercise components of the program and the intention of those exercises. If greater emphasis is placed on injury prevention with exercises that predominantly target knee alignment, balance, and dynamic stability, then tests should be chosen that are associated with injury risk factors (such as the SEBT or single-leg hop) over performance tests (such as sprints, agility, and vertical jump) and vice versa (Collings et al., 2021; Filipa et al., 2010; Vescovi & VanHeest, 2010). This may prevent inferring supposed ineffectiveness of programs when tests and program components may not align. All in all, there is, as discussed, compelling evidence that established INMT programs, particularly the 'FIFA 11+', are both effective in preventing injury incidence, decreasing specific injury risk factors (e.g., impaired balance, SEBT) as well as improving performance measurements in youth team athletes.

The literature presented should be interpreted with caution. Sport selection bias is evident, as an overwhelming 11 out of 14 studies assessed adolescent football players. Therefore, generalisability to other team sports may be limited, despite the intermittent high-intensity nature and comparable physiological requirements of sports such as field hockey and basketball. All but one study were conducted in club-sport settings, leaving room for assessment in school sport environments.

Overall, in combination with the previously outlined injury risk reduction benefits in Table 2.2, there seems to be strong evidence for the implementation of INMT programs to enhance performance and should be encouraged for (youth) athletes. It is important to determine the most appropriate context in which INMT interventions should be implemented to achieve maximum benefits, as the best program is only such that can be adhered to.

Summary

In summary, it is evident from the outlined literature that INMT interventions reduce injury incidence, reduce injury risk factors, and enhance specific physical performance parameters. INMT programs should include, strength, plyometrics, agility, and dynamic balance, for at least 15 - 20 minutes. Interestingly, Rahlf et al. (2020) proposed preliminary evidence that an adapted 10 min version of the 'FIFA 11+' may be just as effective to prevent injury, compared the full 20 min version. Further assessments are required to support this notion and determine whether performance enhancement can also be achieved with a decreased program duration. Proposed mechanisms for the outlined improvements include improved proprioception, leading to enhanced dynamic postural stability, as well as performance measures such as improved CMJ, vertical jump, and shorter agility test times, suggesting a superior utilization of the SSC to produce lower-limb power. Most of these adaptations have been attributed to the inclusion of repeated jump exercises. This is in line with findings that INMT that includes plyometric exercises, is more effective to enhance performance than isolated strength training alone (DiStefano et al., 2013; Sañudo et al., 2019). This knowledge is of benefit to coaches and trainers to utilize the limited contact time with youth athletes in the most effective manner for optimal injury prevention and performance outcomes. These findings also inform of the design and allow appropriate exercise selection for this study in female adolescent field hockey players. The current study, however, will assess performance measurements that are closer related to the components of the program, compared to some of the presented studies in Table 2.3. These measurement outcomes will be discussed separately. Further, this study will incorporate the novelty of a second intervention group performing the same INMT program barefoot. The rationale for the inclusion of a barefoot group is explained in section G. 'Barefoot Training'.

E. INMT AS A WARM-UP

A warm-up is commonly defined as a phase of bodily preparation prior to exercise or competition to attain optimal performance by evoking changes to body temperature and metabolic, neural, and psychological processes (McGowan et al., 2015). This definition, however, merely addresses short-term bodily changes in relation to upcoming exercise and not whether structured warm-ups with specific neuromuscular components may elicit performance enhancing or injury reducing effects. Table 2.2 and Table 2.3 presented the several injury prevention and physical performance benefits of targeted INMT warm-up programs.

A majority of the described INMT interventions in youth team sport were commonly applied at the beginning of regular sport practice as a warm-up. Only five out of 14 interventions described in Table 2.3 required additional equipment, mainly for balance and proprioception exercises, such as wobble boards and foam pads (Filipa et al., 2010; Barendrecht et al., 2011; Heleno et al., 2016; Ondra et al., 2017; Isla et al., 2021). Despite the positive performance enhancing and injury reducing benefits, this may pose a practical challenge for coaches and strength and conditioning practitioners. Notably, the commonly studied ‘FIFA 11+’ program, as well as the ‘HarmoKnee’ and ‘KIPP’ intervention, which all resulted in the highest reported injury prevention benefits (Table 2.2), did not require additional equipment. This indicates that additional equipment may not be required for the effective implementation of INMT programs to prevent injury and enhance performance. Since coaches may not want to sacrifice field and court training contact times with their athletes, it appears useful to incorporate INMT interventions into a team’s warm-up protocol (Herman et al., 2012). Furthermore, economic resources may be limited in many impoverished schools with lack of infrastructure and sport equipment in general, which is of special concern in countries such as South Africa with its large socio-economic divide (Burnett, 2020). Therefore, a chosen program should reflect an environment’s ecological validity to account for real-life challenges and limitations. These factors encourage the implementation of warm-up programs with comprehensive and available educational material and no additional costs, such as the ‘FIFA 11+’, to ensure large-scale- and grassroot availability and application.

The following section provides a detailed analysis of the ‘FIFA 11+’, ‘KIPP’, and ‘HarmoKnee’ programs in the context of the youth team sport.

Existing warm-up interventions without additional equipment

1. ‘FIFA 11+’ program

Soligard and colleagues’ (2009) study with the ‘FIFA 11+’ intervention resulted in similar injury prevention effects, by significantly decreasing risk of lower-limb injuries overall, overuse injuries, and severe injuries in 1892 (1055 intervention and 837 control) 13-17-year-old Norwegian female football players. These findings are supported by Longo et al. (2012), Steffen et al. (2013) and Owoeye et al. (2014) (Table 2.2). An adapted ‘FIFA 11+ Kids’ program also showed small improvements in motor performance in 7 – 12-year-old football players (Rössler et al., 2016), adding to the effectiveness of the program in pre-adolescent age groups. Soligard et al. (2009) provide a thorough description of all exercises and elements of the ‘FIFA 11+’ program, namely strength, plyometrics, balance, speed, and change of direction, which can be viewed in **Appendix 1**. The 'FIFA 11+' intervention coaches and team captains received training and informational material, including DVDs, books, and cards with all exercises prior to implementation of the program. Compliance was also reported as 'good' with 52 out of 60 intervention clubs completing 44 injury prevention sessions (77%) throughout the season, despite no follow-up visits. Expectedly, injury incidence incrementally decreased with increased compliance. The researchers highlighted that the implementation of such injury prevention programs at community level should be possible, given that educational material is made available to the teams, coaches, players, and parents, to ensure compliance and correct exercise execution (Soligard et al., 2009). Compliance appears to be a major confounding factor in the effectiveness of injury prevention programs and needs to be prioritized when conducting future research. Utilizing the same 'FIFA 11+' program, Steffen and colleagues (2008) attributed a lack of difference in overall observed injury rate between the intervention and control group to low compliance and indicated that only 14 out of 58 intervention teams completed at least 20 injury prevention sessions across an eight-month football season period. Further, a prospective cluster randomized control trial in competitive male collegiate football players (675 intervention-, 850 control group) who utilized the 'FIFA 11+' showed a 77% reduction in ACL injury incidence over the course of one season (Silvers-Granelli et al., 2017). Recent systematic reviews and meta-analysis on further studies with the 'FIFA 11+' program in various age groups, males and females, and performance levels, concluded that the warm-up may decrease lower limb injuries by 29% to 39% and adds support to its effectiveness (Al Attar & Alshehri, 2019; Barengo et al., 2014; Sadigursky et al., 2017; Thorborg et al., 2017).

2. 'HarmoKnee' program

The second football-specific INMT program 'HarmoKnee', was associated with a 77% (90% non-contact) decrease in knee injury incidence rate amongst 1506 female football players, aged 13 to 19 years (Kiani et al., 2010). The warm-up components included strength, plyometrics, balance, core stability, and muscle activation and can be viewed in **Appendix 2**. Kiani and colleagues (2010) suggested that the multifaceted aspects may lead to performance-enhancing benefits alongside injury protection. To date, no further "HarmoKnee" studies exist that assess specific injury risk factors and only one study examined specific performance factors and found improvements in sprint and vertical jump in upper competitive female youth football players (Ayala, et al., 2017).

The ‘FIFA 11+’ and ‘HarmoKnee’ programs have received broader scholarly attention to examine their effectiveness on specific measurement outcomes, alongside the studies in youth athletes presented in Table 2.2 and Table 2.3. Research showed that both programs positively affect proprioception, dynamic and static balance, concentric hamstring strength, and isometric quadriceps strength, following an eight-week intervention in under-21 professional male football players (Daneshjoo et al., 2012a; Daneshjoo, Mokhtar, Rahnama, & Yusof, 2013b; Daneshjoo, Rahnama, et al., 2013). Further, the ‘FIFA 11+’, but not the ‘HarmoKnee’ intervention, showed significant improvements for jump height, agility, conventional strength ratio (hamstring to quadriceps strength) and anthropometric measures (body mass index and waist to hip ratio) (Daneshjoo et al., 2012b; Daneshjoo, Mokhtar, Rahnama, & Yusof, 2013a; Daneshjoo, Mokhtar, Rahnama, Tourouni, et al., 2013). It is important to mention, that all these studies have been conducted by the same Iranian research group with the same research participants (n=36), consisting of only under-21 male professional football players. Akbari and colleagues (2018) found that vertical jump height improved following eight weeks of the ‘FIFA 11+’ warm-up in 24 under-19 elite male football players. Notably, the improvements could not be retained after one-month follow up testing, which highlights the importance of sustained implementation of the program to maintain possible performance enhancing benefits (Akbari et al., 2018). This study is, however, also limited to only Iranian male youth football players. Nevertheless, the research does add further support for the possible injury-preventing- and performance-enhancing mechanisms of the two (primarily the ‘FIFA 11+’) football-specific warm-up programs.

3. ‘KIPP’ program

The content of the ‘KIPP’ program is not as readily available as the ‘FIFA 11+’ or ‘HarmoKnee’. Upon contacting the ‘KIPP’ program creators at the Ann & Robert H. Lurie Children’s Hospital in Chicago, USA, the researcher received a detailed transcript of the list of exercises, descriptions, and warm-up components, including strength, plyometrics, balance and agility. The script and researcher’s exercise protocol of the ‘KIPP’ program are attached in **Appendix 3.1 and 3.2**. The ‘KIPP’ intervention was conducted with 1492 female football- and basketball athletes, from predominantly low-income urban public high schools in Chicago, USA (LaBella et al., 2012). Like the ‘FIFA 11+’, the intervention coaches attended a training session with the principal researcher and head athletic trainer, and received DVDs with narrative videos on exercise technique, cards with correct exercise order and printed educational material. The coaches’ self-reported program compliance across the eight-month intervention period was ‘good’ at 80%. LaBella and colleagues (2012) found that gradual-onset injuries were reduced by 65%, acute non-contact injuries by 56%, and acute non-contact ankle sprains by 66%, compared with control athletes. The protective effects of the ‘KIPP’ warm-up may have, in fact, been underestimated, as most intervention coaches did not use all prescribed exercises from the protocol (LaBella et al., 2012). A cost-effectiveness analysis highlighted that the costs to train 16 coaches ($1280, or ~R17.500) are significantly less compared to the estimated surgical treatment of one ACL reconstruction ($17.000-$25.000, or ~R232.000 – R340.000) (LaBella et al., 2012). The low-income population who participated in this study, combined with the effectiveness of the program and low educational costs for coaches, underlines the importance and practicality to consider and encourage interventions that do not require additional equipment to ensure large-scale accessibility.

Within the context of the present study, Table 2.4 provides a comparison of the main components and study outcomes of the ‘FIFA 11+’, ‘HarmoKnee’, and ‘KIPP’ programs in youth team sport athletes.

Table 2.4 Comparison of the 'FIFA 11+', 'HarmoKnee' and 'KIPP' programs implemented to prevent injury and improve neuromuscular performance in youth team athletes since 2010.

Program	**Context**	**Content**	**Duration**	**Outcomes**
FIFA 11+	Football-specific neuromuscular warm-up program to prevent lower-limb injuries, designed by FIFA Medical Assessment Centre, in collaboration with Oslo Sports Trauma Research Centre and Santa Monica Orthopaedics and Sports Medicine Centre	Strength (lower limb & core) Plyometrics Balance Speed COD Equipment: none	20min	↓ all-, training-, lower limb-, acute-, severe knee- & ankle injuries in elite adolescent male *basketball* players (Longo et al., 2012) ↓ injury incidence, ↑ dynamic postural stability and balance in upper competitive female adolescent *football* players (Steffen et al, 2013) ↑ lower-limb strength, sprint (5m, 30m), agility, skill ability, leg power (vertical jump), and balance in male adolescent *futsal* players (Reis et al., 2013) ↓ any- and lower limb injury rate in male adolescent *football* players (Owoeye et al., 2014) ↑ dynamic postural stability, single-leg hop limb symmetry, sprint and leg power (vertical jump) in upper competitive female adolescent *football* players (Ayala et al., 2017) ↑ leg power (vertical jump), anaerobic power (Bosco CMJ 15s), agility (Illinois), and sprint (9.1m) in upper competitive male adolescent *football* players (Zarei et al., 2018) Similar lower limb injury prevention effects of an adapted 10min version compared to the full 20min program in male adolescent *football* players (Rahlf et al., 2020)
HarmoKnee	Football-specific neuromuscular warm-up program designed to prevent knee injuries	Strength (lower limb, core) Plyometrics Balance Core stability Muscle activation Equipment: none	20 - 25min	↓ any knee-, NC knee-, severe knee injuries in lower- to upper competitive female *football* players (Kiani et al., 2010) ↑ sprint and vertical jump in upper competitive female adolescent *football* players (Ayala et al., 2017)

KIPP	Neuromuscular warm-up program designed and implemented in collaboration with H. Lurie Children's Hospital, Chicago, USA, in urban public high schools to prevent knee injuries in female football and basketball athletes	Strength (lower limb) Plyometrics Balance Agility Equipment: none	20min	↓ NC ankle-, NC knee-, NC ACL-, gradual-onset lower limb injuries in urban public school female *football* and *basketball* athletes (LaBella et al., 2012)

As demonstrated, injury prevention effects of INMT warm-ups have been identified through direct measurement of injury rates (incidence), as well as injury risk- and performance factors (physical performance measures). However, these findings are largely limited to football and may therefore limit their generalisability. More research would allow for the development of new and optimization of existing programs for different sports and age groups, as well as managing at-risk athletes. As previously mentioned, Longo et al.'s (2012) 'FIFA 11+' study on male basketball players alludes to the possible effectiveness of the program in sports other than football and warrants further assessments in other (female) sports.

The present study addresses the football bias in literature by assessing the effectiveness of an INMT warm-up program in female youth field hockey players. The researchers chose the 'FIFA 11+' program for the present study due to its rigorous program design, large body of evidence and effectiveness to reduce injury risk and enhance performance, as presented in Tables 2.2, 2.3, and 2.4. To date, the 'FIFA 11+' program has only been utilized in youth football, futsal, and basketball (Table 2.3). Hence, this current study will contribute to further evidence of the possible benefits of the program to other sports (field hockey) in an ecologically valid school sport environment. Further, the study's novelty is the inclusion of a barefoot intervention group, which is the first study in female youth team sport. The purpose of this is the attempt to further optimize the effectiveness of the warm-up program with different training modalities to further incentivise coaches and trainers to implement such program in their regular training time and as warm-up variation with no additional costs. The outlined research on specific injury risk- and performance factors associated with lower-limb injuries in youth team sports, and the described training components in INMT warm-up interventions, allow for the identification of appropriate measurement outcomes. These will be discussed in the section 'Rationale for Selection of Primary Measurement Outcomes'.

Field Hockey

It has been discussed that field hockey is a popular (youth) team sport with a high burden of injury (Ellapen et al., 2009; Ellapen et al., 2014) and limited scholarly attention in South African intervention-based research, making it a suitable sport to assess in this current study. Field hockey is an Olympic sport and played around the word by men and women. It is classified as an intermittent high-intensity sport, played on either grass or artificial (water- or sand based) turf (Spencer et al., 2004). There are eleven players on a team, ten field players and one goalkeeper. Field players are generally divided into attackers, midfielders, and defenders, with specific sub-categories. The aim is to outscore the opposition team by bringing the ball into the opposing team's circle and shooting a goal (Lord et al., 2021). Players are required to lead the ball with a stick only on the flat side across a 91.4m times 55m field. A hockey game typically lasts 70 min, consisting of two halves of 35 min with a 5 min halftime, or four 15 min quarters with 2 min break between each quarter and 15 min break between the second and third quarter. The exact duration structure (halves or quarters) and total duration depend on level of play and federation rules. School hockey games typically last two halves of 30 min. It is, however, common to adjust the length of the halves to 20 min or 25 min according to tournament or league structures. Changing the game duration from halves to quarters, allowing unlimited substitutions and removing the offside rule in the mid-1990s has increased the pace and intensity of the game significantly (Spencer et al., 2004; Lord et al., 2021). The dimensions and physiological demands of intermittent high-intensity play are comparable to football and rugby, and are characterized by walking, jogging, striding, and sprinting (Spencer et al., 2004).

F. RATIONALE FOR THE SELECTION OF PRIMARY MEASUREMENT OUTCOMES

Based on research described in the previous sections and tables, INMT interventions such as the 'FIFA 11+' present both injury risk reducing- and neuromuscular performance enhancing benefits for youth team athletes. To reflect the context of this study, it is therefore vindicated that the measurement outcomes are chosen based on these two key areas (injury risk and performance enhancement). Several studies have been presented and discussed that utilized various combinations of tests to assess these two areas following INMT interventions. To provide congruency between the INMT program and the selection of tests, all five measurement outcomes, namely balance / postural control, functional jumping, lower-limb power, acceleration and speed, and agility, are components that comprise the ‘FIFA 11+’ program (as defined in Table 2.1). The following sections will provide a rationale for the selection of the five measurement outcomes that will be emphasized in the current study. Measurement outcome 1 (balance / postural control) and 2 (single-leg symmetry) relate to the key area *injury risk factors*, and measurement outcome 3 (lower-limb power), 4 (acceleration and speed) and 5 (agility) relate to the key area *performance factors*.

1. Balance / Postural Control

Poor balance alone is significantly correlated with increased risk of injury in numerous sports and can be augmented by (multifaceted) training (Hrysomallis, 2007). As stated in Filipa et al. (2010, p. 552), the SEBT (Star Excursion Balance Test) “is a functional screening tool developed to assess lower extremity dynamic stability, monitor rehabilitation progress, assess deficits following injury, and identify athletes at higher risk of lower extremity injury”. Five out of seven studies in Table 2.3 that included the SEBT, out of which two studies utilized the ‘FIFA 11+’ program (Steffen et al., 2013; Ayala et al., 2017), showed positive adaptations. The SEBT was also commonly cited by Collings and colleagues (2021) who revealed that any lower limb injury risk factor in female athletes included a greater SEBT anterior reach, and ankle injury risk a smaller SEBT anterior reach. As previously stated, it has been established, that an individual’s reach distance in any direction is highly correlated with the reaching distance in any of the other seven directions in the original eight-direction SEBT (Gribble et al., 2012; Hertel et al., 2006). Six out of seven studies in Table 2.3 that utilized the SEBT used an adapted Y-Balance test, assessing the anterior-, posterolateral-, and posteromedial reach directions. Hence, to be congruent with previous research, it is appropriate to utilize the modified SEBT (Y-Balance) in this current warm-up intervention to assess a possible improvement in balance. A composite score of ≤94% limb length (calculated by distance of the three reach directions / (3x limb length) x 100) derived from the Y-Balance, has also been associated with a sixfold greater injury risk (Plisky et al., 2006). Further, an anterior reach asymmetry of ≥4cm between the right and left leg in the Y-Balance test has been associated with a 2.5 times greater injury risk (Plisky et al., 2006).

2. Functional Jumping

Three discussed articles incorporated the Single-leg Hop test for distance in youth team sports, with improvements in two (Ayala et al., 2017; Barendrecht et al., 2011; Lindblom et al., 2020). Local, as well as international research highlighted that the ankle is a common injury site in female (youth) field hockey (Barboza et al., 2018; Ellapen et al., 2014; Murtaugh, 2001). The test is both a measure of unilateral lower-limb power production as well as dynamic stability as it is required to 'stick the landing'. Collings and colleagues' (2021) revealed that a single-leg hop test distance asymmetry of >10cm, results in a greater risk of lower limb (ankle-) injuries in female field- and court-sports. As previously discussed, Barendrecht et al. (2011) reported that single-leg hop distance improvements were accompanied by improved knee kinematics (knee valgus angle, contact time, knee flexion angle) in both male and female adolescent handball players, which may further decrease the risk of landing-related knee injuries. Should this warm-up intervention show significant improvements in minimizing possible between-limb asymmetries, it may have implications for decreased injury risk. Further, should the hop distance increase significantly, it may also inform of possible performance-enhancing benefits due to greater unilateral power production and dynamic stability during the landing manoeuvre.

3. Lower-limb Power

Lower-body power describes the rapid and dynamic expression of muscular strength (i.e., explosive strength) to propel the body forward during jogging and sprinting actions (Markovic and Mikulic, 2010). Several previously discussed studies on injury prevention warm-up programs have reported improvements in variations of vertical jump tests, which are common field tests to assess lower-body power (Ayala et al., 2017; Isla et al., 2021; Reis et al., 2013; Zarei et al., 2018). The Counter-movement Jump (CMJ) was used extensively in studies to reliably assess lower-body neuromuscular performance and explosive strength (Claudino et al., 2017; Cometti et al., 2001; Isla et al., 2021). Correlations between the CMJ and match speed has been reported in professional field hockey players (Lombard et al., 2021). The CMJ requires a coordinated and efficient utilization of the stretch-shortening cycle, hence the sequencing of rapid eccentric to concentric transference of force in the lower limbs (McMahon et al., 2018). The development of coordinated neuromuscular movement patterns is desirable in any athletic group, specifically in the developmental phases of foundational youth sport development to prevent injury and enhance performance (Frisch et al., 2009). This study utilizes the CMJ without arm-swing to assess solely lower-body power and prevent possible interference as a result of different swing- and coordination techniques of the participants. It has previously been stated that vertical jump height, linear sprinting and agility share strong correlations but are independent locomotor skills that should be assessed through a variety of tests (Vescovi & McGuigan, 2008). Hence, this study assesses vertical jump (CMJ) alongside speed and agility tests to present a thorough testing battery that covers various relevant locomotor skills. The best of three attempts will be used for statistical analysis.

4. Acceleration and Speed

Sprint and repeated sprint efforts are significant components of intermittent high-intensity sports such as field hockey and comparable to other team sports such as football and rugby (Spencer et al., 2004). A study in high-level female youth field hockey indicated that players reached up to 16 sprints per game (Vescovi & VanHeest, 2010). Six studies in Table 2.3 utilized different variations of straight-line sprint tests, ranging from 20m to 36.6m, and split intervals at 5 or 10m, with four resulting in performance improvements (Vescovi and VanHeest, 2010; Lindblom, Waldén and Hägglund, 2012, 2020; Reis et al., 2013; Ayala et al., 2017; Zarei et al., 2018). Notably, the three studies (Reis et al., 2013; Ayala et al., 2017; Zarei et al., 2018) that measured speed and utilized the 'FIFA 11+' program all showed improvements in sprint performance following the intervention period. Vescovi (2014) compared maximal sprint speed and peak match speed and found that players only attained approximately 90% of their maximum sprint speed during games, with an average match sprint distance of 14 – 16m. Maximum sprint speeds were recorded at distances between 25-35m. These findings support the suggestion of utilizing split distances to measure initial acceleration, to assess both maximal sprint speed as well as match-specific acceleration demands (Vescovi, 2014). The current study utilizes a 40m sprint test with a split interval at 10m, with the fastest of two maximum effort attempts (separated by 2-3min recovery) reported as the score. The 40m sprint with 10m split has previously been used to assess physical profiles of South African elite field hockey and football players (Durandt et al., 2009).

5. Agility

The terms ‘agility’ and change of direction ‘speed’ are often used interchangeably, and the differences must be noted and clarified. Agility is commonly defined as the ability to rapidly change direction following the exposure to a decision-making situation (reactive component), such as the actions of an opposing players (Young et al., 2015). Change of direction speed, however, is defined as a rapid change of velocity (acceleration and deceleration) or direction manoeuvres during running tasks (e.g., diagonal cutting) without a reactive decision-making component (Young et al., 2015). However, the discussed INMT intervention programs are structured and prescriptive in nature and did not include decision-making aspects. Most researchers referred to ‘agility’ testing in their studies, albeit testing change of direction speed (Table 2.3). Hence, it is appropriate to be congruent with the discussed literature to assess ‘agility’ with an established test, although it does not utilize reactive decision-making components. Future studies should standardize the terminology used for ‘agility’ or ‘change of direction speed’ assessments. The six studies included in Table 2.3 that assessed agility showed mixed results with only three studies reporting positive adaptations (Lindblom, Waldén and Hägglund, 2012; Reis et al., 2013; Zarei et al., 2018). The three studies that assessed agility and utilized the ‘FIFA 11+‘ program showed more favourable outcomes with two studies indicating improvements in agility (Reis et al., 2013; Zarei et al., 2018). Notably, the Illinois Agility test was most commonly used in four out of the six studies. The Illinois Agility test has previously been validated and is a reliable test to assess agility in football players (Daneshjoo, Mokhtar, Rahnama, & Yusof, 2013a; Katis & Kellis, 2009; Kilding et al., 2008). Field hockey players, like football, experience many multi-directional and rapid change-of-direction actions during a game. This is replicated more closely in the Illinois Agility test, compared to other known agility tests that mainly measure agility in only sagittal and frontal plane movements (e.g., 5-0-5 agility test, Agility T-test). It is common for players to utilize ball and stick during field hockey agility testing. However, for the context of the current study that assesses the adaptations to a structured warm-up program which does not incorporate skill-related tasks, it is most appropriate to not carry playing equipment during the test, to purely assess physical adaptations. The fastest time of two maximum effort attempts (separated by 2-3min recovery) will be recorded as the score.

G. BAREFOOT TRAINING

It is important to consider current training trends that may be associated with additional injury-protecting- and performance-enhancing mechanisms. One such popular trend is barefoot training, which gained significantly scholarly attention in recent years and may be considered in the implementation of INMT warm-ups.

A growing body of literature informs of the kinetic and kinematic changes associated with barefoot training, yet no study exists to date that examines possible performance-related adaptations in (female) youth sports. Most studies on the performance effects of barefoot training included participants from distance running populations with support on both sides (Nigg, 2009; Lieberman et al., 2010; Perkins, Hanney and Rothschild, 2014; Da Silva Azevedo et al., 2016; Warne and Gruber, 2017; Hannigan and Pollard, 2019). Prevalent findings in runners include altered foot strike mechanics towards a forefoot strike patterns (FFS), resulting in decreased vertical ground reaction forces (vGRF) at initial contact and possible injury protecting mechanisms (Lieberman et al., 2010; Perkins, Hanney and Rothschild, 2014; Da Silva Azevedo et al., 2016). FFS patterns are hypothesized to stem from greater ankle plantarflexion, greater cadence, shorter stride length, more knee flexion and greater medial gastrocnemius activation, which may result in smaller collision forces and greater ankle compliance upon impact and could serve as a protecting mechanism for overuse injuries (Da Silva Azevado et al., 2016; Lieberman et al., 2010). These changes may, however, not be observed in all runners that transition from shod to barefoot, and, therefore, remain subject to individual adaptations (Mullen et al., 2014; Tam et al., 2016). Consequently, long-term effects of habitual barefoot running have yet to be established due to limited evidence and lack of prospective research (Hollander, Heidt, Van Der Zwaard, et al., 2017; Tam et al., 2014). The likely individuality of adaptations is supported by studies in habitually barefoot adolescents that showed that inherent foot-strike mechanics, such as degree of ankle dorsiflexion, appear to be influenced by long-term footwear and age (Hollander et al., 2018; Krabak et al., 2021). So far, many mechanisms and conclusive evidence on long-term effects remain to be explored, despite the growing research interest in barefoot training across various age groups. Further, most research has examined the implications of barefoot running, and only one study looked at possible performance-enhancing benefits (Hollander et al., 2017).

It is suggested that barefoot training employs more lower limb muscles during physical activity, changing the mechanical properties of small and large muscles surrounding the ankle joint. The smaller, intrinsic muscles within the foot, stabilize the ankle during dynamic movement (Nigg, 2009; Nigg and Enders, 2013). Normal foot function requires the stability of the foot core system (i.e., the foot arch architecture) and the storing and releasing of elastic energy during locomotion (McKeon et al., 2015). The dual relationship of stability and energy transfer is achieved by the intrinsic and extrinsic muscles around the foot and develop in response to increased demands of loading and running (McKeon et al., 2015). It would, therefore, seem that barefoot training may lead to greater activation and development of the foot core system, due to higher direct loading rates as a consequence of greater deformation during foot-strike due to a lack of shock absorption from cushioned shoes. Barefoot training may also recondition the neuromuscular feedback mechanisms through proprioceptive feedback (Lieberman, 2012). A barefoot training study in female university netball players showed positive effects on agility and ankle stability (de Villiers & Venter, 2014). Players participated in netball-specific-drills two- to three-times per week, with either netball shoes or barefoot. Exposure to the barefoot condition group started at five minutes and gradually increased over the eight-week intervention until they completed 30-45 min of barefoot training in the final week. Agility was measured with the 5-0-5- agility test, which requires rapid 180-degree change-of-direction, and balance by means of a single-leg balance test on the Biodex Balance system. Post-test scores increased significantly greater for the barefoot group. It was suggested that the improved balance may have been caused by greater proprioceptive abilities due to strengthening of the smaller intrinsic musculature of the feet in the barefoot group (de Villiers & Venter, 2014). Proprioception may be increased in barefoot conditions, as sensory feedback between the plantar surface of the foot and the ground stimulates the central nervous to enhance stability and avoid injury by increasing activation (and hence, strengthening) of smaller intrinsic muscles (Lieberman, 2012).

Ekizos and colleagues (2017) observed a decrease in dynamic stability when immediately transitioning from shod to barefoot running on a treadmill, which may heighten injury risk during the initial transition phase. However, this study was descriptive and limited to the acute transition from shod to barefoot and did not have an intervention to determine possible long-term effects on dynamic stability, nor did it have gradual exposure. A recent eight-week randomized control study showed that running barefoot compared to shod may lead to a decrease in local dynamic running stability following weekly 15min treadmill running (Hollander et al., 2021). While this study may provide some insight into longer-term implications on measurement outcomes such as running stability, it only utilized treadmill running at an intervention frequency of one session per week for 15min. More studies are needed that address long-term effects of barefoot running in various training environments and with multiple sessions per week to closer resemble a traditional training regime. Further, more studies are needed that address the relationship of specific measurement outcomes, such as dynamic stability, to a potentially heightened injury risk and incidence. Notably, the netball study highlighted that no participant had to discontinue participation due to injuries or discomfort experienced during the eight-week barefoot netball-specific exercises (de Villiers & Venter, 2014). Hence, it is reasonable to assume that a gradual increase in exposure to barefoot conditions in sport-specific drills may not heighten injury risk.

Even though there have been promising effects of barefoot training in studies, very limited research on performance implications of barefoot training in team sport athletes exists. In addition, there is scarcity of available research in female youth sports, which warrants the investigation of barefoot training in intervention studies. An INMT warm-up program may be ideally suited for such intervention due to its practicality and relevancy. The promising results of de Villiers and Venter’s (2014) netball study, as well as the general adaptations to the foot core system (McKeon et al., 2015) highlight the potential positive effects of sport-specific barefoot training on proprioception and balance over traditional shod training. The suggested benefits of barefoot training could therefore be valuable in managing injury risk and for strength and conditioning for the lower limbs. The INMT warm-up interventions described by Herman et al. (2012), and in particular the ‘FIFA 11+’, include variations of strength, plyometrics, agility, dynamic- and static balance. Therefore, the program components (such as jump-landing and balance tasks and running and cutting manoeuvres) are comparable to those included in Villiers and Venter’s (2014) study and provide grounds to determine whether a barefoot INMT warm-up intervention would result in different adaptations compared to a shod group.

It is important to consider the country-specific habits of the population that is studied to contextualize research findings of barefoot training compared to shod. Hollander et al. (2017; 2016) found that children in South Africa grow up habitually barefoot. Growing up habitually barefoot has significant effects on the development of foot morphology, including an increase in foot arch angles, and motor performance (Hollander et al., 2016, 2017). Zech et al. (2018) found that habitually barefoot children show superior balance and jumping performance compared to shod during childhood, with greater jump distances persisting during adolescents. Therefore, the evaluation and transition for the barefoot group to performing the intervention without shoes must be interpreted with caution, as both groups were likely already adapted to performing activities barefoot. The findings of the current study can, hence, not be generalized to all youth athletes, and further research with non-habitually barefoot athletes is needed for comparison.

F. SUMMARY

This chapter highlighted the need for intervention-based research into youth sport, including female participants, aiming to decrease injury risk and enhance performance as measured by selected physical performance tests in an ecologically valid school sport environment. Integrated Neuromuscular Training (INMT) seems to have a positive impact on the mentioned two aims. Most research on INMT in youth team athletes has largely been conducted in male and female football players and utilized the established ‘FIFA 11+’ program. The ‘FIFA 11+’ program also showed superior results to reduce injury incidence, decrease injury risk factors and enhance performance compared to other programs (Table 2.4). The academic support and readily available educational material justify the selection of the ‘FIFA 11+’ program as an appropriate INMT program for the present study. Other popular team sports besides football have not received similar scholarly attention. The most popular female team sport in South African high schools is netball, followed by field hockey with concerning reports of high injury prevalence (Ellapen et al., 2009; Ellapen et al., 2014). Field hockey is therefore a suitable sport for the current study to broaden the general academic literature on the effects of INMT (warm-up) programs on injury risk- and performance factors in team sports other than football. Further, it adds to missing local research that assesses possible interventions to counteract the high injury prevalence and enhance performance in South African female youth field hockey under consideration of current training trends (barefoot training) and general footwear habits of the studied population.

CHAPTER THREE
RESEARCH METHODOLOGY

A. INTRODUCTION

The exploration of current literature revealed that there is a need for intervention-based research to address the high injury prevalence in popular South African team sports. Increasing competitive high school sport developments add to this concern with limited intervention-based research and specific focus on female (youth) athletes in South Africa to enhance performance- and decrease injury risk factors. A key focus for successful intervention programs and their implementation in the South African context is their practicality. This focus is informed by persistent inequality regarding broad accessibility to equipment and skilled coaching staff. Due to these reasons the widely researched ‘FIFA 11+’ program was chosen as the intervention. This program only requires readily available equipment (cones) and has open-source educational- and instructional material, provided by FIFA (**Appendix 1**). This allows coaches of all levels to educate themselves and subsequently implement the program in a safe manner.

This chapter provides the study design, recruitment methods, and the criteria for inclusion and exclusion of the participants. Thereafter, the study outline and timeline that guided the preparation, testing- and intervention procedure are described, as well as details regarding the equipment that was used in the testing and measurement of the participants. In closing, the statistical analysis of the obtained data from pre- and post-intervention testing is explained.

B. STUDY DESIGN

This study utilized a randomized controlled trial, whereby, injury risk factors (balance, and dynamic stability) and performance factors (lower-limb power, speed, and agility) were assessed pre- and post a nine-week neuromuscular warm-up intervention. All participants were randomly assigned to one of two intervention groups, barefoot or shod, by use of a randomization schedule. The study had no passive control group. There was no crossover between the two intervention groups. The researcher could not be blinded to the footwear conditions during the intervention. Participant codes were used during testing. The researcher was, therefore, blinded during post-testing because the allocated footwear condition of the participants was not known to the researcher.

C. ETHICS

This study was approved by the Health Research Ethics Committee at Stellenbosch University (S21/07/131) (**Appendix 4.1 and 4.2**). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), and the Department of Health Ethics in Health Research: Principles, Processes and Structures (2015). The researcher ensured participant- and data confidentiality at all times. An emphasis was placed on the voluntary participation in the study and the ability for any participant to drop out of the study at any point throughout the testing- or intervention process without repercussion. This was communicated both in writing on the informed consent and assent forms, as well as in person. In light of conducting research with a youth participation, particular attention was paid to the safety and well-being of all participants. The researcher encouraged the participants on a regular basis to share or raise any concerns surrounding physical- or mental discomfort. The researcher's private cell phone number was forwarded to all participants and parents, should any participant or parent have any questions or concerns throughout the entire research process.

D. PARTICIPANTS

1. Sample Size

A statistician from the Department of Statistics and Actuarial Sciences, Stellenbosch University, aided with the calculation of the sample size. A previous study on the effects of warm-up programs on proprioception, static and dynamic balance in male soccer players, as well as two studies with similar measurement outcomes were referred to determine the sample size per group (Daneshjoo et al., 2012a; Souhaiel & Denis, 2001; Sueyoshi et al., 2017). An *a priori* power analysis with $\alpha = 0.05$, Power($1-\beta$) = 0.80 was done with the use of G*Power™ (3.1.9.2) statistical software. It was determined that the minimum number of participants needed to achieve the study objectives was 34, with 17 participants in each of the two intervention groups.

2. Sampling Method

The study used non-probability sampling, specifically sampling from a convenience sample of field hockey players from one Stellenbosch High School, HMS Bloemhof. The sample consisted of participants from the First Team, under-19B, and under-16A teams, who have voluntarily agreed to form part of the research. The convenience sample was informed by findings that adherence is a major confounding variable when assessing the effectiveness of structured warm-up interventions (Steffen et al., 2008). Focusing on one school enabled the researchers to be consistently and personally involved in the implementation of the intervention program. Further, the participants represented the three highest performing teams at the school, which is in line with the level of competition of participants (experienced and upper-competitive) from the studies presented in Table 2.2 and 2.3. HMS Bloemhof's First Team is ranked in the Top 15 of the country (*SuperSport Schools* ranking, 2022 season). The principal investigator is a strength and conditioning coach at HMS Bloemhof and was able to work together with the coaches and managers to oversee the adherence and compliance to the program.

3. Recruitment

Female under-16 and under-18 field hockey players from one high school in Stellenbosch were recruited to participate in the study. HMS Bloemhof is a female-only school. The participants were informed verbally about the voluntary possibility to participate in a study by their coaches after the principal investigator informed the coaches of the purpose of the study and received their approval.

4. Inclusion Criteria

Participants could participate in the study if they were 14 to 18 years old at time of the study and were selected for the school's First Team (under-19A), under-19B or under-16A teams. To be included in the study, participants had to attend the intervention sessions as part of their regular hockey practice twice per week. Participants could participate after voluntarily providing signed assent and parental consent.

5. Exclusion Criteria

Participants were unable to participate in this research study if they participated in gymnastics or martial arts prior to or during the hockey season, because these sporting codes are regarded as "barefoot sports" (Vormittag et al., 2009). Participants were further unable to participate if they suffered a head or lower-limb injury within three months prior to the intervention (Wikstrom et al., 2010) or indicated a current injury during the time of testing and/or intervention that prevented them from practicing and completing the warm-up intervention with the required intensity for each exercise.

Data of participants who did not complete both pre- and post-intervention testing sessions, or who failed to complete at least ≥ 80% of the intervention sessions were excluded from the statistical analysis (Steffen et al., 2013) .

E. STUDY OVERVIEW

1. Approvals & Consent Forms

Written approval for the study was obtained by the Western Cape Education Department (**Appendix 5**) and verbal approval provided by the head mistress of HMS Bloemhof. HMS Bloemhof's Sport Manager sent out electronic consent forms (**Appendix 6**) to the parents of the First Team, under-19B, and under-16A field hockey teams at HMS Bloemhof. The team's coaches were informed of the study's purpose and provided their verbal consent. The assent forms (**Appendix 7**), participant questionnaires (**Appendix 8**) and barefoot questionnaires (**Appendix 9**) were handed out in-print by the principal investigator one week prior to pre-intervention testing of the study. The barefoot questionnaire was used to determine the barefoot habits of the participants growing up during primary- and high school (Hollander et al., 2016; 2017).

2. Proof-of-Concept

The research team, consisting of the principal investigator and 12 study assistants, conducted a proof-of-concept prior to the pre-intervention testing, to determine the duration of a testing session, as well as to secure a fast progression and flow of procedures on the day of testing. The study assistants who conducted the pre- and post-intervention testing on the study participants served as participants during the proof-of-concept. The proof-of-concept included a thorough run-through of all tests and technique execution to ensure that all assistants were adequately trained to assess the participants. Each testing station had two identical set-ups to ensure that 12-15 participants per day from one team could be tested within a 75min hockey practice period on the school's field hockey turf.

3. Assistants

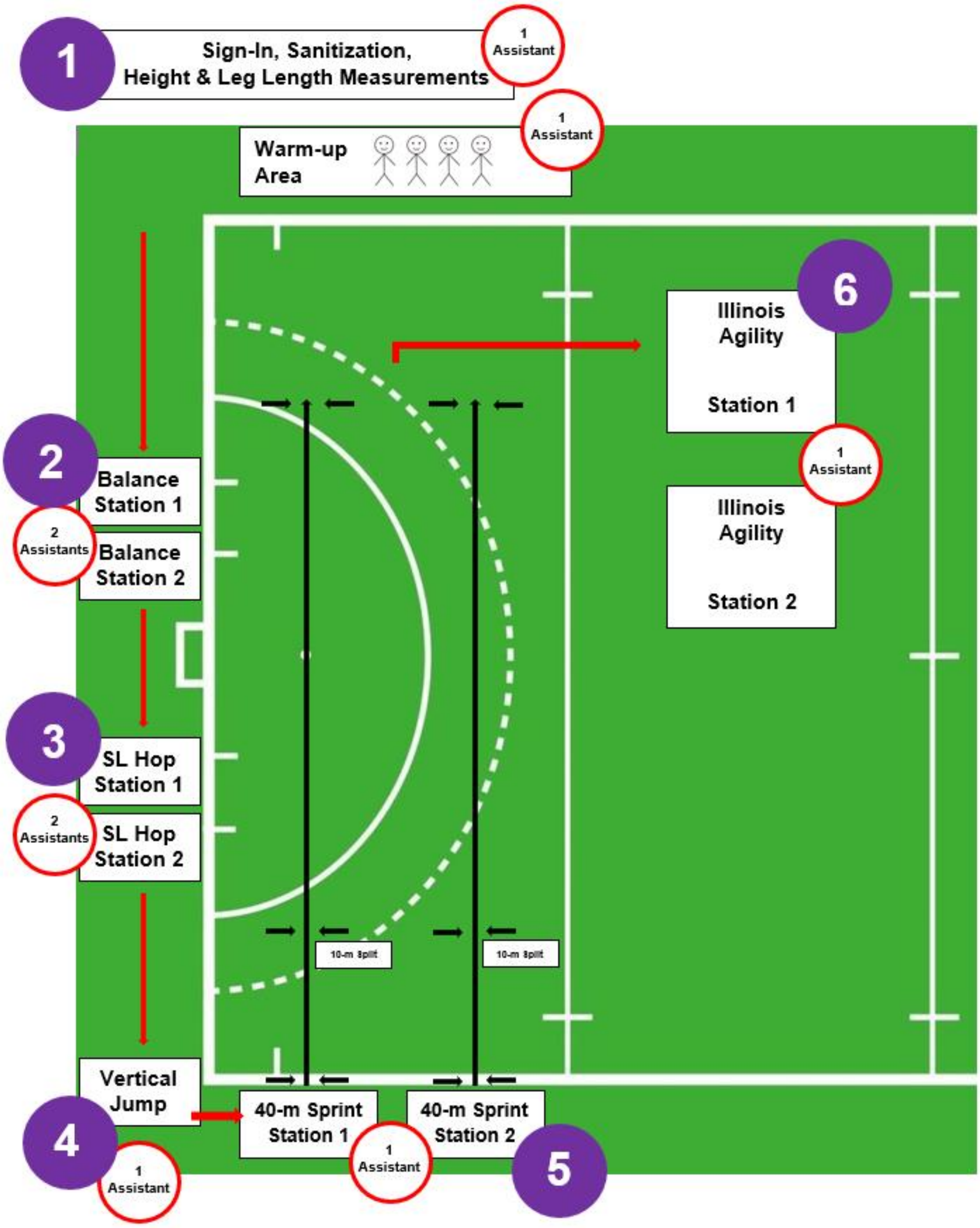
The researcher was assisted during data collection by BSc Hons students in Sport Science. These students were familiar with testing procedures from being involved in testing and data collection in their undergraduate program, as well as in the postgraduate program. As mentioned, all 12 research assistants were part of the proof-of-concept trial, and were provided a document with written guidelines, cues, and set-up protocols to standardize the testing as best as possible. All assistants were instructed to provide positive and reinforcing feedback and verbal encouragement during the maximal attempts of the vertical jump, sprint, and agility tests. The assistants were assigned to the same stations in both pre- and post-intervention testing to decrease potential inter-rater bias.

4. Pre- and Post-Intervention Testing

The testing map with the layout and order of each test (**Figure 1**) and a detailed description of each test was sent out to the participants via WhatsApp, a communication application. The testing map was printed and laminated in large and placed at the waiting area for participants to familiarize themselves with the flow of testing and ensure a fast progression. All participants were instructed to refrain from strenuous physical activity 24 hours prior to testing. Since the testing was conducted on the school's hockey turf, all participants were instructed to wear their regular hockey training shoes on the day for both pre- and post-testing. One team was tested per day, resulting in a total of three testing days for pre-intervention and three testing days for post-intervention. On each testing day, the researcher and assistants met one hour prior to the participant's arrival to prepare each testing station and ensure full functionality of all equipment with practice trials. The set-up included two sets of speed gates (Fusion Sport, USA) that were rented from the Maties Sport High Performance Unit at Stellenbosch University. Two sport scientists from the Maties Sport division, Stellenbosch University, operated the equipment on each testing day as they are well acquainted with the technology.

Figure 1. Testing Map

Highlighting the lay-out and order of the pre- and post-testing procedure on the hockey turf at the school.



On the day of testing, participants arrived directly after school in the early afternoon at the field hockey turf and were divided into groups of four. Each participant received a printed scoring card to carry to the different testing stations (**Appendix 10**). The research assistants filled in the scores for each attempt at each station and handed the score card back to the participants. Anthropometric measurements (height and leg length) were taken for each participant by a qualified Biokineticist. Weight was not measured as per request from the school. Each group of four then proceeded with a standardized warm-up protocol (**Appendix 11**), consisting of jogging, shuffling, dynamic stretching, jumping, lunging, and accelerating, and progressed to the next stations. A scientific order of testing was adhered to and progressed from least to most strenuous to not affect testing results due to premature fatigue from a previous test (Winter et al., 2006). The order of testing was: 1) Y-balance test, 2) Single-leg Hop Test, 3) Counter-Movement Jump, 4) 40-m Sprint, and 5) Illinois Agility test. The same protocol was followed for post-testing. The researcher personally instructed all study participants prior to the pre-intervention testing on technique and testing procedure to prevent a learning effect between pre- and post-testing.

Upon completion of the study a lucky winner was drawn from each team to receive a R250 voucher who completed both testing dates and attended at least ≥ 80% of all intervention sessions. Participants could also request a free consultation with the PI to view their recorded data and receive explanations of differences between pre- and post-testing scores and discuss any follow-up questions.

F. TESTS AND MEASUREMENTS

The literature and rationale for the selection of the five chosen tests in this study has been presented in Chapter 2. This section describes the tests and equipment in detail. The same research assistants were assigned to the same testing stations for pre- and post-intervention testing to minimize inter-rater bias. The participants performed all tests in shod conditions, which is in line with common field-testing procedures Further, it has been previously reported that footwear conditions, compared to shod, did not affect reach distances in the SEBT (Sogut et al., 2022).

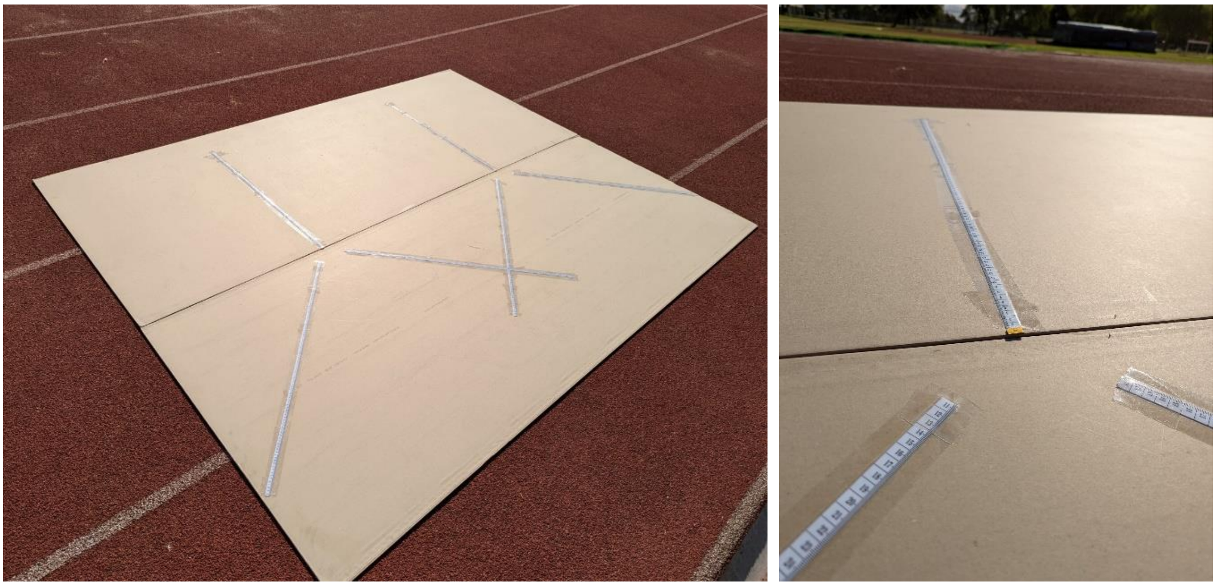
Star Excursion Balance Test

To assess balance and dynamic postural control, the current study utilized the adapted Y-Balance version of the SEBT, assessing each participant's anterior-, posterolateral-, and posteromedial reach direction with each foot. The participants were required to hold a stable base of support with the stance leg in the middle of a grid, whilst reaching the foot as far forward as possible on each of the lines without shifting weight off the stance leg or resting on the foot, before returning to a bilateral stance. A farther distance reached with the distal end of the longest toe indicates superior dynamic postural stability (Gribble et al., 2012). Reaching distances are normalized to each participant's limb length to make valid comparisons, by measuring the anterosuperior iliac spine to the medial malleolus, correlated to the reach distance and expressed as a percentage of limb length (Gribble et al., 2012; Hertel et al., 2006). As previously mentioned, a trained exercise therapist measured leg length before the testing commenced.

International studies have previously utilized a specialized Y-Balance platform for optimal precision and standardization (Shaffer et al., 2013). With such platform participants are required to stand on a centre footplate and push a wooden block with the free limb as far away as possible on a metal distance measurement railing (**Appendix 12**). The researchers unfortunately did not have access to this equipment, as it is not sold in South Africa. For this reason, the researchers constructed their own Y-Balance platform with readily available material (**Figure 2**). Low-cost clothing measurement tape was duct-taped to two adjacent Gyproc Rhino boards (6.4 x 1200 x 3000mm). This allowed the researchers to build a portable testing station that was stored at the school and could be used for pre- and post-testing. The platform was stable for use during testing. Markers were placed on the boards to ensure correct alignment for accurate testing. Assistants regularly checked the alignment throughout testing.

Figure 2. Y-Balance Test Platform Set-up

The rhino boards were purchased from a local Builders Warehouse (https://www.builders.co.za/Building-Materials/Roof/Ceilings/Ceiling-Boards/Gyproc-Rhinoboard-%286-4-x-1200-x-3000mm%29/p/000000000000007309).



(Source: Jannick Schlewing)

The participants were instructed to tap with the reaching foot as far away as possible on the measurement tape. The designated research assistants reported the reaching distances by reading the distance at the furthest point the shoe touched on the tape. An attempt was valid when a participant maintained foot contact with the stance foot at all times, kept contact with both hands on their waist, did not shift their bodyweight onto the reaching foot, tapped the measurement tape and returned to a bilateral stance under control. An attempt was invalid and repeated when a participant violated any or multiple requirements as mentioned above. Each participant was granted a maximum of six trials per leg. Three valid attempts per leg were recorded for each participant. Both the average and maximum reach distances were used for analyses (Shaffer et al., 2013). The test has previously been shown to be valid and reliable to assess dynamic postural control and lower limb symmetry (Gribble et al., 2012; Hertel et al., 2006).

Single-leg Hop Test

The test to identify between-limb asymmetry and unilateral lower limb power production is a hop performed with one leg for maximal horizontal displacement (van der Harst et al., 2007). The test was measured with a standard metal five-meter tape measure (Stramm) and in accordance with a previously established protocol by Xergia and colleagues (2013; 2015) (**Figure 3**). Each participant performed one practice jump, followed by six attempts for three valid jumps with each leg. For all participants three valid attempts for the right leg were recorded first, followed by three valid attempts for the left leg. Participants were instructed to position themselves on one leg with the foot behind a side line on the field hockey turf. A jump was deemed successful if the participants “stuck” a one-foot landing without requiring extra hops to correct balance and always maintained their hands on their hips. Participants were also instructed to hold the landing position and not use the contralateral leg for stance support until the assistant measured the distance. An attempt was deemed invalid and repeated when a participant violated one or multiple requirements listed above. The distance was measured from the most distal part of the toes (shoe) to the most proximal part of the heel after a successful jump. Both maximum and average distances of the three valid trials per leg were used for analyses. The Single-leg Hop has been previously used as a valid and reliable test to assess lower limb asymmetry and single-leg power deficits following ACL reconstructive surgery (Chmielewski, 2011; Noyes et al., 1991; Xergia et al., 2013, 2015).

Figure 3. Single-leg Hop Test Set-up

Performed during the proof-of-concept with the principal investigator and research assistants.

(Source: Jannick Schlewing)

Counter-Movement Jump Test

Counter-movement jump performance was measured with a vertical jump device, the Takei Vertical Jump Meter (Takei Scientific Instruments Co., Ltd., T.K.K.5406, Japan). Participants were instructed to attach a Velcro strap belt with a digital display around their waist and stand on a small rubber platform (**Figure 4**). A string is attached from the belt to the mat and when pulled out of the display box during jumping, indicates the height in centimetres the athlete has jumped. The participants were instructed to stand still on the platform with upright posture to allow the research assistant to tighten the string via a handle on the display box. Each participant was granted a practice trial and then completed three valid attempts. An attempt was valid when the participant completed a full jump by bending downward (triple flexion at the hips, knees, and ankles), immediately jumping up as high as possible, and landing whilst always maintaining their hands on their hips. The highest score of the three attempts was used for statistical analysis. The Takei Vertical Jump Meter was previously used to assess vertical jump (Gül et al., 2019; Sintara Kawiya & Sonchan Nikorn, 2015). The Takei Vertical Jump meter has been previously reported as a valid and reliable tool to measure countermovement jump height (Pun, 2021).

Figure 4. Counter-movement Jump Test Set-up

A participant performing the Counter-Movement Jump test with a research assistant recording the testing scores.

(Source: Jannick Schlewing)

40-m Sprint Test

Maximal speed and acceleration were measured via a 40-m sprint test with a 10-m split time. Smart Speed infrared speed cells (Fusion Sports, www.fusionsports.com, United States of America) were rented from Maties Sport, Stellenbosch University, to accurately report speed measurements to the millisecond (**Figure 5**). Trained sport scientists from Maties Sport operated the equipment during both pre- and post-testing and always ensured full functionality of the equipment on testing days. Each pair of cells includes one signal- and one receiver cell facing towards each other, trans ponding an infrared signal, and are interlinked with subsequent cell pairs to record a continuous 40-m time with 10-m split. The cells record the time intervals when the signal is interrupted ("broken") by running through it until the next gate is interrupted. The speed cells are linked via Bluetooth to iPads (Apple) for immediate feedback. Each sprinting lane consisted of three cell pairs, one at the start, one at the 10-m distance to measure initial acceleration, and one at the 40-m finish line to measure maximum speed. A cone was placed 50cm behind the starting line, to ensure that the speed gates were not prematurely activated by unwanted hand- or body movement during the starting position. Cones were also placed 5-m behind the finish line and participants were encouraged to run at full speed through the 10-m and 40-m gates towards the cone to ensure no premature slowing down.

Figure 5. Sprint Test Set-up

Smart Speed cells, a participant is shown at the two-point sprinting start set-up during testing.

(Source: Jannick Schlewing)

The participants were instructed to set up with a common two-point sprint start (one foot in front of the other). The two-point sprint start was chosen above a sprint-specific three-point start (with one hand on the ground), as a three-point start has not previously been trained in this group of field hockey players and does not resemble a common position during field hockey sprinting actions. The research assistant corresponded with the Maties Sport staff about the readiness of the equipment and then instructed the participants to resume their starting positions. The assistant's standardized signal for the start was a loud **"Ready… GO!"**, with verbal encouragement for maximum effort during each sprint. Each participant completed two attempts with a two-minute resting period in between. Reaction and response time did not play a role in the maximum speed times, as the speed gates only started to record the time once the athlete ran through the gates, which were placed 50cm in front of their starting position. The fastest of the two attempts of the 40-m sprint time and the corresponding 10-m split time were used for the analysis. The 40-m sprint and 10-m split have been previously reported to reliably reflect maximum speed and acceleration capabilities in soccer players (Young et al., 2008).

Illinois Agility Test

Change-of-direction speed was measured with the Illinois Agility test and the same Smart Speed system, rented from Maties Sport, Stellenbosch University. The speed cells were placed at the beginning and end of the agility course. Cones were placed 50cm from the first pair of cells and the participants were instructed to resume their starting position behind the cones. This was done, like for the 40-m sprint, to ensure that the cells were not prematurely activated during the starting set-up with unwanted arm- or body movements.

The Illinois Agility test consists of rapid accelerations and decelerations, change-of-direction maneuverers and slalom running (**Figure 6.1**). The starting position required the participants to lay in a supine position on the stomachs with their hands on the ground besides their shoulders, waiting for the start signal. The research assistant corresponded with the Maties Sport staff about the readiness of the equipment. The assistant's standardized signal for the start was a loud **"Ready… GO!"**, with verbal encouragement to complete the course with maximum effort. As for the 40-m sprint test, reaction and response time did not play a role in the agility times, as the speed gates only started to record the time once the athlete ran through the gates, which were placed 50cm in front of their starting position. Each participant was granted one practice trial at 60-70% effort to familiarize themselves with the course. Two valid attempts were recorded with a two-minute break in between attempts. A trial had to be repeated if a participant failed to complete the course in the correct order or cut the distance short by not running around the cones. The position of each cone was marked with a piece of duct tape on the ground, to re-position the cones correctly in the case of a knocking-over during a trial. Larger traffic cones were used to ensure that the participants ran around the cones and not cut short by swinging their leg over a smaller cone (**Figure 6.2**). The fastest time of the two attempts was used for the analysis. The Illinois Agility test has previously been shown to be a valid and reliable test to assess change-of-direction speed (Hachana et al., 2013; Raya et al., 2013).

Figure 6.1 Illinois Agility Test Lay-out

Illinois Agility test layout, provided by Top End Sports (www.topendsports.com).

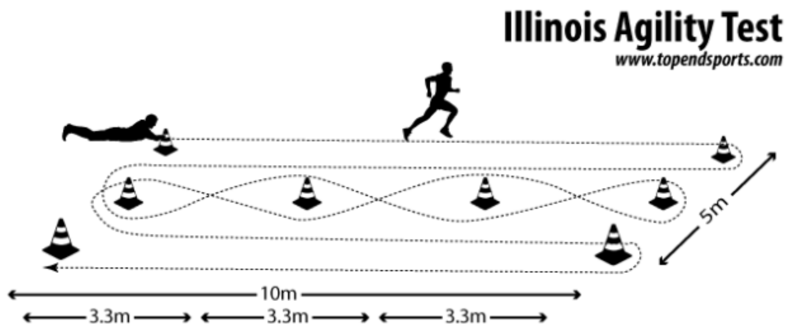


Figure 6.2 Illinois Agility Test Set-up

Smart Speed system set-up and large traffic cones to mark the lay-out of the test course on the hockey turf.

(Source: Jannick Schlewing)

G. INTERVENTION

Participants from the three teams completed nine weeks of the 'FIFA 11+' warm-up program twice per week with a total of 18 sessions, overseen and implemented by the researcher and two research assistants. The researcher has five years of experience in strength and conditioning on recreational- and elite (youth) level in both team- and individual sports. The research assistants were qualified sport scientists and Performance Sport Honours students at Stellenbosch University. The assistants were instructed in the implementation of the program and were provided with educational material consisting of the FIFA-approved manual, cards, and poster (**Appendix 1**). The researcher trained the two assistants to thoroughly practice each exercise and progressions of the program, relevant and standardized cues, and field set-up. The 'FIFA 11+' is divided into three levels of progression. Participants completed pre-season training prior to team selections, were selected for the top three teams of the school and had exercise experience prior to the intervention. For this reason, and to not hinder the progress of well-conditioned athletes, it was determined to start the intervention on level two and progress to level three after four weeks. The research assistants were advised to pay attention to all participants during the intervention sessions to ensure the correct execution of exercise technique and make adjustment, such as exercise regressions, for individuals where necessary. All exercises were performed without a hockey stick. The shod-intervention group performed the warm-up intervention in their regular athletic shoes, since the program took place on grass. One week of school holiday and some public holidays fell into the intervention period. The exercise protocol ('FIFA 11+' poster) was made available to the participants with detailed instructions to execute at home in their respective barefoot- or shod conditions. Before the holiday week and public holidays, the principal investigator reiterated to the participants the importance of completing the program in their respective shod- or barefoot groups. The participants were asked for feedback during the next contact session and confirmed their shoe- or barefoot condition. Further, to minimize dropouts, catch-up sessions were organized for students who missed sessions due to academic or other reasons. No injuries were recorded as a result of the intervention in neither barefoot- nor shod group. **Figures 7** and **8** show participants performing exercises of the warm-up program during the nine-week intervention.

Figure 7. FIFA 11+ Balance Exercise

Participants in the barefoot and shod groups performing the “Test Your Partner” balance variation during an intervention session (FIFA 11+, Part 2, Level 3).

(Source: Jannick Schlewing)

Figure 8. FIFA 11+ Plant & Cut Exercise

Participants in the barefoot and shod groups performing the “Running Plant & Cut” exercise during an intervention session (FIFA 11+. Part 3).

(Source: Jannick Schlewing)

H. STATISTICAL ANALYSIS

Pooled data (research question one) and grouped data (research question two) were used for the statistical analysis. Mixed model ANOVA's were conducted with the participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects. Normal probability plots were inspected to check normality of the residuals, and in all cases found to be acceptable. Post hoc testing was done using Fisher Least Significant Difference (LSD), to reduce the likelihood of type II errors. Cohen's D and Hedges D effect sizes were calculated depending on sample size. The effect sizes were represented as follows: small ($d \geq 0.2$), medium ($d \geq 0.4$), and large ($d \geq 0.8$) (McLeod, 2019).

CHAPTER FOUR
RESULTS AND DISCUSSION

A. INTRODUCTION TO ARTICLES

The results and discussion of the present study are presented in article format.

Article one, titled "**The Influence of the "FIFA 11+" Warm-up Program on Physical Performance in Youth Field Hockey Players**" answers research question one:
Can a nine-week neuromuscular warm-up program be successfully implemented in an ecologically valid environment to affect physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility in female youth field hockey players?

The article was written in accordance with the author's guidelines of the International Journal of Sport Sciences and Coaching (**Appendix 13**). The Vancouver referencing style was applied.

Article two, titled "**Changes in Physical Performance after a nine-week neuromuscular Warm-up Program performed Shod or Barefoot in Youth Field Hockey Players: A Randomized Controlled Trial**" answers research question two:
Does performing the warm-up intervention barefoot, as compared to shod, lead to different adaptations in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility in predominantly habitually barefoot female adolescent field hockey players?

The article was submitted to the Journal of Sport Sciences and follows the CONSORT guidelines for the reporting of randomized controlled trials. The Harvard referencing style was applied to the article. The author's guidelines can be viewed in **Appendix 14**.

THE INFLUENCE OF THE "FIFA 11+" WARM-UP PROGRAM ON PHYSICAL PERFORMANCE IN YOUTH FIELD HOCKEY PLAYERS

Abstract

Background:

The football-specific FIFA 11+ warm-up program has consistently been shown to decrease injury risk and enhance performance in football players in various performance- and age groups. The 11+ is a structured and progressive program that guides coaches to implement the warm-up with standard content and clear guidelines. There is, however, a paucity whether the 11+ is a suitable program for field-based team sports other than football to achieve physical performance improvements.

Objective:

The aim of this experimental study was to assess the influence of the FIFA 11+ warm-up program on various physical performance factors in female youth field hockey players.

Method:

Female field hockey players (n = 40; 16.2 ± 1.23 years) were recruited from three teams from a South African high school. A testing battery consisting of five physical performance tests (Y-Balance, Single-leg hop, Counter-movement Jump, Sprint, and Illinois Agility) was conducted before and after a nine-week intervention utilizing the 11+ twice a week. The full data set of 34 participants was considered for the statistical analysis. Mixed model ANOVA's were conducted with the participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects.

Results:

Participants increased physical performance in all tests ($P \leq 0.05$). Y-Balance test (P 0.05 - <0.01; ES = 0.3 – 0.74; 2.6% - 9.3%) and Single-leg Hop test (P <0.01; ES =

0.41 – 0.49; 5.3% - 8.2%) scores improved significantly in both legs for maximum and mean scores. Counter-movement Jump ($P < 0.01$; ES = 0.48; 5.7%), 40-m Sprint ($P < 0.01$; ES = 0.27 – 0.89; -1.6%) with 10-m split ($P < 0.01$; ES = 0.71; -4.6%) times, and Illinois Agility ($P < 0.01$; -3.8%) time improved significantly.

Conclusion:

The 11+ is a suitable program for youth field hockey players to contribute to the development of physical performance. There were also indications that risk factors associated with lower-limb injury, as determined by the Y-Balance test, and Single-leg Hop test decreased in this population. The current study showed that with clear guidelines and high compliance the 11+ was implemented successfully in this population of female adolescent field hockey players. The current study adds to the body of knowledge on the application of the 11+ in youth team sports. The program’s application in field hockey may help coaches in field sports other than football to follow clear content guidelines in the application of structured warm-up programs.

Background

Integrative neuromuscular training (INMT) has been widely accepted as an effective method to reduce injury incidence and enhance physical performance through the development of physical competencies in athletes of all ages (1–6). INMT incorporates fundamental- and sport-specific strength and conditioning activities, such as dynamic stability, plyometric and agility training, to enhance sport-related skills (7–10). Successful performance measure outcomes, such as improved lower-limb power and agility, may occur with a program duration more than four weeks, a session duration of at least 20-min and performed at least one to three times per week with a high adherence (2,5,11). There is, however, still a lack of standard content and clear guidelines pertaining to the program design in INMT studies. Researchers often rely on their own experience (12) or adaptations from previous reported studies (13,14).

To address this challenge, some INMT warm-up programs have been developed by researchers and organizations to disseminate to coaches to implement with detailed educational- and instructional material. A popular program is the “FIFA 11+” (11+), which is a 20-min football-specific injury prevention warm-up program, developed and endorsed by the Medical Assessment Centre of the Federation Internationale de Football Association (FIFA) (15). The freely available instructional material online (https://www.yrsa.ca/fifa-11.html) allows for the program to be easily implemented by researchers and disseminated to coaches of varying levels of education. Recent systematic reviews and meta-analysis in various age groups, males and females, and performance levels, concluded that the 11+ warm-up may decrease lower limb injuries between 29% to 39% (16–19). The 11+, as well as other multimodal injury prevention programs, focus on the modification of intrinsic neuromuscular injury risk factors (20). In general, intrinsic neuromuscular injury risk factors is an umbrella term that describes a broad range of physical performance measures, such as balance, lower limb strength and power, and change of direction speed, to assess a heightened injury risk in athletes (20). Some physical performance tests, such as the Y-Balance test and Single-leg Hop test for distance, have reported correlations to a variety of knee-, ankle-, and general lower-limb injuries (21–24). On the other hand, physical performance tests, such as sprints and agility, are considered key performance indicators (KPIs) and used to test and predict physical performance improvements following strength and conditioning programs (25,26). Therefore, a battery consisting of tests that cover a wide range of measures typically associated with both heightened injury risk as well as KPIs is useful to determine a program's effect on general physical performance. Other match-specific KPIs in field-based team sports include passing, dribbling, tackling, etc. (27), which were not assessed in the current study.

Several studies in youth soccer populations have shown that the 11+ successfully improved KPIs (such as speed, agility, and lower-limb power), decreased injury incidence and decreased injury risk factors (such as poor dynamic postural stability and lower-limb symmetry) (2,5,6,28,29). The 11+ presents a time efficient program, as an adapted 10-min version resulted in similar lower-limb injury prevention results compared to the full 20-min version (30). The 11+ has also shown superior results on physical performance measures in professional football players compared to other soccer-specific programs like the "HarmoKnee" (31).

To date, limited studies exist that assess the effectiveness of the 11+ program in field sports other than football. Only one randomized controlled trial by Longo and colleagues' (32) with elite adolescent male basketball players exists that reported a decrease in lower-limb-, acute-, severe-, and ankle injuries during a nine-month season. The study, however, did not include measures of physical performance. The findings are significant as they open the door for the 11+ program to be applied and studied in the broader team field sport context and determine the protocol's suitability in sports with similar physiological demands, such as field hockey. No study to date exists that investigates the effect of the 11+ warm-up program on selected physical performance measures that are associated with KPIs and injury risk in adolescent field sport athletes other than football.

Methods

Study population and design

This study utilized an experimental design, whereby physical performance was assessed pre- and post a nine-week 11+ injury prevention program, which was implemented as a warm-up. The study population consisted of a convenience sample of competitive female field hockey players, aged 14 – 18 years, from a high school. The participants were recruited from the First Team (under-19A), Second Team (under-19B), and under-16A teams, representing the highest performing teams at the school. Out of the 45 players in the mentioned teams, 40 players volunteered to participate in the study. Some players could not participate in the study due to simultaneous commitments in other school sports that interfered with training (intervention) attendance. Participant assent and parental consent were obtained with an emphasis on voluntary participation in the study. The high school is a female-only school and is ranked in the top 15 for field hockey in the country (*SuperSport Schools* ranking, 2021 and 2022 season). All players participated in the 11+ intervention with no control group. This was done to conduct the intervention in an ecologically valid environment. Based on the ethical requirements for equal sport participation at the school, it would have been unethical to assign some athletes a different warm-up with less attention from the coaches compared to the rest of the team. Further, the players underwent the same training regime as part of the school's high performance sport program.

Participants were excluded from the study if they suffered a head- or lower-limb injury within three months prior to the intervention or indicated a current injury during the time of testing and intervention that prevented full participation in all organised field hockey practices.

The study was approved by the Health Research Ethics Committee of Stellenbosch University (reference no: S21/07/131) and was conducted in accordance with the Committee on Publication Ethics' International Standards for Authors.

Intervention Program

The 15 individual exercises of the 11+ program are divided into three parts with initial and final running, focussing on general dynamic and higher intensity jumping and cutting actions (parts 1 and 3) and strength, jumping and dynamic stability exercises (part 2). The program provides three levels of progression for each of the six exercises in part 2. Since the recruited participants completed a pre-season strength and conditioning program at the school the intervention started on the second progression level for the exercises of part 2 and moved to level three after five weeks. Players continued with their typical hockey practices, matches and aerobic running but refrained from additional strength and conditioning activities. The coaches who implemented the warm-up program were advised to pay individual attention to each participant during the sessions and regress athletes to a lower intensity level if necessary. Prior to the start of the intervention, the coaches attended a workshop conducted by the principal investigator and were given instructional material from the 11+ program website (https://www.yrsa.ca/fifa-11.html) to thoroughly explain the testing process and program. Each coach completed the intervention sessions with one team. The educational material was also made available online to the participants to familiarize themselves with the exercises and catch up missed sessions at home, due to occasional interruptions of the school sport schedule on public holidays. The coaches carried out the warm-up program twice per week, either at school hockey practice or before a match. The intervention duration was nine weeks with a total of 18 intervention sessions.

Neuromuscular Performance Tests

One week prior to the start of the nine-week intervention, all participants were asked to complete a field-based testing battery to assess physical performance. The testing consisted of six stations and lasted for approximately 60 minutes. The same post-testing battery was completed within one week after the end of the intervention. At the time of pre-intervention testing the players have undergone their pre-season conditioning program and were selected into their designated teams.

This study assesses CMJ, speed, and agility, as previous research stated that vertical jump height, linear sprinting and agility share strong correlations but are independent locomotor skills that should be assessed through a variety of tests (54). The tests were conducted in the following order: anthropometric measurements (height and limb length), Y-Balance test (cm) (23,24), Single-leg Hop test (cm) (33,34), Counter-movement Jump (cm) (35), 40-m sprint with 10-m split (sec) (36), and Illinois Agility (sec) (37–39). The order was determined to test from least to most fatiguing (40). A document with the detailed testing procedure and lay-out of testing stations was handed to all participants (Appendix 1). The coaches and principal investigator were assigned to the same stations for pre- and post-testing and gave verbal instructions and visual demonstrations for each test. A qualified and registered exercise therapist conducted the anthropometric measurements. Height was determined by means of a portable sliding height scale (in 0,5cm units) and limb length by measuring the distance from the most inferior aspect of the anterior superior iliac spine to the most distal aspect of the medial malleolus (in 0,1cm units). Limb length was measured to normalize the Y-Balance test results for each participant and express as a percentage score. The Y-Balance test and Single-leg Hop test were carried out with both feet, starting with the right- and then the left leg. Participants completed sufficient familiarization trials in accordance with previous protocols (41) to prevent a carry-over effect of being more familiar with the test. The participants completed a six-minute standardized warm-up consisting of jogging, sprinting, hops, and dynamic stretches under supervision of the researcher. All tests were performed in the participants' regular training shoes. The protocol for each test is presented in Table 1.

Statistical Methods

Mixed model ANOVA's were conducted with the participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects. Normal probability plots were inspected to check normality of the residuals, and in all cases found to be acceptable. Post hoc testing was done using Fisher Least Significant Difference (LSD). Cohen's *d* and Hedges *g* effect sizes were calculated and represented as follows: small ($d \geq 0.2$), medium ($d \geq 0.4$), and large ($d \geq 0.8$) (McLeod, 2019).

Table 1. Protocol for each neuromuscular performance test, pre- and post-intervention.

Test	Outcome	Validity & Reliability	Protocol
Y-Balance	Balance Postural control	(24,42)	Six practice trials per leg. Maximum and average scores out of three valid attempts with each foot in the anterior-, posterolateral-, and posteromedial direction. An attempt was valid when participants maintained foot contact with stance foot, kept contact with both hands on their waist, did not shift bodyweight onto reach foot, and returned to bilateral stance under control.
Single-leg Hop for distance	Postural control Lower-limb power (unilateral)	(43–46)	One practice jump per leg. Maximum and average scores of three valid attempts with each foot, starting with the right and then the left leg. An attempt was valid when participants “stuck” a one-foot landing without requiring extra hops to balance, kept contact with both hands on their waist, and not use contralateral leg for stance support.
Counter-movement Jump	Lower-limb power (bilateral)	(35)	One practice trial. Maximum score of three valid trials. An attempt was valid when participants completed a full jump with maximum effort and landing with both feet whilst maintaining contact with both hands on their waist at all times.
40-m Sprint with 10-m Split	Maximum speed Acceleration	(47)	One practice acceleration. Fastest time out of two valid attempts with two minutes rest between attempts. All participants started in a two-point split stance start position. An attempt was valid when participants sprinted through the 10-m and 40-m timing gates with maximum effort.
Agility Illinois	Change-of-Direction speed	(48,49)	One slow practice trial. Fastest out of two valid attempts with two minutes rest between attempts. All participants started in a laying supine position on their stomach with their hands on the ground besides their shoulders. An attempt was valid when participants completed the course in the correct order and by sprinting with maximum effort around the cones

Results

Initially, pre-intervention testing was conducted with a total of 40 participants that fulfilled the inclusion criteria. Six participants did not complete the study, equalling a drop-out rate of 13,6%. The drop-out were for various reasons, including being dropped to a lower team to a lower team (n = 1), sustaining a lower-limb injury during games (n = 2), not fulfilling the required ≥80% attendance (n = 1), and sick on the day of post-testing (n = 2) (see Figure 1). The full dataset of 34 participants was considered for the final statistical analysis. Descriptive characteristics of the participants are presented in Table 2. Groups did not differ in age and body height ($p = 0.23$). The 34 participants completed the 11+ intervention program in 585 out of 612 possible sessions throughout the nine-week study period, corresponding to an average compliance rate of 95,6%.

Table 2. Descriptive characteristics of the participants.

			Participants (n = 34)
Age	in years		16.12 ± 1.23 SD
Body Height	in cm		164.8 ± 6.8 SD
Team	in %	First Team	35% (n = 12)
		Under-19B	32% (n = 11)
		Under-16A	32% (n = 11)
Player Position	in %	Defender	32% (n = 11)
		Midfielder	32% (n = 11)
		Striker	26% (n = 9)
		Goalkeeper	9% (n = 3)

Table 3. Y-Balance test results pre- and post-intervention to assess balance and dynamic postural stability.

Type	Direction	Lower Extremity	Pre-intervention Distance (in cm) Mean ± SD	Post-intervention Distance (in cm) Mean ± SD	P-value	Effect Size
Maximum Reach	Anterior	Right	59.9 ± 5.8	61.8 ± 4.1	0.01	0.38 (small)
		Left	59.3 ± 6.1	61.5 ± 4.8	<0.01	0.41 (medium)
	Posteromedial	Right	86.9 ± 9.4	92.3 ± 7.5	<0.01	0.64 (medium)
		Left	89.4 ± 8.4	93.3 ± 7.9	<0.01	0.48 (medium)
	Posterolateral	Right	90.3 ± 7.8	98.7 ± 6.3	<0.01	0.48 (medium)
		Left	94.5 ± 8.7	97.3 ± 7.7	<0.01	0.34 (small)
	Composite*	Right	91.7 ± 6.4	95.8 ± 4.5	<0.01	0.74 (medium)
		Left	92.1 ± 6.5	95.6 ± 5.9	<0.01	0.55 (medium)
Average Reach of 3 Trials	Anterior	Right	58 ± 5.8	59.5 ± 4.1	0.05	0.3 (small)
		Left	57.7 ± 6.3	59.6 ± 4.8	0.01	0.34 (small)
	Posteromedial	Right	83.7 ± 9.4	89.2 ± 7.4	<0.01	0.65 (medium)
		Left	85.9 ± 9	90.3 ± 7.6	<0.01	0.53 (medium)
	Posterolateral	Right	92.6 ± 7.7	96.1 ± 6.9	<0.01	0.48 (medium)
		Left	91.8 ± 8.7	95 ± 7.4	<0.01	0.4 (medium)
	Composite*	Right	88.8 ± 6.3	92.8 ± 4.9	<0.01	0.69 (medium)
		Left	89.2 ± 6.7	92.9 ± 5.9	<0.01	0.58 (medium)
Maximum Asymmetry	Anterior	Right/Left	3.1 ± 2.8	2.5 ± 2.2	0.18	0.21 (small)
Average Asymmetry	Anterior	Right/Left	3.2 ± 3.1	2.8 ± 2.2	0.54	0.13 (negligible)

SD = Standard Deviation; absolute reach distance was used for anterior, posteromedial- and posterolateral reach directions; *composite score was normalized and expressed as a percentage by calculating three reach distances / (3x) limb length (anterior superior iliac spine to medial malleolus) x 100 for each limb

Table 4. Single-leg Hop test for distance results pre- and post-intervention to assess dynamic postural stability and lower limb symmetry.

Jump Distance	Lower Extremity	Pre-intervention Reach (in cm) Mean ± SD	Post-intervention Reach (in cm) Mean ± SD	P-value	Effect Size
Maximum	Right	121.9 ± 15.7	128.4 ± 15.9	<0.01	0.41 (medium)
	Left	118.9 ± 20.2	128.2 ± 17.9	<0.01	0.49 (medium)
Average of 3 Trials	Right	115.8 ± 15.4	122.7 ± 16	<0.01	0.44 (medium)
	Left	113.3 ± 19.8	122.6 ± 19.3	<0.01	0.48 (medium)
Maximum Asymmetry	Right/Left	8.7 ± 10.4	8.2 ± 8.9	0.7	0.05 (negligible)
Average Asymmetry	Right/Left	8 ± 9	7.7 ± 9	0.72	0.03 (negligible)

SD = Standard Deviation

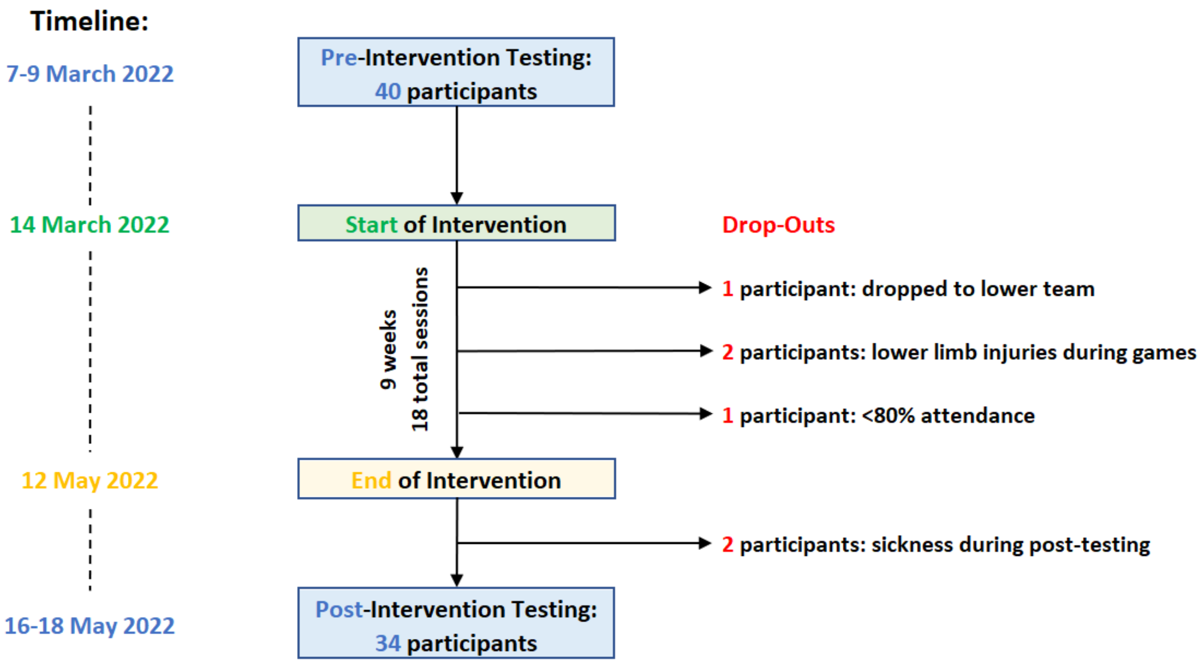
Table 5. Counter-movement Jump, Sprint, and Agility test results pre- and post-intervention to assess key performance indicators.

Test		Pre-intervention Mean ± SD	Post-intervention Mean ± SD	P-value	Effect Size
Counter-movement Jump (cm)		38.6 ± 4.3	40.8 ± 4.8	<0.01	0.48 (medium)
Sprint	10-m Split (sec)	2.05 ± 0.09	1.96 ± 0.11	<0.01	0.89 (large)
	40-m Split (sec)	6.43 ± 0.35	6.33 ± 0.39	<0.01	0.27 (small)
Agility Illinois (sec)		17.96 ± 1	17.31 ± 0.78	<0.01	0.71 (medium)

SD = Standard Deviation

Participants showed a significant ($P \leq 0.05$) increase in all neuromuscular performance tests). Table 3 and Table 4 show the results for the pre-and post-intervention assessments regarding the injury risk factors. Significant improvements for the Y-Balance test (YBT) were observed for both maximum (furthest reach of three valid trials) and average (average reach of three valid trials) values (P = <0.01-0.05, ES = 0.3-0.74) (see Table 3). YBT performance improved in all three reach directions (anterior, posteromedial, and posterolateral) in both legs by 2.6% - 9.3%. Significant improvements were observed for Single-leg Hop test distance (SLH) for both maximum and average values (P = <0.01, ES = 0.41-0.49) (see Table 4). SLH distance improved in both legs by 5.3% - 8.2%. Asymmetries between limbs in anterior reach direction in the YBT (P = 0.18-0.54, ES = 0.13-0.21) and SLH distance (P = 0.7-0.72, ES = 0.03-0.05) decreased, however, not significantly. Table 5 shows the results for the pre- and post-intervention assessments regarding performance factors as measured by the Counter-movement Jump (CMJ), 40-m Sprint with 10-m split, and Illinois Agility test. Significant improvements in key performance indicators were recorded for the CMJ (P = <0.01, ES = 0.48), 40-m Sprint (P = <0.01, ES = 0.89) and 10-m split (P = <0.01, ES = 0.27) and Illinois Agility test (P = <0.01, ES = 0.71). CMJ height improved by 5.7%, 40-m Sprint time by 1.6% with 10-m split by 4.6%, and Illinois Agility time by 3.8%.

Figure 1. Timeline of the study and participant flow chart.



Discussion

The main finding of this experimental study was that all physical performance tests improved following a nine-week intervention utilizing the 11+ program in this sample of youth field hockey players. The findings are generally in line with other RCT studies that utilized the 11+ program in female and male youth football players (2,5,6,29).

Injury Risk Factors

Balance and postural control were assessed with the Y-Balance test (an adapted version of the Star Excursion Balance Test) and Single-leg Hop for distance. The participants in the present study improved their general balance ability in all three reach directions and composite scores with both maximum and average scores (P = <0.01 – 0.05) (Table 3). These findings are similar to recent studies in youth soccer players with the 11+ (5,6,50). The YBT allows examiners to determine general single-leg balance ability, assess deficits following injury, and identify athletes at higher risk of lower extremity injury (21,22,24). In general, impaired balance is correlated with an increased risk of lower limb injury, particularly ankle and knee sprains (23). More specifically, deriving from the YBT, a composite score of ≤94% limb length (calculated by adding the distance of the three reach directions / (3x limb length) x 100), has been associated with a sixfold greater injury risk (23). Further, anterior reach asymmetry of ≥4cm between the right and left leg has been associated with a 2.5 times greater injury risk (23). Anterior reach asymmetry improved, however, not significantly ($P = 0.18 – 0.54$). Zazulak and colleagues (51) demonstrated that neuromuscular control of the core and trunk enhances dynamic postural stability of the lower limbs during athletic manoeuvres that demand high-speed and change-of-direction, as experienced in soccer and field hockey. The balance and core exercises in the 11+ program (Level 1 & 2) have a strong focus on single-leg balance position with adequate knee flexion, core bracing and knee alignment, which is replicated in the execution of the YBT. The addition of an external stimulus, such as tossing a ball to a partner (Level 2) stimulates the athletes' cognitive ability to balance and attend to accurate throwing and catching movements. The last balance progression of the 11+ (Level 3) combines core strength and dynamic postural control by challenging athletes off-balance and regaining an appropriate balanced single-leg stance. Coaches in different sports may prefer certain progressions due to the demands of their sports, such as variations of challenging the partner off-balance (Level 3) for rugby, to mimic ruck and maul actions. The improved balance ability in this sample may indicate a reduction in lower-limb injury risk with similar results compared to studies that utilized the YBT in youth soccer players (2,5). The progressions also allow coaches in different sports to make necessary adjustments to the 11+ protocol without changing the purpose of the exercise, e.g., exchanging the tossing of a soccer ball in the single-leg balance stance (Level 2) with a hockey ball or rugby ball. This versatility of the 11+ program encourages the application in various field-based team sports without deviating too far from the original program protocol developed by FIFA.

Despite significant improvements in both maximum and average scores, there are notable discrepancies in YBT composite score improvements. When using maximum scores, 22 out of 34 participants (65%) were flagged with a ≤94% composite score (i.e., a sixfold greater injury risk) after pre-testing, and only nine out of 34 (26%) after post-testing. However, when using average scores, more participants were flagged, with 27 pre-testing (79%) and 20 post-testing (59%). It is reasonable to assume that poor balance is best determined and replicated across several trials (24). Therefore, using only a maximum attempt for analysis may not be an accurate depiction of an athlete’s repeatable balance performance (24) and would likely lead to an underreporting of at-risk athletes, as evident in the large post-testing discrepancies (26% for maximum and 59% for average scores). The current findings support the utilization of average scores to determine at-risk athletes and present a more accurate depiction of an athlete’s superior or inferior balance performance as displayed across multiple trials.

The SLH assesses dynamic postural control and single-leg power production, as it requires the athlete to jump as far forward as possible with one leg and ‘stick the landing’ without losing balance or shuffling the foot (5,34). A between-limb asymmetry of >10cm has been associated with a greater risk of ankle injuries in female field- and court-sports (52). Barendrecht et al. (41) reported that SLH distance improvements were accompanied by improved knee kinematics (knee valgus angle, contact time, knee flexion angle) in both male and female adolescent handball players, which may decrease the risk of landing-related knee injuries. SLH distance improved significantly in both legs for maximum and mean values (P = <0.01), suggesting a possible improvement in postural control and lower-limb power performance (Table 4). The 11+ includes single-leg power exercises such as Lateral Jumps (Level 2, Part 2) and continuous bounding (Part 3), which likely contributed to these improvements. There was a non-significant decrease in between-limb asymmetry (P = 0.72). Jump distance improved for both legs and with no significant difference between right and left side, which may explain the lack of improvement in asymmetry. The participant sample presented with a mean asymmetry of less than the 10cm threshold during pre-testing (8cm – 8,7cm) and post-testing (7,7cm - 8,2cm), suggesting overall low injury risk across the sample group. However, the standard deviations were large for maximum and mean values (8,9cm and 10,4cm respectively) in both pre- and post-testing, resulting in 12 flagged participants after pre-testing and 9 after post-testing. These findings highlight the large interpersonal variability of this test to assess lower-limb asymmetry as an injury risk factor and the need to analyse each athlete individually to compare to mean team values. Evaluators must be cautious in interpreting such data, as some athletes may present with large asymmetries compared to average team values and should be assessed further. However, the suggested improved knee kinematics as a result of SLH improvements (41) together with the balance improvements in the YBT may contribute to a decreased injury risk in this study’s sample. Apart from performance, the SLH has also been used to assess athletes muscular balance and dynamic stability following anterior cruciate ligament injuries and may be a useful test in return-to-play protocols to predict future risk of re-injury (5,34). One athlete in particular from this study presented with a large 53,5cm right-left asymmetry in the SLH during pre-testing and 48,5cm post-testing. On the participant questionnaire the athlete indicated no current injury (within three months before the study begin) which made her eligible to participate but reported a minor knee injury in the prior season. Upon further communication with the athlete, it became known that this athlete was cleared from a medical doctor and resumed all sport activity without following an appropriate rehabilitation protocol. The athlete reported that she chronically preferred the non-injured leg for jumping and balance exercises. This is an example of the usefulness of the SLH to assess post-injury discrepancies and (mal-)adaptive movement patterns and imbalances, which, if left undetected, can significantly increase an athlete's risk of re-injury.

Due to the several jumping and plyometric exercises in the 11+ program, the overall improvements in SLH performance may be primarily interpreted as an increase of lower-limb power, and secondarily an increase of balance and postural stability. These improvements, in combination with the improvements in all directions in the YBT point towards an increase in balance ability and subsequently decreased injury risk in this sample. The current findings suggested that due to the large dynamic jump focus of the SLH, this test may not be used as a sole test to assess injury risk (balance), but rather in conjunction with a test that is primarily designed to assess balance as a possible risk factor, such as the YBT. Yet, the SLH may present a valuable tool to identify potential at-risk athletes by means of right-left discrepancy, discrepancies following injury, and assess adaptations in unilateral lower-limb power production.

Key Performance Indicators

The dimensions and physiological demands of intermittent high intensity play in field hockey players are comparable to football and rugby, and are characterized by walking, jogging, striding, sprinting, acceleration and deceleration, and repeated change-of-direction ability (53). These key performance indicators were assessed by means of the CMJ, 40-m sprint with 10-m split, and Illinois Agility test.

CMJ performance improved significantly (5.7%) in the current study. This is comparable to several previous studies on injury prevention warm-up programs which utilized variation of vertical jump tests, such as the CMJ and squat jump (5,6,29,55). The CMJ improvements in the present study can likely be attributed to the incrementally progressing jump exercises in the 11+ program. The inclusion of lower-limb strength exercises such as Nordic hamstrings, walking lunges, and single-leg squats, likely facilitated this adaptation as improvements in strength have been correlated with enhanced lower-body power production (25). The CMJ has been used extensively in studies to assess lower-body neuromuscular performance and explosive strength and is correlated with match speed in professional field hockey players (26,35,55,56). The CMJ requires a coordinated and efficient utilization of the stretch-shortening cycle, hence the sequencing of rapid eccentric to concentric transference of force in the lower limbs (57). The development of coordinated neuromuscular movement patterns is desirable in any athletic group, specifically in the developmental phases of foundational youth sport development to prevent injury and enhance performance (58). From a strength and conditioning point of view, the teaching and movement acquisition of a coordinated eccentric-to-concentric jump, such as the CMJ, also presents as a valuable baseline skill for further conditioning programs that incorporate bilateral-, unilateral-, and continuous jumping variations. Therefore, tracking CMJ performance is desirable to not only assess improvements in lower-limb power production as a performance indicator, but also as a tool to assess coordinated lower-limb movement proficiency and quality.

Sprint performance improved significantly for both 40-m sprint and 10-m split times. Improvements in sprint performance have been reported in several football studies that utilized the 11+ program in youth athletes (5,6,29). Notably, in the present study, 10-m split times improved more (-4.6%) than the 40-m sprint (-1.6%). Similar results were reported in a study by Reis and colleagues' (6) in futsal players utilizing the 11+ program, that measured 5-m (-8.9%) and 30-m sprint (-3.3%) performance. A possible reason is that the plyometrics- and running based exercises in Part 1 and 3 of the 11+ encourage shorter bursts of acceleration and planting and cutting, and only include one exercise that emphasises longer sprinting at 75-80% intensity across the pitch. The overall small, yet significant improvements in 40-m sprint time may, therefore, be attributed to an increase in initial acceleration and lower-limb power (as demonstrated in the improvements in CMJ) rather than an increase in top speed. It has been reported that maximal sprint durations in elite field hockey players was on average 4.1 ± 2.1 seconds with a mean number of sprints within a repeated-sprint bout of 4 ± 1 and separated by approximately 20 seconds of active recovery (53). Therefore, the improvements in 10-m acceleration in particular may subsequently translate well into the context of match performance in field hockey players. Repeated multidirectional acceleration capacity may be considered more important than maximum speed due to the shorter average sprint time efforts (4.1 ± 2.1 seconds) which are mostly not long enough to attain top speed (53).

The present sample showed significant improvements (-3.8%) in agility times after post-testing. So far, mixed results have been reported assessing the effect of the 11+ on agility performance in youth soccer players (5,6,29). Adaptations in CMJ (power) and acceleration, as well as specific 11+ exercises that target change-of-direction speed likely contributed to this improvement. The running exercises (Part 1 and 3) of the 11+ incorporate rapid forward-backward- and multidirectional change-of-direction manoeuvres with angles less than 90 degrees. This demand is replicated in the Illinois Agility test, as it requires repeated turning around cones at sharp angles followed by immediate re-acceleration. Agility is a complex combination of eccentric and concentric strength, speed, coordination, dynamic balance, and coordination (29). It is, thus, likely that the previously discussed improvements in balance, power, and acceleration contributed to the agility improvement. It is important to mention that the current study did not utilize stick and ball for the Agility test, and solely focused on assessing adaptations in physical performance. Skill is a major determining factor to effectively utilize and express power, speed, and agility ability during field hockey match play. Therefore, it may be advisable for coaches to assess agility performance with and without stick and ball to assess possible discrepancies between physical fitness- and skill abilities. This can help coaches to create more detailed player profiles and prescribe individual programs that target either more physical- or skill-training.

The current study presented a higher-than-average adherence compared to other neuromuscular injury prevention interventions (50,59). It has been suggested that a compliance of ≥80% can result in greater reduction in injury risk (72%) compared to lower adherence (2). It is reasonable to assume that the high average adherence of

95.6% positively impacted the significant improvements in the neuromuscular performance tests and should encourage coaches to incentivise high attendance rates during training sessions.

Limitations

We acknowledge some limitations in the present study. The first limitation is the absence of a control group. Previous randomized controlled trials with control groups that utilized the 11+ in youth soccer populations reported significant improvements in various physical performance measures, such as balance, lower-limb power, speed, and agility (2,5,6,29). Due to the similar physiological demands of field hockey (53) it is, therefore, reasonable to draw correlations to these RCT studies and assume that the improvements in the current study were as a result of the program and not only due to a normal maturation effect over a ten-week period in this youth population. However, no index of maturity was assessed in this study. Secondly, the study utilized only female field hockey players from one high school to which the researchers had access to and monitor adherence. There is a need for future studies to broaden the scope to other sporting codes as well as male and female youth populations.

Conclusion

The FIFA 11+ program could be successfully implemented with high adherence within a female youth field hockey population over a period of nine weeks. The current findings suggest that the warm-up program could contribute to the improvement of physical performance in field hockey players, although results are presented with caution due to the lack of a control group. It is only the second study that utilized the 11+ with youth athletes in a sport other than football (32) and the first study to assess the contribution of the 11+ on physical performance in youth field hockey players.

Practical Implications

The 11+ program covers a variety of important motor skills and competencies, such as balance, strength, power, dynamic postural control, speed, and agility. These skills are inherent to many field-based high-intensity intermittent team sports, such as soccer, rugby, and field hockey. Coaches with varying levels of education can confidently utilize the 11+ program as a substitute for their regular warm-up before practice or games due to the readily available handbook and clear guidelines with descriptions of exercises and progressions at no extra cost.

Conflict of Interest

The authors of this article declare no conflict of interest. This article is part of a broader study that was approved by the Health Research Ethics Committee, Stellenbosch University (S21/07/131).

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Appendix 1 – Testing Procedure

Testing procedure information as provided to the participants for both pre- and post-testing.

Hockey Testing Procedure Information:

Please refer to the picture "Testing Map" on the next page as a reference for each step of the testing process.

Please arrive at your time right after school at the café on your testing day. For your testing you will be allocated into groups of 4. Your total measurement & testing duration will take approximately 60min. We will set up two stations per test so that the testing runs smoothly.

The procedure of the tests is the same for both the first- and second round of testing, but you will receive all instructions for the different tests on the day again by the assistants. All study assistants are knowledgeable about each test, so please feel free to ask questions at any time!

Station 1. An assistant will guide you through a structured warm-up before the testing commences, it will include general exercises and accelerations to prepare for the sprint and agility test → please ask questions if you are unsure about anything

Station 2. One by one you perform the Balance Test with each leg → you will be instructed on the correct execution of the test and 3 valid attempts per leg and direction will be recorded

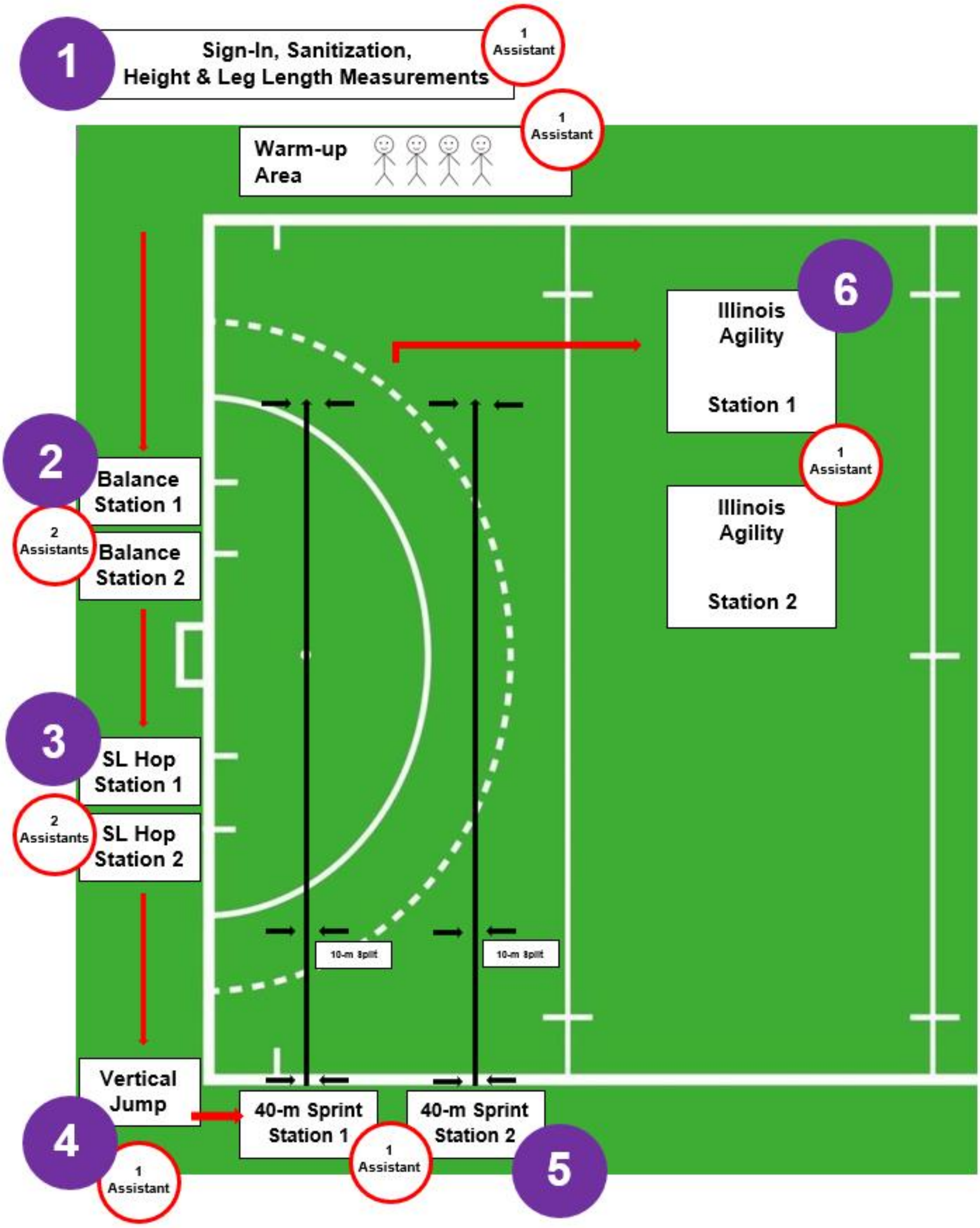
Station 3. Next up is the single leg hop test → you aim to jump as far as possible with each leg, three attempts per leg will be recorded

Station 4. The second jump test is a vertical jump test with a belt device → you aim to jump as high as possible, three attempts will be recorded

Station 5. The fourth test is a 40-m sprint test → the time will be measured by electronic speed gates through which you have to run through to make it accurate, 2 attempts will be recorded and the fastest of two attempts will be counted

Station 6. The last test is the Illinois Agility test → you will also complete, and record two attempts and we will count your fastest time with the use of speed gates

Testing Map


1
Sign-In, Sanitization,
Height & Leg Length Measurements
1 Assistant
Warm-up Area
1 Assistant
2
Balance Station 1
2 Assistants
Balance Station 2
3
SL Hop Station 1
2 Assistants
SL Hop Station 2
Vertical Jump
4
1 Assistant
40-m Sprint Station 1
1 Assistant
40-m Sprint Station 2
5
10-m Split
10-m Split
6
Illinois Agility Station 1
1 Assistant
Illinois Agility Station 2

CHANGES IN PHYSICAL PERFORMANCE AFTER A NINE-WEEK NEUROMUSCULAR WARM-UP PROGRAM PERFORMED SHOD OR BAREFOOT IN YOUTH FIELD HOCKEY PLAYERS: A RANDOMIZED CONTROLLED TRIAL

This article has been submitted to the Journal of Sports Sciences (Appendix 14) and is currently under review. This article is included herewith in accordance with the guidelines for authors of this journal. This does not imply that the article has been accepted or will be accepted in the said journal. As a result, the referencing style may differ from other chapters of the thesis. The co-authors of the article, Prof Ranel Venter (supervisor), as well as Dr Shaundré Jacobs and Prof Karsten Hollander (co-supervisors) hereby give permission to the candidate, Mr Jannick Schlewing, to include the article in his thesis.

Abstract

A growing body of literature addresses the public and scientific interest in barefoot vs. shod running and locomotion. However, most studies are limited to distance running and little is known about the effects of barefoot training in youth team sport athletes. This randomized controlled trial assessed the efficacy of a nine-week neuromuscular warm-up program (20min twice per week) on balance, functional jumping, speed, acceleration, and agility, in female youth field hockey players. Hockey players (16.2 ± 1.23 years), from three teams from a South African high school volunteered and consented to participation and were randomly assigned to either a barefoot or shod intervention group. Mixed model ANOVAs were conducted with the full data set of 34 participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects. No statistically significant differences ($p>0.05$) were found between the two groups with small ($ES \geq 0.2$) to medium ($ES \geq 0.4$) effect sizes. However, both groups significantly improved ($p<0.05$) their performance pre- to post intervention in all tests. Performing the warm-up program barefoot or shod appeared to be equally effective to improve physical performance in almost entirely habitually barefoot youth athletes.

Keywords

Team sport, warm-up, footwear, performance, adolescent, FIFA 11+

Background

A growing public and scientific interest address the differences in barefoot vs. shod running and has received support on both sides (Nigg, 2009; Lieberman *et al.*, 2010; Nigg and Enders, 2013; Warne and Gruber, 2017; Hannigan and Pollard, 2019; Hollander *et al.*, 2019). Most barefoot running studies include participants from distance running populations and investigate the effects on performance-, biomechanical-, physiological- and injury-related measurement outcomes (Lieberman *et al.*, 2010; Perkins, Hanney and Rothschild, 2014; da Silva Azevedo *et al.*, 2016).

Prevalent findings of studies with barefoot running compared to shod mostly report on acute differences which include more forefoot or midfoot foot strike patterns with greater plantar flexion at the ankle, greater cadence and shorter stride length, more knee flexion, as well as greater activation of the medial gastrocnemius (Lieberman *et al.*, 2010; Perkins, Hanney and Rothschild, 2014; da Silva Azevedo *et al.*, 2016; Azeem, Rathod and Tushar J., 2021). It has been suggested that forefoot strike patterns contribute to smaller collision forces and greater ankle compliance upon impact and may serve as a protecting mechanism for overuse injuries (Lieberman *et al.*, 2010; da Silva Azevedo *et al.*, 2016), but these findings have been criticized by other researchers in the field (Hamill and Gruber, 2017) and were not found in clinical studies (Hollander et al., 2017). Aforementioned changes due to barefoot running may, however, not be observed in all runners that transition from shod to barefoot, and, therefore, remain subject to individual adaptations (Mullen *et al.*, 2014; Tam, Tucker and Astephen Wilson, 2016). Consequently, long-term effects of habitual barefoot running have yet to be established due to limited evidence and lack of prospective research (Tam *et al.*, 2014; Hollander, Heidt, Van Der Zwaard, *et al.*, 2017). The likely individuality of adaptations is supported by studies in habitually barefoot adolescents that showed that inherent foot-strike mechanics, such as degree of ankle dorsiflexion, appear to be influenced by long-term footwear and age (Hollander *et al.*, 2018; Krabak *et al.*, 2021).

Little is known about the effects of barefoot training on physical performance in team field-sport athletes. South African female university netball players showed significant improvements in agility and ankle stability (de Villiers and Venter, 2014) following an eight-week barefoot training intervention. Players participated in netball-specific-drills two- to three-times per week, with either netball shoes or barefoot. These findings indicated promising results in favour of barefoot training for demanding multi-directional sport-specific actions and potentially injury reducing physical abilities, such as improved ankle stability. However, barefoot habits were not reported in this study. More research is needed in different team- and field sport populations and on various physical performance measures (such as agility and balance) to determine the potential usefulness of barefoot training in strength and conditioning environments in order to enhance sport performance. Based on research by Hollander et al. (2016; 2017), most South African children and adolescents have been classified as habitually barefoot. Barefoot habits need to be considered in conducting intervention studies in populations that are classified as either habitually barefoot or shod. A cross-sectional study by Zech and colleagues (2018) with children and adolescents showed that footwear habits impact motor skills development. Particularly jumping and balance skills appear to be positively influenced by regular barefoot physical activity in 6- to 10-year-olds. No study exists to date that examines physical performance-related adaptations in habitually barefoot youth team sport athletes following barefoot training compared to shod.

Strength and conditioning programs aim to develop several physical performance abilities, such as muscular strength and power, dynamic stability, and change-of-direction speed, to enhance the successful execution of fast-paced match demands (Fort-Vanmeerhaeghe *et al.*, 2016). It is generally accepted that integrative neuromuscular training (INMT) facilitates the development of these physical competencies in athletes of all ages with particular focus on adolescent sport to foster long-term athletic development (Hübscher *et al.*, 2010; Kiani *et al.*, 2010; LaBella *et al.*, 2011; Reis *et al.*, 2013; Steffen *et al.*, 2013; Ayala *et al.*, 2017). INMT incorporates fundamental- and sport-specific strength and conditioning activities, such as dynamic stability, plyometric and agility training, to enhance sport-related skills (Markovic and Mikulic, 2010; Myer *et al.*, 2011; Rameshkannan and Chittibabu, 2014; Fort-Vanmeerhaeghe *et al.*, 2016). Several warm-up programs, such as the FIFA 11+ (Steffen *et al.*, 2008; Soligard *et al.*, 2009), HarmoKnee (Kiani *et al.*, 2010), and KIPP (LaBella *et al.*, 2011), have been designed that utilize the principles of INMT to achieve performance adaptations and mitigate the costs associated with access to training facilities, physical trainers and time needed to implement thorough conditioning programs. It is suggested that neuromuscular warm-ups should be utilized before matches or team practices at least twice per week, for at least four weeks and between 15-20min minutes per session with high adherence (Steffen *et al.*, 2013).

Although literature supports the use of the FIFA 11+ neuromuscular warm-up program to improve performance measures and decrease injuries in youth team sport populations (Steffen et al., 2008, 2013; Soligard et al., 2009; LaBella et al., 2011; Longo et al., 2012; Reis et al., 2013; Owoeye et al., 2014; Ayala et al., 2017), most reports are on (youth) male and female football players in club settings. Little is known about youth team sport athletes in school sport environments and sports other than football. The study aimed to determine if a nine-week neuromuscular warm-up program implemented in habitually barefoot female youth field hockey athletes resulted in different adaptations to selected measures of physical performance when performed barefoot compared to shod. It was hypothesized that the barefoot group would perform significantly better than the shod group in physical performance, as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, between the barefoot and shod group.

Methods

Study design

This study utilized a randomized controlled trial with two intervention groups (barefoot and shod). Physical performance was assessed pre- and post a nine-week neuromuscular warm-up. Reporting of this study adhered to the CONSORT guidelines (Consolidated Standards of Reporting Trials) (Altman et al., 2001). The study was approved by the Health Research Ethics Committee of the institution (reference no: S21/07/131), registered *a priori* on the National Clinical Trials Registry, and conducted in accordance conducted according to the ethical guidelines and principles of the international Declaration of Helsinki.

Participants and Setting

For the sample of convenience three field hockey teams (n = 45) were approached for recruitment from a high school, namely the First Team (under-19A), under-19B, and under-16A teams, which represented the highest performing teams at the school. A total number of 40 players, aged 14 – 18 years, volunteered to participate. Prior to the start of the study the participants provided written assent and parental consent. It was explained that participation was voluntary and that participants could drop out of the study at any time without consequences. Five players from the under-19B and under-16A team simultaneously competed in other school sports during school field hockey practice times and could not participate in the study. At pre-testing, the players completed their pre-season conditioning program, played trials, and were selected into their teams. Hence, the players had the level of fitness required to play competitive matches. The players were not familiar with the 'FIFA 11+' program prior to the start of the intervention. The high school is a female-only school and is ranked in the top 15 for field hockey in the country (SuperSport School ranking, 2021 and 2022 season).

The exclusion criteria were 1) suffered a head- or lower-limb injury within three months prior to the intervention or 2) indicated a current injury during the time of testing and intervention that prevented full participation in all organised field hockey practices. Barefoot habits were confirmed with a habitual barefoot questionnaire (three-point Likert scale) (Hollander *et al.*, 2016; 2017) (Appendix 1).

Intervention Program

The established FIFA 11+ warm-up program was chosen for this study (Appendix 2). The 11+ is a 20-min soccer-specific warm-up program, developed and endorsed by the Medical Assessment Centre of the Federation Internationale de Football Association (FIFA) (Soligard *et al.*, 2009). Recent systematic reviews, meta-analysis and randomized controlled trials in various age groups, males and females, and performance levels, concluded that the 11+ warm-up may enhance several physical performance measures (Reis *et al.*, 2013; Steffen *et al.*, 2013; Owoeye *et al.*, 2014; Ayala *et al.*, 2017; Zarei *et al.*, 2018) and decrease lower limb injuries between 29% to 39% (Barengo *et al.*, 2014; Sadigursky *et al.*, 2017; Thorborg *et al.*, 2017; Al Attar and Alshehri, 2019). The wide body of literature and the similar physiological demands of soccer and field hockey (Spencer *et al.*, 2004) make the 11+ program a suitable program for the current study. Further, the readily available coaching manual (https://www.yrsa.ca/fifa-11.html) makes the program user friendly for coaches of all education levels.

Players were instructed to continue with their typical hockey practices, matches and aerobic running but to refrain from additional fitness activities that included balance, jumping, and plyometric exercises. Prior to the start of the intervention, the two conditioning coaches that implemented the intervention sessions attended a workshop conducted by the principal investigator to explain the program and testing protocol. The conditioning coaches carried out the warm-up program twice per week with their designated teams, either at school hockey practice or before a match on the warm-up grass area next to the school's field hockey field. Over the nine weeks, 18 warm-up sessions were implemented (Figure 1). The data of participants was considered for the statistical analysis if players completed ≥80% attendance of the intervention sessions (Steffen *et al.*, 2013).

Outcomes

The primary outcome of the study was improvements in physical performance following a nine-week intervention performed in either barefoot- and shod conditions with a field-based testing battery one week prior to the start- and one week immediately after intervention. The nine-week intervention duration is in line with the above-mentioned FIFA 11+ studies (Reis *et al.*, 2013; Steffen *et al.*, 2013; Owoeye *et al.*, 2014; Ayala *et al.*, 2017; Zarei *et al.*, 2018) that showed improvements in physical performance in youth football. The testing set-up consisted of five stations and could be completed by each team in approximately 60 minutes. The testing was conducted on the school's field hockey turf and in the participants regular field hockey training shoes.

The conducted tests were 1) Y-Balance test (cm) (Plisky *et al.*, 2006; Shaffer *et al.*, 2013), 2) Single-leg Hop test (cm) (Orishimo *et al.*, 2010; Sueyoshi *et al.*, 2017), 3) Counter-movement Jump (cm) (Claudino *et al.*, 2017), 4) 40-m sprint with 10-m split (sec) (Durandt *et al.*, 2007), and 5) Illinois Agility (sec) (Kilding, Tunstall and Kuzmic, 2008; Katis and Kellis, 2009; Daneshjoo *et al.*, 2013). The order was determined to test from least to most fatiguing, to not affect testing results due to premature fatigue from a previous test (Winter *et al.*, 2006). The participants received a document with the detailed testing procedure and lay-out of testing stations to ensure fast progression on their designated days of testing (Appendix 3). The purpose of the study was communicated to the coaches and players as required from the school. The coaches and principal investigator conducted testing at the same stations for pre- and post-testing and gave verbal instructions and visual demonstrations for each test. A six-minute standardized warm-up consisting of jogging, sprinting, hops, and dynamic stretches was completed by each participant under supervision of the researcher. All tests were performed in the participants' regular training shoes. The protocol for each test is presented in Table 1.

Table 1. Protocol for each physical performance test, pre- and post-intervention.

Test	Outcome	Validity & Reliability	Protocol
Y-Balance	Balance Postural control	(Gribble, Hertel and Plisky, 2012; Shaffer *et al.*, 2013)	Six practice trials per leg. Maximum and average scores out of three valid attempts with each foot in the anterior-, posterolateral-, and posteromedial direction, starting with the right and then the left leg. An attempt was valid when participants maintained foot contact with stance foot, kept contact with both hands on their waist, did not shift bodyweight onto reach foot, and returned to bilateral stance under control.
Single-leg Hop for distance	Postural control Lower-limb power (unilateral)	(Noyes, Barber and Mangine, 1991; Chmielewski, 2011; Xergia *et al.*, 2013; Xergia, Pappas and Georgoulis, 2015)	One practice jump per leg. Maximum and average scores of three valid attempts with each foot, starting with the right and then the left leg. An attempt was valid when participants "stuck" a one-foot landing without requiring extra hops to balance, kept contact with both hands on their waist, and not use contralateral leg for stance support.
Counter-movement Jump	Lower-limb power (bilateral)	(Claudino *et al.*, 2017)	One practice trial. Maximum score of three valid trials. An attempt was valid when participants completed a full jump with maximum effort and landing with both feet whilst maintaining contact with both hands on their waist at all times.
40-m Sprint with 10-m Split	Maximum linear speed Acceleration	(Young *et al.*, 2008)	One practice acceleration. Fastest time out of two valid attempts with two minutes rest between attempts. All participants started in a two-point split stance start position. An attempt was valid when participants sprinted through the 10-m and 40-m timing gates with maximum effort.
Illinois Agility	Change-of-Direction speed	(Hachana *et al.*, 2013; Raya *et al.*, 2013)	One slow practice trial. Fastest out of two valid attempts with two minutes rest between attempts. All participants started in a laying supine position on their stomach with their hands on the ground besides their shoulders. An attempt was valid when participants completed the course in the correct order and by sprinting with maximum effort around the cones
Anthropometric measurements	Height		Portable sliding height scale (in 0,5cm units).
	Limb length	(Plisky *et al.*, 2006)	Distance from the most inferior aspect of the anterior superior iliac spine to the most distal aspect of the medial malleolus (in 0,1cm units). Limb length was measured to normalize the Y-Balance test results for each participant. Absolute reach distance (in cm) was used for anterior, posteromedial- and posterolateral reach directions. Composite score was normalized and expressed as a percentage by calculating three reach distances / (3x) limb length (anterior superior iliac spine to medial malleolus) x 100 for each limb.

Sample size and randomisation

The minimum sample size (n = 34) was calculated (alpha = 0.05, power = 0.80) based on previous studies with similar measurement outcomes in male football players (Souhaiel and Denis, 2001; Daneshjoo *et al.*, 2012; Sueyoshi *et al.*, 2017). Immediately after pre-testing, a randomization schedule (R software) (Uschner *et al.*, 2018) provided by the institution assigned the participants to the barefoot group or shod group.

Statistical Methods

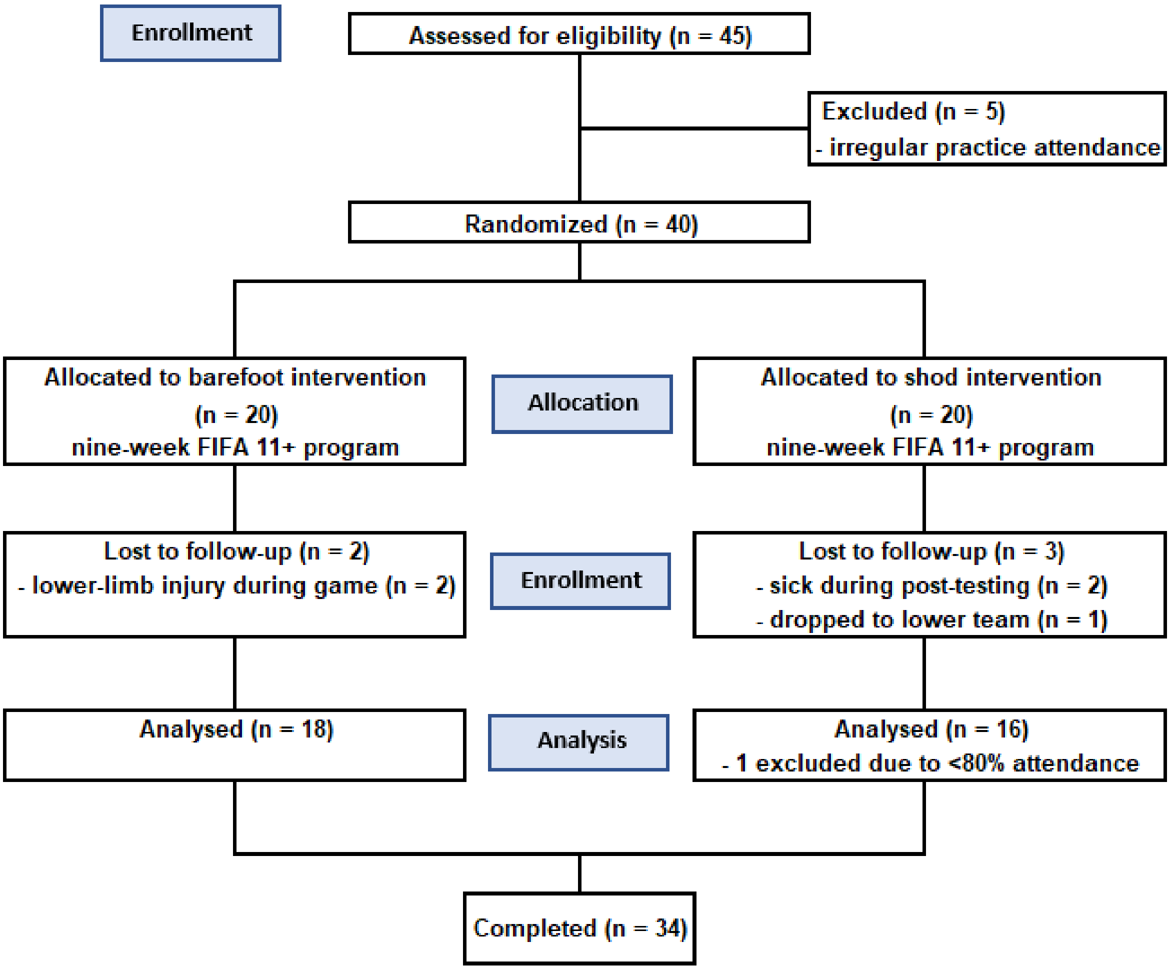
Mixed model ANOVA's were conducted with the participants as random effect (to account for repeated measurements), and intervention, time, limb side as fixed effects. Normal probability plots were inspected to check normality of the residuals, and in all cases found to be acceptable. Post hoc testing was done using Fisher Least Significant Difference (LSD), to reduce the likelihood of type II errors. Cohen's *d* and Hedges *g* effect sizes were calculated and represented as follows: small (d ≥ 0.2), medium (d ≥ 0.4), and large (d ≥ 0.8) (McLeod, 2019).

Results

Participants

Recruitment was conducted in February 2022 and players were given two weeks to respond to the invitation to participate. Pre-intervention testing (7 – 9 March 2022) was conducted with a total of 40 participants that fulfilled the inclusion criteria. The randomization schedule allocated 20 participants to the barefoot group and 20 participants to the shod group. The nine-week intervention started on 14 March 2022 and ended on 12 May 2022. The intervention took place on the school's warm-up grass area. Post-testing was conducted from 16 – 18 May 2022. The testing was conducted on the school's field hockey turf in the participant's regular training shoes. The full dataset of 34 participants (mean age 16.12 ± 1.23 SD, mean height 164.8 ± 6.8 SD, barefoot n = 18, shod n = 16) were considered for the final statistical analysis (see Figure 1). Groups did not differ in age (p = 0.73) and body height (p = 0.08). The compliance rate for the nine-week study period was 95,6%. Out of the 34 final participants, 31 were classified as habitually barefoot (barefoot: n = 17; shod: n = 14) by means of a previously validated barefoot questionnaire (Appendix 1) (Hollander et al., 2016; 2017).

Figure 1. Participant flow diagram.



Outcomes

The outcomes and comparison for each physical performance test for the barefoot- and shod intervention groups are presented in Table 2, 3, and 4 and listed below. There were no statistically significant differences at pre-testing between the two footwear groups.

Balance test

Table 2 shows the results for the pre- and post-intervention assessments for the barefoot and shod intervention groups for the Y-Balance test (YBT). Significant improvements YBT were observed for most reach directions for both maximum (furthest reach of three trials) and average values (average reach of three trials) in the barefoot group ($P = \leq 0.01 – 0.04$, $ES = 0.38 – 0.83$) and shod group ($P = \leq 0.01 – 0.04$, $ES = 0.37 – 0.7$) (see Table 3). YBT performance improved in most of the three reach directions (anterior, posteromedial, posterolateral) and composite scores in both legs by 2.6% - 6.7% in the barefoot group and by 2.5% - 7.2% in the shod group. There were no statistically significant differences in improvements between the barefoot and shod intervention group in any reach direction ($P = 0.08 – 0.86$, $ES = 0.08 – 0.54$). Asymmetries between limbs in the anterior reach direction in the YBT (barefoot: $P = 0.26 – 0.41$, $ES = 0.14 – 0.24$; shod: $P = 0.28 – 0.82$, $ES = 0.09 – 0.41$) did not decrease significantly in either group.

Table 2. Results of the Y-Balance test for pre- and post-testing of the barefoot and shod groups and post-test comparisons between groups.

			Barefoot Intervention				Shod Intervention				BF vs SH Post-test	
Distance	**Direction**	**Lower Extremity**	**Pre-test (in cm) Mean ± SD**	**Post-test (in cm) Mean ± SD**	**P-value**	**Effect size**	**Pre-test (in cm) Mean ± SD**	**Post-test (in cm) Mean ± SD**	**P-value**	**Effect size**	**P-value**	**Effect size**
Maximum Reach	ANT	Right	59 ± 5.7	61.3 ± 4.2	0.03	0.45 (med)	60.9 ± 6.1	62.4 ± 4	0.17	0.28 (small)	0.53	0.27 (small)
		Left	57.7 ± 6.1	60.4 ± 5.2	<0.01	0.48 (med)	61.1 ± 5.8	62.7 ± 4.1	0.14	0.32 (small)	0.22	0.47 (med)
	PM	Right	86.1 ± 9.3	90.7 ± 6.4	<0.01	0.56 (med)	87.8 ± 9.6	94.1 ± 8.3	<0.01	0.68 (med)	0.24	0.45 (med)
		Left	88.1 ± 8.3	91.9 ± 8	<0.01	0.45 (med)	90.8 ± 8.6	94.9 ± 7.8	<0.01	0.49 (med)	0.3	0.37 (small)
	PL	Right	93.6 ± 7.6	97.5 ± 5.3	<0.01	0.77 (large)	97.2 ± 7.9	100 ± 7.3	0.04	0.37 (small)	0.34	0.38 (small)
		Left	92 ± 9	95.1 ± 6.9	0.02	0.38 (small)	97.3 ± 7.6	99.7 ± 8	0.08	0.3 (small)	0.08	0.6 (med)
	COMP	Right	91.4 ± 6.8	95.7 ± 5.3	<0.01	0.68 (med)	92 ± 6.2	96 ± 7.3	<0.01	0.78 (large)	0.86	0.08 (neg)
		Left	91 ± 7.8	94.8 ± 7	<0.01	0.49 (med)	93.4 ± 4.6	96.5 ± 4.3	<0.01	0.68 (med)	0.41	0.28 (small)
Average Reach of 3 Trials	ANT	Right	57.3 ± 5.3	58.8 ± 3.8	0.15	0.32 (small)	58.8 ± 6.3	60.3 ± 4.5	0.19	0.26 (small)	0.42	0.35 (small)
		Left	56.2 ± 6.6	58.4 ± 5.2	0.04	0.36 (small)	59.4 ± 5.7	61 ± 4	0.15	0.32 (small)	0.16	0.54 (med)
	PM	Right	82.3 ± 8.7	87.8 ± 6.5	<0.01	0.7 (med)	85.3 ± 10.1	90.8 ± 8.2	<0.01	0.58 (med)	0.31	0.39 (small)
		Left	84.6 ± 8.7	88.8 ± 7.4	<0.01	0.51 (med)	87.4 ± 9.4	92 ± 7.7	<0.01	0.52 (med)	0.28	0.41 (med)
	PL	Right	90.9 ± 6.8	94.6 ± 6	<0.01	0.83 (large)	94.6 ± 8.4	97.9 ± 7.6	0.02	0.39 (small)	0.22	0.46 (med)
		Left	89.4 ± 8.5	93.2 ± 6.7	<0.01	0.48 (med)	94.6 ± 8.3	97.1 ± 7.8	0.06	0.31 (small)	0.14	0.53 (med)
	COMP	Right	88.3 ± 6.7	92.5 ± 5.7	<0.01	0.65 (med)	89.3 ± 6.7	93.2 ± 4	<0.01	0.68 (med)	0.76	0.13 (neg)
		Left	88.1 ± 8	92.1 ± 7.1	<0.01	0.51 (med)	90.4 ± 4.9	93.8 ± 4.4	<0.01	0.7 (med)	0.43	0.28 (small)
Maximum Asymmetry	ANT	Right/Left	3.4 ± 3.6	3 ± 2.7	0.41	0.14 (neg)	2.7 ± 1.6	2 ± 1.4	0.28	0.41 (med)	0.27	0.44 (med)
Average Asymmetry	ANT	Right/Left	3.5 ± 3.9	2.7 ± 2.5	0.26	0.24 (small)	2.8 ± 1.9	3 ± 1.9	0.82	0.09 (neg)	0.8	0.1 (neg)

SD = Standard Deviation; med = medium; neg = negligible; ANT = anterior; PM = posteromedial; PL = posterolateral; COMP = composite (expressed as % score); BF = Barefoot; SH = Shod

Jump tests

Table 3 and 4 show the results for the pre- and post-intervention assessments for the barefoot and shod intervention groups for the Single-leg hop test for distance (SLH) and Counter-movement Jump (CMJ). Significant improvements were observed in the SLH for both maximum (furthest of three trials) and average values (average of three trials) in the barefoot group ($P = \leq 0.01 – 0.03$, ES 0.39 – 0.45) and shod group ($P = \leq 0.01 – 0.01$) (see Table 4). SLH distance improved in both legs by 4.4% - 9.6% in the barefoot and by 6.4% - 6.9% in the shod group. There were no statistically significant differences in improvements between the barefoot and intervention group ($P = 0.34 – 0.81$, ES = 0.23 – 0.36). Asymmetries in the SLH distance (barefoot: $P = 0.54 – 0.75$, ES = 0.04 – 0.09; shod: 0.27 – 0.43, ES = 0.21 – 0.4) did not decrease significantly in neither barefoot nor shod group. Significant improvements were recorded for the CMJ (barefoot: $P = 0.03$, ES = 0.31; shod: $P = \leq 0.01$, ES = 0.74) with a 4.4% increase in the barefoot and a 7.3% in the shod group. There were no statistically significant differences between the barefoot and shod group ($P = 0.62$, ES = 0.16).

Sprint test

Table 4 shows the results for the pre- and post-intervention assessments for barefoot and shod intervention groups for 40-m Sprint with 10-m split. There was an increase in 40-m Sprint (barefoot: $P = \leq 0.01$, ES = 0.21; shod: $P = \leq 0.01$, ES = 0.4) and 10-m split (barefoot: $P = \leq 0.01$, ES = 0.7; shod: $P = \leq 0.01$, ES = 1.18) performance. 40-m Sprint time decreased by 1.6% in the barefoot and 1.8% in the shod group, and 10-m split time by 4% in the barefoot and by 5.2% in the shod group. There were no statistically significant differences in improvements in 40-m sprint ($P = 0.25$, ES = 0.38) and 10-m split ($P = 0.34$, ES = 0.3) between the barefoot and shod intervention group.

Agility test

Table 4 shows the results for the pre- and post-intervention assessments for barefoot and shod intervention groups for the Illinois Agility test. There was an increase in agility performance in both intervention groups (barefoot: $P = \leq 0.01$, ES = 0.64; shod: $P = \leq 0.01$, ES = 0.74). Illinois Agility time decreased by 3.2% in the barefoot and 4.3% in the shod group. There were no significant differences in improvements between the intervention groups ($P = 0.78$, ES = 0.11).

Table 3. Single-leg Hop test for distance results pre- and post-testing for intervention barefoot- and intervention shod group and post-testing comparison between groups.

		Barefoot Intervention				Shod Intervention				BF vs SH Post-test	
Jump Distance	**Lower Extremity**	**Pre-test (in cm) Mean ± SD**	**Post-test (in cm) Mean ± SD**	**P-value**	**Effect Size**	**Pre-test (in cm) Mean ± SD**	**Post-test (in cm) Mean ± SD**	**P-value**	**Effect Size**	**P-value**	**Effect size**
Maximum	Right	120.7 ± 16.3	126 ± 15	0.08	0.33 (small)	123.3 ± 15.5	131.2 ± 16.9	0.01	0.47 (med)	0.4	0.32 (small)
	Left	115.9 ± 23.9	126.1 ± 21.2	<0.01	0.44 (med)	122.3 ± 15.2	130.6 ± 13.5	<0.01	0.56 (med)	0.47	0.24 (small)
Average of 3 Trials	Right	113.9 ± 14.9	119.9 ± 15.1	0.03	0.39 (small)	118 ± 16	125.8 ± 16.8	<0.01	0.46 (med)	0.34	0.36 (small)
	Left	109.9 ± 23.2	120.5 ± 23	<0.01	0.45 (small)	117 ± 14.8	125.1 ± 14.4	<0.01	0.53 (med)	0.81	0.23 (small)
Maximum Asymmetry	Right/Left	9.6 ± 13	10.8 ± 11.2	0.54	0.09 (neg)	7.6 ± 6.6	5.4 ± 4.2	0.27	0.4 (small)	0.11	0.61 (med)
Average Asymmetry	Right/Left	9.4 ± 11.2	9.6 ± 11.4	0.75	0.04 (neg)	6.75 ± 5.7	5.6 ± 4.5	0.43	0.21 (small)	0.21	0.43 (med)

SD = Standard Deviation; med = medium; neg = negligible; BF = Barefoot; SH = Shod

Table 4. Counter-movement Jump, Sprint, and Agility test results pre- and post-testing for intervention barefoot- and intervention shod group and post-testing comparison between the groups.

Test		Barefoot Intervention				Shod Intervention				BF vs SH Post-test	
		Pre-test Mean ± SD	**Post-test Mean ± SD**	**P-value**	**Effect Size**	**Pre-test Mean ± SD**	**Post-test Mean ± SD**	**P-value**	**Effect Size**	**P-value**	**Effect size**
CMJ (cm)		38.7 ± 4.7	40.4 ± 6	0.03	0.31 (small)	38.5 ± 4	41.3 ± 3.2	<0.01	0.74 (med)	0.62	0.16 (small)
Sprint	10-m Split (sec)	2.06 ± 0.1	1.98 ± 0.13	<0.01	0.7 (med)	2.04 ± 0.09	1.94 ± 0.07	<0.01	1.18 (vLarge)	0.34	0.3 (small)
	40-m Split (sec)	6.5 ± 0.42	6.4 ± 0.48	<0.01	0.21 (small)	6.36 ± 0.26	6.25 ± 0.26	<0.01	0.4 (med)	0.25	0.38 (small)
Illinois Agility (sec)		17.9 ± 0.89	17.35 ± 0.78	<0.01	0.64 (med)	18.02 ± 1.15	17.27 ± 0.79	<0.01	0.74 (med)	0.78	0.11 (neg)

CMJ = Counter-movement Jump; SD = Standard Deviation; med = medium; vLarge = very large; BF = Barefoot; SH = Shod

Harm

No harm or unintended effects (injuries, or other) were reported throughout the study.

Discussion

The main finding of this randomized controlled trial was that a neuromuscular warm-up produced similar positive effects on five physical performance tests when conducted in barefoot- or shod conditions in a sample of almost entirely habitually barefoot female adolescent field hockey players. This was the first study to assess physical performance in a youth team sport population classified as predominantly habitually barefoot following a barefoot warm-up program. The evaluation and transition for the barefoot group to performing the intervention without shoes must be interpreted with caution, as both groups were classified as growing up habitually barefoot. Hollander and colleagues (2016; 2017) found that growing up habitually barefoot has significant effects on the development of foot morphology, including an increase in foot arch angles, and motor performance. Zech et al. (2018) found that children who grow up habitually barefoot compared to shod show superior balance and jumping performance during childhood, with greater jump distances persisting during adolescents.

This study utilized measures of balance, dynamic stability and agility (YBT, SLH, and Illinois Agility), similar to de Villiers and Venter‘s (2014) study in female university netball players. De Villiers and Venter (2014) showed a greater increase in agility and ankle stability in the barefoot group compared to the shod group. The current study showed similar outcomes in the barefoot- and shod groups. It should be noted that the footwear habits of the adult netball players were not reported, which is different from the youth field hockey players in the current study. Differences in outcomes between the two studies could also be partially attributed to the session durations and exercise selections of the two study protocols. The netball study utilized netball-specific agility drills with the barefoot group gradually increasing their footwear exposure over the eight-week intervention until they completed 30-45min of barefoot training in the final week for all exercises (de Villiers and Venter, 2014). The neuromuscular warm-up utilized in this study was 20min per session and included only some exercises in the dynamic running parts (Part 1 and Part 3) that were particularly aimed at changing direction quickly, and progressively challenging the athletes' balance (Part 2) (Appendix 1) (Soligard *et al.*, 2009). The other exercises that comprise the 11+ program, are aimed at increasing strength, lower-limb power, and core stability (Part 2) (Soligard *et al.*, 2009). It was suggested that the improved balance in the netball barefoot group may have been caused by greater proprioceptive abilities due to strengthening of the smaller intrinsic musculature of the feet in the barefoot group (de Villiers and Venter, 2014). Barefoot training is believed to employ more lower limb muscles during physical activity, changing the mechanical properties of small and large muscles surrounding the ankle joint and foot (de Villiers and Venter, 2014). The smaller, intrinsic muscles within the foot, stabilize the ankle during dynamic movement (Nigg, 2009; Nigg and Enders, 2013). These intrinsic muscles may also be strengthened through an increase in proprioception, as sensory feedback between the plantar surface of the foot and the ground stimulates the central nervous system to enhance stability and avoid injury by increasing activation (Lieberman, 2012).

Some evidence suggests that there could be a decrease in dynamic stability when immediately transitioning from shod to barefoot running on a treadmill, which may heighten injury risk during the initial transition phase (Ekizos, Santuz and Arampatzis, 2017). However, this study was descriptive and limited to the acute transition from shod to barefoot and did not have an intervention to determine possible long-term effects on dynamic stability, nor did it have gradual exposure. A recent eight-week randomized control study showed that running barefoot compared to shod may lead to a decrease in local dynamic running stability following weekly 15min treadmill running (Hollander, Hamacher and Zech, 2021). While this study may provide some insight into longer-term implications on measurement outcomes such as running stability, it only utilized treadmill running at an intervention frequency of one session per week for 15min. In comparison, the field hockey players in the current study performed various running-, multi-directional-, strength-, and balance exercises on a grass surface in their school sport environment and resulted in improved balance and postural control. De Villiers and Venter (2014) highlighted that no participant had to discontinue participation due to injuries or discomfort experienced during the eight-week barefoot netball-specific exercises and is congruent with the current study. Hence, it is reasonable to assume that a gradual increase in exposure to barefoot conditions in sport-specific drills may not heighten injury risk.

There was a tendency, although not significant, for greater improvements in the YBT in the barefoot group, despite the significantly shorter session durations over a similar time span (eight- vs. nine-weeks) as compared to the netball study. This can suggest that balance overall (in both groups) and specifically in barefoot conditions can be improved with the inclusion of only few specific balance exercises, as presented in the 11+ program (Part 2). This is significant, as, previously mentioned, children who grow up habitually barefoot compared to shod show greater balance and jumping ability (Zech *et al.*, 2018). The results show that further training in barefoot conditions may benefit more to improve balance ability compared to shod. Such considerations are important for the design of strength and conditioning- and injury prevention programs, as impaired balance is generally correlated with an increased risk of lower limb injury, particularly ankle and knee sprains (Plisky *et al.*, 2006). Including some barefoot balance and dynamic stability exercises in a team's warm-up may have injury protecting effects and adds more support for the utilization of structured neuromuscular warm-ups.

The improvements in agility were accompanied with improvements in the CMJ and sprint performance (40-m and 10-m split) in both barefoot and shod groups in this sample of field hockey players with no significant difference between the two groups. Field hockey consists of repeated periods of high intensity play, and is characterized by walking, jogging, sprinting, and rapid change-of-direction efforts, which requires lower-limb power and speed (Spencer *et al.*, 2004). Vertical jump height, linear sprinting and agility tests share strong correlations to match-performance but are generally considered as independent locomotor skills that should be assessed independently (Vescovi and McGuigan, 2008; Claudino *et al.*, 2017; Lombard *et al.*, 2021). Previous studies that utilized neuromuscular warm-up programs have reported improvements in variations of vertical jump tests, linear sprinting, and agility (Reis *et al.*, 2013; Ayala *et al.*, 2017; Zarei *et al.*, 2018; Isla *et al.*, 2021). The significant improvements in the CMJ, sprint, and Illinois Agility tests indicate an improvement in physical performance in both intervention groups. The lack of difference in improvements between the groups may again be partially explained by the classification of both groups growing up habitually barefoot and the shorter session durations of 20min per session. Longer sessions may be necessary to reveal possible different adaptations in the barefoot group, as well as the comparison between habitually barefoot and shod groups. The overall improvements in both groups are encouraging and can show coaches the effectiveness of a targeted neuromuscular warm-up twice per week on physical performance without the addition of longer strength and conditioning programs. Further, the application of the program on grass appears to have had no negative effect on the performance measurements. This is supported by previous research that showed that plyometric training successfully improved squat jump and CMJ performance in volleyball players on both grass and concrete surfaces (Ramlan, Pitil and Wahed, 2018).

The findings of the present study provide some insight that barefoot training may lead to similar adaptations in physical performance in habitually barefoot youth sport populations. It may allow coaches to offer athletes the choice to complete training barefoot (where applicable), in line with the athlete's habitual barefoot habits, and without compromising desired performance adaptations, such as speed and agility.

Limitations

The first limitation is that the sample was classified as predominantly habitually barefoot (31 out of 34 participants). Future studies should include participants classified as habitually non-barefoot as well to better compare research findings for the broader youth team sport environment. Secondarily, the convenience sample only consisted of youth athletes from one high school. Therefore, research findings cannot be generalised to all other populations. Thirdly, no index of maturity was assessed in this study. Lastly, the program was administered as a 20min warm-up program (as per the protocol) twice per week over a nine-week period. Future studies could utilize programs with longer session durations and more weeks of training to reveal potential different long-term adaptations to barefoot conditions in a strength and conditioning program.

Practical Implications

The study adds to the growing body of literature to support the utilization of a structured neuromuscular warm-up program, such as the 11+, to improve physical performance in team sport athletes, irrespective of footwear conditions (Reis *et al.*, 2013; Steffen *et al.*, 2013; Owoeye *et al.*, 2014; Ayala *et al.*, 2017; Zarei *et al.*, 2018). Coaches and trainers can allow their athletes the footwear condition of their choice to complete a team's warm-up program without compromising the desired performance adaptations. Youth athletes that grow up habitually barefoot may prefer to train barefoot and should be encouraged to do so under their preferred conditions.

Conclusion

The present study suggests that a nine-week neuromuscular warm-up program does not lead to different adaptations when performed barefoot compared to shod in a habitually barefoot sample. Both barefoot and shod groups showed similar improvements in all physical performance tests that measured balance, postural control, lower-limb power, linear speed, and change-of-direction speed (agility). The presented findings add a new dimension to the growing academic interest in barefoot research by including a youth population from a field-based team sport (field hockey).

Geolocation information

This study was conducted at a Stellenbosch High School, Western Cape, South Africa.

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Author's Contributions

The four authors (JS, SDJ, KH, REV) participated in the conception and design of the study as well as drafting the manuscript. JS was responsible for the implementation of the intervention and collection of data. The four authors have contributed to read and approved the final manuscript.

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Availability of data

The datasets used and/or analysed during the current study are not publicly available. The data are available from the corresponding author on reasonable request.

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Appendixes

Appendix 1 – Barefoot Questionnaire

Barefoot questionnaire to identify habitual barefoot habits

Name:

Vraelys oor hoe gereeld jy kaalvoet is
Questionnaire on how often you are barefoot

Omkring hoe baie jy kaalvoet loop by die skool:
Circle how often you are barefoot at school:

As dit warm is
When it is warm

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

As dit koud is
When it is cold

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

Omkring hoe baie jy kaalvoet is tydens sport:
Circle how often you are barefoot during sport activities:

As dit warm is
When it is warm

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

As dit koud is
When it is cold

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

Omkring hoe baie jy kaalvoet is in en om die huis:
Circle how often you are barefoot in and around the home:

As dit warm is
When it is warm

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

As dit koud is
When it is cold

Amper nooit Almost never	Helfte van die tyd Half of the time	Amper altyd Almost always

Omkring hoe baie jy kaalvoet was toe jy in die laerskool was:
Circle how often you were barefoot while at primary school:


As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*


As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was tydens sport in die laerskool:
Circle how often you were barefoot during sport activities at primary school:


As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*


As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was in en om die huis toe jy in die laerskool was:
Circle how often you were barefoot in and around the home while you were at primary school:


As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*


As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Baie dankie! Thank you!

Appendix 2 – FIFA 11+ Program

The FIFA 11+ warm-up program, provided by FIFA, with a summary of all exercises, progressions, and repetitions.

Appendix 3 – Testing Procedure

Testing procedure information as provided to the participants for both pre- and post-testing.

Hockey Testing Procedure Information:

Please refer to the picture “Testing Map” on the next page as a reference for each step of the testing process.

Please arrive at your time right after school at the café on your testing day. For your testing you will be allocated into groups of 4. Your total measurement & testing duration will take approximately 60min. We will set up two stations per test so that the testing runs smoothly.

The procedure of the tests is the same for both the first- and second round of testing, but you will receive all instructions for the different tests on the day again by the assistants. All study assistants are knowledgeable about each test, so please feel free to ask questions at any time!

Station 1. An assistant will guide you through a structured warm-up before the testing commences, it will include general exercises and accelerations to prepare for the sprint and agility test → please ask questions if you are unsure about anything

Station 2. One by one you perform the Balance Test with each leg → you will be instructed on the correct execution of the test and 3 valid attempts per leg and direction will be recorded

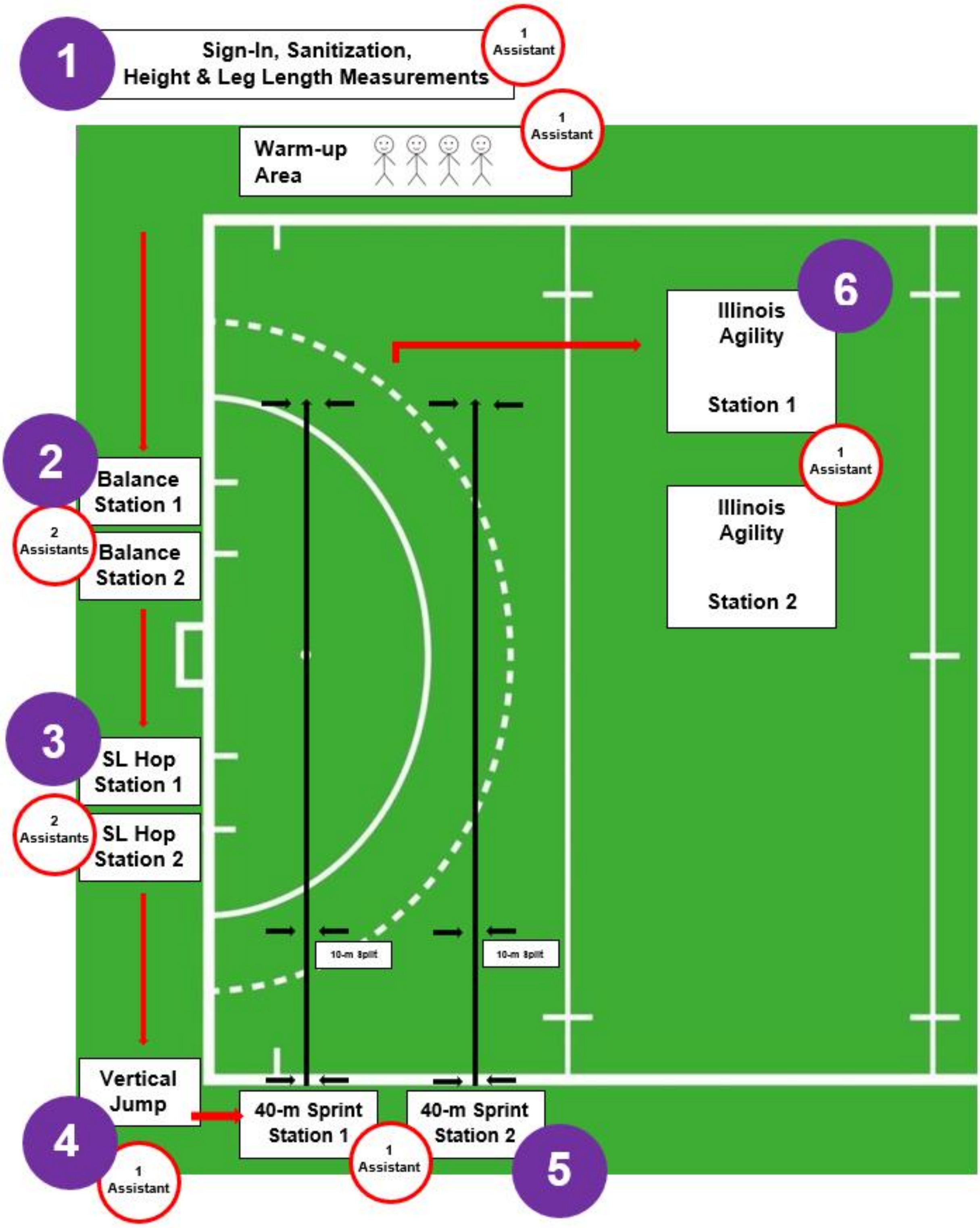
Station 3. Next up is the single leg hop test → you aim to jump as far as possible with each leg, three attempts per leg will be recorded

Station 4. The second jump test is a vertical jump test with a belt device → you aim to jump as high as possible, three attempts will be recorded

Station 5. The fourth test is a 40-m sprint test → the time will be measured by electronic speed gates through which you have to run through to make it accurate, 2 attempts will be recorded and the fastest of two attempts will be counted

Station 6. The last test is the Illinois Agility test → you will also complete, and record two attempts and we will count your fastest time with the use of speed gates

Testing Map


1
Sign-In, Sanitization,
Height & Leg Length Measurements
1 Assistant
Warm-up Area
1 Assistant
2
Balance Station 1
2 Assistants
Balance Station 2
3
SL Hop Station 1
2 Assistants
SL Hop Station 2
Vertical Jump
4
1 Assistant
40-m Sprint Station 1
1 Assistant
40-m Sprint Station 2
5
10-m Split
10-m Split
6
Illinois Agility Station 1
1 Assistant
Illinois Agility Station 2

CHAPTER FIVE

CONCLUSION

A. INTRODUCTION

Neuromuscular (NM) warm-up programs for team sports were developed to address a high burden of injury and enhance performance with minimal additional time investment or costs associated with equipment and irrespective of the coaches' level of education (LaBella et al., 2011; Soligard et al., 2009; Steffen et al., 2008). A broad body of literature exists on the injury preventing- and performance enhancing benefits of neuromuscular warm-up programs in male and female athletes in both youth and adult team sports (Chapter two, Table 2.2 and 2.3). In the context of youth team sport research, warm-up programs were mainly implemented by a large margin in football in mainly club sport settings, followed with minimal research in basketball and handball in male and female populations. There is currently a lack of research in youth team sports other than football and in school sport settings that represent a large platform of participation for South African youth. Further, it is also unclear if the effects on neuromuscular performance following a warm-up intervention differ with barefoot- or shod conditions. This is of interest for the South African context, as most South African children have previously been classified as growing up habitually barefoot (Hollander et al., 2016; 2017) and differ in footwear habits compared to similar studies with youth populations in Western countries. The barefoot questionnaire in the current study revealed that 31 out of 34 participants were classified as growing up habitually barefoot and is in line with the findings by Hollander et al. (2016; 2017). The current study, firstly, set out to determine whether a NM warm-up program could be successfully implemented in a youth field hockey environment to improve physical performance- and reduce injury risk factors, and secondly, whether physical performance adaptations differed in barefoot or shod conditions following a nine-week intervention. Physical performance was measured by a field-based testing battery consisting of balance, functional jump performance, lower-limb power, acceleration and speed, and agility measurements.

This chapter of the thesis contains a final summary regarding the outcomes of the study as discussed in the two articles (Chapter four), followed by the identified limitations and suggestions for future research.

B. IMPLEMENTATION OF THE FIFA 11+

The FIFA 11+ program is supported by a large body of scientific evidence to enhance physical performance and decrease injury risk in athletes (Ayala et al., 2017; Longo et al., 2012; Rahlf et al., 2020; Reis et al., 2013; Steffen et al., 2013; Zarei et al., 2018). The 11+ is endorsed by FIFA and provides detailed open-source educational material. The educational resources make the program easily accessible and readily available to disseminate to coaches across all levels of education and at no extra cost.

The first aim of the present study was to determine whether a nine-week neuromuscular warm-up program (11+) could be successfully implemented in an ecologically valid environment to improve physical performance and reduce injury risk, as measured by five field-based tests, in female youth field hockey players.

The emphasis on the application of the intervention in an ecologically valid environment is of importance to the context of this study. South African high schools present the largest platform for learners to participate in organized sports (Lombard, 2018), yet many high schools lack resources such as equipment, training facilities, and access to qualified coaches to implement conditioning programs. Reported barriers to the implementation of programs to reduce injury risk in youth sport athletes include coach and players engagement, education, resources, and time (Rowe et al., 2021). This can be mitigated with the structured and comprehensive approach of the ‘FIFA 11+’ program. Its readily available and comprehensive educational resources, training material, exercise cards, instructions, the simplicity of the exercises, and the progressive exercise levels, made the program easy to understand and implement to both coaches and players. The minimal required equipment (only cones) and time period of 20 minutes prior to training or matches made the implementation of the warm-up intervention cost effective and time efficient within the context of a school system.

Regarding coach and player engagement, the current study showed that the nine-week 11+ warm-up intervention could be successfully implemented in a South African high school setting with female youth field hockey players. Previous research has highlighted poor implementation rates and low adherence as specific challenges when implementing neuromuscular programs in a youth population with diminished performance improvements compared to high adherence groups (Rowe et al., 2021; Steffen et al., 2013). To address these issues, the researcher supervised the intervention sessions and documented attendance for every session over the nine-week period. Participant adherence was 95.6% for the current study. The adherence in the current study is higher compared to other similar neuromuscular injury prevention interventions with youth athletes (Steffen et al., 2008; Waldén et al., 2012), who reported an average adherence rate between 64 – 80%. It has been suggested that a compliance of ≥80% can result in greater reduction in injury risk (72%) compared to lower adherence (Steffen et al., 2013). Therefore, monitoring adherence was of significant interest for the current study to determine its successful implementation in a school sport environment in South Africa.

The pooled data of all 34 participants showed improvements in all physical performance tests, namely balance (YBT), functional jump performance (SLH), lower-limb power (CMJ), acceleration and speed (40-m sprint with 10-m split), and agility (Illinois Agility). Metrics derived from the YBT (composite score ≤94% limb length and anterior reach asymmetry ≥4cm) and SLH (jump distance asymmetry >10cm) are commonly used to identify athletes with an increased risk of lower-limb injury (Collings et al., 2021; Filipa et al., 2010; Gribble et al., 2012; Hanlon et al., 2020; Plisky et al., 2006; Shaffer et al., 2013). There was a significant improvement in all reach directions and composite score of the YBT in both legs, as well as a significant increase in jump distance in both legs in the SLH, with no improvement in asymmetry in both tests. These results could indicate a decrease in lower-limb injury risk in this population with an improvement in overall balance ability (YBT) and postural control (SLH), as well as improved unilateral lower-limb power production (SLH). Key performance indicators, as measured by the CMJ, 40-m sprint (with 10-m split), and Illinois Agility test also improved significantly in this study. These findings are generally in line with discussed literature on the 'FIFA 11+' in youth football, futsal, and basketball athletes (Chapter two, Table 2.3 and 2.4) and add youth field hockey players to the body of studied populations.

Practical Recommendations

It is reasonable to assume that the high adherence for the 11+ intervention contributed to the significant improvements in physical performance and reduction in injury risk. The program is, therefore, a suitable program to develop physical abilities, such as balance, power, speed, and agility in a school team sport environment and coaches should be encouraged to incentivise high attendance rates during training sessions. The results of the pooled data, however, need to be interpreted with caution. The findings add to the large body of evidence of the 11+ program for performance improvements in youth sport. The freely available- and comprehensive educational material allow for a broader dissemination of the program in South African high schools and to coaches of all levels of education.

The research null hypothesis that a nine-week neuromuscular warm-up program could not be successfully implemented with high adherence, improvements in physical performance, and reduction in in jury risk in female youth field hockey players in a school setting is rejected.

C. COMPARISON BETWEEN FOOTWEAR CONDITIONS

The second aim of the study was to determine whether performing the warm-up intervention barefoot, as compared to shod, would lead to different adaptations in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility in (almost entirely habitually barefoot) female youth field hockey players.

The primary finding of the current study is that both footwear groups significantly increased their performance in all physical performance tests, with no significant differences between the footwear groups. Potential superior adaptations after barefoot training have been reported in female university netball players, who improved balance and agility significantly more than the shod group (de Villiers & Venter, 2014). This study, however, did not report barefoot habits and the session durations were longer (45min) than the present study. It is reasonable to assume that the 20min session duration of the 11+ program was too short to invoke similar superior results in the barefoot group in the current study. In general, the habitual barefoot habits of both groups in the current study may have influenced the non-significant differences, since players may have already been adapted to physical activity performed barefoot. This is supported by broader research on South African children that grow up habitually barefoot. Hollander and colleagues (2017; 2016) found that growing up habitually barefoot effects foot morphology, foot arch height, and motor performance. Zech et al. (2018) found that children who grow up habitually barefoot compared to shod show superior balance and jumping performance during childhood, with greater jump distances persisting during adolescents. Therefore, barefoot habits likely influenced why no significant differences in physical performance were observed.

It is also important to mention that comparisons between the current study involving habitually barefoot participants and other studies are limited and findings cannot be generalized to populations that are not habitually barefoot. It is notable to highlight that the warm-up intervention was conducted on a natural grass surface. All players were willing to participate in a barefoot program prior to the intervention and did not complain about the footwear condition during the intervention.

Practical Recommendations

The findings are of importance, as coaches can be encouraged to allow their athletes the footwear condition of their choice without compromising the intended performance adaptations, such as balance, power, speed, and agility. This recommendation is particularly beneficial for children who grow up habitually barefoot (like in this study's population) and may prefer to train without shoes. The findings add a new dimension to the scientific interest in barefoot training by studying a youth team sport population. Further, it is reasonable to state that the improvements in physical performance in both groups translate into game situations, as testing was conducted on the school's field hockey turf and in the participants' regular field hockey training shoes.

The research hypothesis that there will be a difference in physical performance, as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, between barefoot and shod conditions in female youth field hockey players with the barefoot condition showing superior results compared to shod is rejected.

D. SUMMARY OF OUTCOMES

Table 5.1 presents a summary of the outcomes of the study based on the variables assessed for research question one and research questions two.

Table 5.1. Summary of the outcomes of the study based on the variables assessed.

Research questions	Outcomes	Comments
Can a nine-week neuromuscular warm-up program be successfully implemented in an ecologically valid environment to affect physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility, in female youth field hockey players?	Adherence: 95.6% Improvement in all variables (P<0.05). Lowered injury risk factors in most variables of the assessments (P<0.05) (YBT, SLH). Enhanced performance factors in all assessments (P<0.05) (CMJ, Sprint, Illinois Agility).	Pooled data with no control group.
Does performing the warm-up intervention barefoot, as compared to shod, lead to different adaptations in physical performance as measured by balance, functional jump performance, lower-limb power, acceleration and speed, and agility in habitually barefoot female adolescent field hockey players?	No significant difference (P>0.05) between barefoot and shod intervention groups. Similar significant improvements in both barefoot and shod intervention group in most assessments and variables (P<0.05).	Randomized controlled trial with barefoot and shod intervention. No passive control group.

E. LIMITATIONS

The first limitation is the absence of a control group when considering the pooled data of all participants (article one). Previous randomized controlled trials with control groups in male and female youth football populations that utilized the 11+ program reported significant improvements in various physical performance measures, such as balance, lower-limb power, speed, and agility (Ayala et al., 2017; Reis et al., 2013; Steffen et al., 2013; Zarei et al., 2018). The similar physiological demands of field hockey (Spencer et al., 2004) make it reasonable to draw correlations to these RCT studies and assume that the improvements in the current study were because of the program and not only due to a normal maturation effect over a ten-week period in this youth population. However, no index of maturity was assessed in this study. The second limitation was that the study utilized only female field hockey players from one high school to which the researchers had access to and monitor adherence. Thirdly, the study only utilized field-based tests. This was a requirement by the school to allow the research to take place, as all testing had to be implemented on the school grounds and within school sport practice hours. Lastly, the participants sample was almost entirely classified as habitually barefoot. Therefore, the research findings in article two cannot be generalized to habitually non-barefoot populations.

F. FUTURE RESEARCH

The current findings show that performing a warm-up intervention barefoot compared to shod for 20min twice per week over a nine-week period was not detrimental nor more beneficial to selected measures of physical performance. This statement needs to be considered with caution, since the participant sample was classified as almost entirely habitually barefoot and was likely already adapted to barefoot physical activities. More research is needed to examine possible different performance adaptations following barefoot training and with habitually non-barefoot participants to allow adequate comparisons. The 20min session duration as a warm-up makes the program an ideal choice for regular training and match preparation for coaches with limited available time and resources. However, to understand possible differences in performance adaptations when comparing barefoot to shod conditions, strength and conditioning programs with longer session durations may be required in future research.

The overall findings of the current study are encouraging to incentivise future research on the successful application of neuromuscular warm-up programs in various team sports and youth populations. Studying valid and ‘real-world’ ecological environments is of importance to guide best-practice and evidence-based program selection (such as the FIFA 11+) to improve performance and decrease injury risk in youth athletes. Further, the findings open the door for future studies on the adaptations of barefoot training with various training modalities (e.g., warm-ups) and populations, such as in team sport environments, with both male and female participants. Future research could also include different laboratory-based tests. This may provide insight into the potential mechanisms of adaptations of barefoot training compared to shod following NM warm-up (and other strength and conditioning) programs with regards to muscular activation, biomechanical adaptations, and other intrinsic factors.

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APPENDICES

Appendix 1 – FIFA 11+ Program

The 'FIFA 11+' program, provided by FIFA, with a summary of all exercises, progressions, and repetitions. The complete coaching manual and exercise cards are available at https://www.yrsa.ca/fifa-11.html.

Appendix 2 – HarmoKnee Program

The 'HarmoKnee' program, designed by Kiani et al. (2010), with all exercises and repetitions.

Table 1. The HarmoKnee Preventive Training Program[a]

Exercise	Duration[b]
Warm-up	≥10 min
During each of the warm-up exercises we encouraged straight alignment hip-knee-foot; low center of gravity; lightly flexed knees; and soft and controlled landing. Optionally, ball and passing drills can be introduced where appropriate.	
Jogging	≥4-6 min
Backward jogging on the toes	Approximately 1 min
High-knee skipping: skip with an exaggerated motion by driving the left knee and the right arm toward the sky. Soft landing on the right foot. The sequence is repeated using the opposite leg and arm. No need to jump high or long.	Approximately 30 s
Defensive pressure technique: sliding slowly, zigzag backward.	Approximately 30 s
One and one: alternating forward zigzag running and pressure technique zigzag backward.	≥2 min
Muscle activation	Approximately 2 min
During each of the muscle activation exercises we encouraged carefully holding and contracting the muscle for approximately 4 s, focusing on "finding" your muscles. We recommend stretching only in cases of limited range of motion; stretching is not recommended for players with joint laxity.	
Activation of calf muscles	4 s for each leg/side
Activation of quadriceps muscles	4 s for each leg/side
Activation of hamstring muscles	4 s for each leg/side
Activation of hip flexor muscles	4 s for each leg/side
Activation of groin muscles	4 s
Activation of hip and lower back muscles	4 s for each leg/side
Balance	Approximately 2 min
Proper landing and take off in a jump is the most important movement in this exercise. We encouraged straight line hip-knee-foot; standing with feet shoulder-width apart; soft and controlled landing with flexed knees; freezing the landing before taking off again; and keeping a low body-center of gravity. Contract and hold stomach and buttocks during the whole exercise. Perform exercises slowly; no need to jump high.	
Forward and backward double leg jumps	Approximately 30 s
Lateral single leg jumps	Approximately 30 s
Forward and backward single leg jumps	Approximately 30 s
Double leg jump with or without ball (optional)	Approximately 30 s
Strength	Approximately 4 min
We encouraged soft and controlled landing; contracting stomach and buttocks; straight line hip-knee-foot.	
Walking lunges in place	Approximately 1 min
Hamstring curl (in pairs)	Approximately 1 min
Single-knee squat with toe raises	Approximately 1 min
Core stability	Approximately 3 min
We encouraged contracting stomach and buttocks; straight line through the body; if there is back pain, stop or modify the exercise (do not hold your breath).	
Sit-ups	Approximately 1 min
Plank on elbows and toes	Approximately 1 min
Bridging	Approximately 1 min

[a] All exercises were described in detail. Teams received a manual with written instructions and photographs in addition to practical education on how to correctly perform the exercises. Also see the eAppendix.
[b] Total program duration, approximately 20 to 25 minutes.

Appendix 3.1 – KIPP Program

The 'KIPP' program, provided by LaBella et al. (2012) upon request, with all exercises, progressions, and repetitions.

eTable 1. Twenty-Minute Neuromuscular Warm-up

Jog [1,2,3,4]
2 Laps around court or 1 lap around field

Dynamic motion [1,2,3,4]
Traveling exercises (2 lengths* each)
- Jogging
- Skipping
- Carioca/grapevine
- Side shuffle with arm swing
- Sprint at 75% maximum
- High-knee skipping
- High-knee carioca
- Sprint at 100% maximum
- Backward jog
- Bear crawl
- Butt kickers
- Backward jog half-length, turn and sprint
- Diagonal skipping

Arm swings – forward and backward (20 reps† each)
Trunk rotations (10 in each direction)
Leg swings
- Front-to-back (10 reps/leg)
- Side-to-side (10 reps/leg)

Strengthening exercises
Heel raises [1,2,3,4]
Squats [1,2,3]
Plank and side plank [1,2,3,4]
Push-ups [1,2,3,4]
Lunges – forward [1], lateral [2,3,4], diagonal [2,3,4]
Walking lunge – forward, lateral [3,4]
Prone lifts
- Lift arms and legs together [1,2,3,4]
- Lift opposite arm, leg [1,2,3,4]
- Knees flexed to 90°, heels together, hips externally rotated, lift arms/legs [2,3,4]
-

Plyometrics (timed‡)
Ankle bounces (timed) [1,2,3,4]
Tuck jumps (timed) [1,2,3]
Jump in place, rotating 180° (timed) [1]
Squat jumps (timed) [1,2,3,4]
Broad jumps – hold landing (5 reps) [1]
Jump over 3-inch cones (timed) [1,2,3,4]
- Front-to-back
- Side-to-side

Bounding in place (timed) [1]
Scissor jumps (timed) [2]
Side-to-side bounding (timed) [2,4]
Single leg hop, hop, stick landing (5 reps/leg) [2,3,4]
Jump, jump, jump, vertical jump (reps) [2]
Single leg jump for distance (5 reps/leg) [3,4]
Jump into bounding (4 lengths) [3]
Diagonal bounding (2 lengths) [3,4]

Agility runs
Shuttle run [1,2,3,4]
- Between 2 rows of 5 cones; rows 50 ft apart
- Sprint to cone, backward jog to next cone (10 reps)

Diagonal run [1,2,3,4]
- Between 2 rows of 5 cones; rows 50 ft apart
- Sprint to cone, turn, sprint to next cone (10 reps)

Lateral shuffle [1,2,3,4]
- Between 2 rows of 5 cones; rows 15 ft apart
- Side shuffle from cone to cone (10 reps)

*Length = one length of a basketball court (50 ft)
†Reps = repetitions
‡Timed = repeated for 10 s (week 1); 20 s (week 2); 30 s (weeks ≥3)
[1] Week 1; [2] Week 2; [3] Week 3; [4] Week 4 and beyond

Appendix 3.2 – KIPP Program Protocol

The researcher's exercise protocol, provided by LaBella et al. (2012) upon request.

KIPP

Strengthening

Purpose: Increase muscular strength of the core and lower extremities.

Single leg heel raises

Standing on one foot, rise up and down on toes slowly and with control.

Purpose: To strengthen the calf muscles and increase balance.

Traditional squats

Start in Athletic Position. First motion is to go back with hips (not down at knees). Do not let knees go beyond toes.

Purpose: To strengthen the gluteus muscles, hamstrings and quads. Increase balance and proprioception.

Single Leg Squat

Start on one leg with finger tips on the wall. Bend knee and squat down, making sure knee does not pass in front of toes. Continue squatting for 30 seconds. Switch legs.

Advance to: Single leg squat lowering self onto chair, tap bottom on chair and come back up

Plank

Lying on stomach, elevate body onto forearms and toes. Maintain plank position using abdominal and gluteus muscles.

Purpose: Strengthens abdominals, gluteus muscles, scapular/thoracic, scapular/humeral and pectoral muscles.

Advance to: 1 minute instead of 30 seconds as needed

Prone lifts (traditional)

Lying on stomach, arms out in front, thumbs up. Simultaneously raise arms, chest and legs off ground.

Purpose: To strengthen total body extensor groups.

Prone lift (knee flexion/hip external rotation)

Lying on stomach, arms out in front, thumbs up. Bent knees to 90 degrees with heels together. Raise arms, chest and legs off ground.

Purpose: To strengthen total body extensor groups with increased focus on the gluteus maximus (upper fibers).

Lunge (single plane)

Start in standing position, step forward into lunge then return to standing. Keep back straight during exercise. Do not allow knee to pass toes.

Purpose: To strengthen the quadriceps, hamstrings and gluteus muscles.

Forward lunges with rotation

Start in standing position, step forward into lunge and rotate trunk to the left after lunging, then rotate back to the front once in a deep lunge, then return to standing position. Keep back straight during exercise and do not let the knee go past the toes. Repeat forward lunges with alternating rotating left then right for 30 seconds. Switch legs.

Lunge (3 plane)

Start in the standing position. Do forward, side and diagonal lunge in that order. Do not let lunging knee pass toes. Keep back straight through exercise.

Purpose: To strengthen core and lower extremities in the sagittal, frontal and transverse planes. Increase balance and proprioception.

Push-ups

Start in the up position with weight on hands and toes, not knees. Hands a little more than shoulder-width apart and directly under the shoulders. Maintain straight body position.

Purpose: To strengthen the triceps, shoulder, gluteus muscles, abdominal and pectoral muscles.

Advance to: Cross over Push-ups

- Do a push up, once back in plank position with arms extended, cross arm over and tap floor in front of other hand, move to the other side and tap floor again, repeat with opposite arm. Continue push ups alternating arm cross overs for 30 seconds.

Side plank

Lying on side propped on forearm with feet stacked. Maintain plank position using abdominal and gluteus muscles.

Purpose: To strengthen the transverse and oblique abdominals, scapular stabilizers and gluteus medius.

Advance to: 1 minute on each side instead of 30 seconds as needed

Single Leg Reach

Standing on one leg with slight bend in knee, athlete reaches same arm as balancing leg straight out in front of them. Bend down and reach arm towards the floor and come back up maintaining core strength, continue to reach up and down for 30 seconds. Switch legs.

Athletic position

Before starting the instruction on the plyometric exercises, athletes should be shown proper athletic position. The athletic position is a functionally stable position with the knees comfortably flexed, shoulders back, eyes up, feet approximately shoulder-width apart, slight lordotic curve in the low back and body weight evenly distributed through both feet. The athlete-ready position is the starting and finishing position for most of the training exercises. *(During some exercises, the finishing position is exaggerated with deeper knee flexion in order to emphasize the correction of certain biomechanical deficiencies.)*

Single leg athletic position is achieved by starting in the athletic position described and then lifting one foot off the ground while maintaining functionally stable position.

Plyometrics

Purpose for all plyometrics: To teach proper jumping and landing techniques from low to mid to high-level exercises. Increase lower extremity explosive power and improve neuromuscular control of knee motion.

Teaching note: When teaching plyometrics it is important to understand how the foot is interfacing with the surface when landing. Is the landing heel-toe or toe-heel?

Single leg side hop to balance

Standing on one leg with slight bend in knee, athlete hops to the left and holds for five seconds then hops laterally to the right. Continue hopping back and forth for 30 seconds. Switch legs.

Advance to: backwards single leg hop in addition to forwards

Tuck jumps

Start in the Athletic Position. Jump and bring both knees up to chest as high as possible, repeat quickly with good form.

Level: Mid to High | Toe-heel landing

Broad jumps-stick (hold) landing

Start in the Athletic Position. Perform a two-footed jump as far as possible, hold landing for 5 seconds.

Level: Low | Heel-toe landing

Advance to: backwards broad jump in addition to forwards

Squat jumps

Start in the Athletic Position. Jump up bringing both hands over head, land in a squat position.

Level: Mid | Toe-heel landing

Line jumps

Start in the Athletic Position. Perform a double-legged jump with feet hip-width apart, jump forward and back over line quickly, repeat side-to-side.

Level: Low to Mid | Toe-heel landing

180 jumps

Start in the Athletic Position. Perform a two-footed vertical jump, rotate 180 degrees in air and hold landing for 2 seconds; repeat in reverse direction.

Level: Mid | Toe-heel landing

3 broad jumps, vertical jump

Start in the Athletic Position. Perform three broad jumps with vertical jump immediately after landing the third broad jump.

Level: Low to Mid | Broad jump: Heel-toe landing | Vertical jump: Toe-heel landing

Ice skaters (side-to-side bounding)

Start in Athletic Position. Jump side-to-side landing softly and landing with control each time in the single leg athletic position, repeat this jump going the other direction.

Level: Low to Mid | Toe-heel landing

Scissors jump

Start in stride position with one foot in front of the other, jump up alternating foot positions in mid-air.

Level: Low to Mid | Toe-heel landing

Hop, hop, stick

Start in single leg Athletic Position. Perform two single-legged hops, stick second landing and hold for 5 seconds. Increase distance of hop as technique improves.

Level: Mid to High | Heel-toe landing

Diagonal bounding

Start in single leg Athletic Position. Jump out on a 45 degree angle off of one foot and land on the opposite foot. Land softly and with control each time in the single leg athletic position, repeat this jump going the other direction.

Level: Mid to High | Heel-toe landing

Jump into bounding forwards and backwards

Start in Athletic Position. Perform a two-footed broad jump, land on single leg, then reset the feet and repeat alternating landing on both legs. Once made it the length of room, start in the athletic position and hop backwards landing on one leg for the length of the room. Alternating landing on right and left feet with each hop. Perform smaller hops when going backwards.

Level: High | Broad jump: heel-toe landing

Single-leg jump for distance

Start in single leg Athletic Position. Perform a one-legged hop for distance, hold landing (knee bent) for 2 seconds. If unable to hold, decrease distance of jump and work to increase that as technique improves.

Level: High | Heel-toe landing

Single-leg backwards bunny hop

Start in single leg Athletic Position. Perform a small bunny hop backwards landing on the same leg, hold landing (knee bent) for 3 seconds. If unable to hold, decrease distance of jump and work to increase that as technique improves.

Level: High | Heel-toe landing

Agility running

Purpose: Teach proper running, deceleration and change of direction techniques. Improve aerobic fitness

Shuttle run (with forward/backward running)

Starting at the first cone, sprint forward to the second cone, run backwards to the third cone, sprint forward to the fourth cone, etc. Introduce hip turn when changing directions.

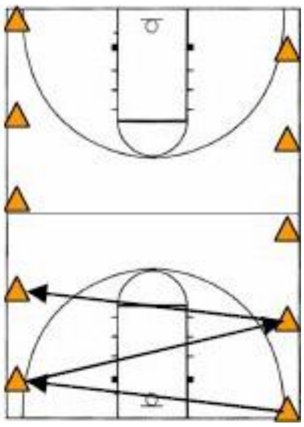
Purpose: Increase dynamic stability of the ankle, knee and hip. Teach safe deceleration techniques.

Diagonal run

Face forward and run to the first cone and perform a triple-step stop. Plant left foot, change directions and run to second cone. Perform a triple-step stop, plant right foot, change directions and to next cone, etc… Make sure that the outside leg does not cave in at the knee. Keep a slight bend in the knee and make sure the knee stays over the ankle

Purpose: To encourage proper technique and stabilization of the outside planted foot and train athletes to avoid valgus at the knee when changing directions. Teach safe deceleration techniques.

Lateral shuffle

Stagger cones 50 feet, 15 yards or 15 meters

Starting at the first cone the athlete faces the opposite end of the floor and shuffles across the floor to the second cone, stop and change direction without pivoting on foot, shuffle back across floor to the third cone, etc… (When shuffling, the subject should always face forward and not cross the feet.)
Purpose: To strengthen hip abductors and adductors. Train neuromuscular control of knee motion in the transverse plane.

Cool down and Stretching

Purpose: To help reduce Delayed Onset of Muscle Soreness (DOMS) and to maintain/increase flexibility of major muscle groups.

Appendix 4.1 – Ethics Approval Letter

Ethics approval letter, provided by the Health Research Ethics Committee at Stellenbosch University (S21/07/131).

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Approval Notice

New Application

10/11/2021

Project ID: 22800

HREC Reference No: S21/07/131

Project Title: The effect of an eight-week barefoot neuromuscular warm-up programme in female high-school field hockey players

Dear Mr J Schlewing

The **response to modifications** received on 04/11/2021 08:37 was reviewed by members of **Health Research Ethics Committee** via **expedited** review procedures on 10/11/2021 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Date: 10 November 2021

Protocol Expiry Date: 09 November 2022

Please remember to use your Project ID 22800 and Ethics Reference Number S21/07/131 on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review

Translation of the informed consent document(s) to the language(s) applicable to your study participants should now be submitted to the HREC.

Please note you can submit your progress report through the online ethics application process, available at: Links Application Form Direct Link and the application should be submitted to the HREC before the year has expired. Please see *Forms and Instructions* on our HREC website (www.sun.ac.za/healthresearchethics) for guidance on how to submit a progress report.

The HREC will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Please note that for studies involving the use of questionnaires, the final copy should be uploaded on Infonetica.

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility, permission must still be obtained from the relevant authorities (Western Cape Departement of Health and/or City Health) to conduct the research as stated in the protocol. Please consult the Western Cape Government website for access to the online Health Research Approval Process, see: https://www.westerncape.gov.za/general-publication/health-research-approval-process. Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and instructions, please visit: Forms and Instructions on our HREC website https://applyethics.sun.ac.za/ProjectView/Index/22800

If you have any questions or need further assistance, please contact the HREC office at 021 938 9677.

Yours sincerely,

Ms Brightness Nxumalo
HREC 2 Coordinator

National Health Research Ethics Council (NHREC) Registration Number:

REC-130408-012 (HREC1)•REC-230208-010 (HREC2)

Appendix 4.2 – Ethics Approval Letter (renewal)

Ethics approval letter (renewal), provided by the Health Research Ethics Committee at Stellenbosch University (S21/07/131).

Approval Letter
Progress Report

16/08/2022

Project ID: 22800

Ethics Reference No: S21/07/131

Project Title: The effect of an eight-week barefoot neuromuscular warm-up programme in female high-school field hockey players

Dear Mr J Schlewing

We refer to your request for an extension/annual renewal of ethics approval dated 22/06/2022 11:43.

The Health Research Ethics Committee reviewed and approved the annual progress report through an expedited review process.

The approval of this project is extended for a further year.

Approval date: 10 November 2022

Expiry date: 09 November 2023

Kindly be reminded to submit progress reports two (2) months before expiry date.

Where to submit any documentation

Kindly note that the HREC uses an electronic ethics review management system, *Infonetica*, to manage ethics applications and ethics review process. To submit any documentation to HREC, please click on the following link: https://applyethics.sun.ac.za.

Please remember to use your Project Id 22800 and ethics reference number S21/07/131 on any documents or correspondence with the HREC concerning your research protocol.

Please note that for studies involving the use of questionnaires, the final copy should be uploaded on Infonetica.

Yours sincerely,

Ms Brightness Nxumalo
Coordinator: Health Research Ethics Committee 2 (HREC 2)

National Health Research Ethics Council (NHREC) Registration Number:
REC-130408-012 (HREC1)•REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number:
IRB0005240 (HREC1)•IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006). Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

Appendix 5 – Western Cape Government Approval Letter

Study approval by the Western Cape Government.

Western Cape Government
Education

Directorate: Research

meshack.kanzi@westerncape.gov.za
Tel: +27 021 467 2350
Fax: 086 590 2282
Private Bag x9114, Cape Town, 8000
wced.wcape.gov.za

REFERENCE: 20211109-7504
ENQUIRIES: Mr M Kanzi

Mr Schlewing Jannick
Vila Al Sol
Polkadraai Road
Stellenbosch
7603

Dear Mr Schlewing Jannick,

RESEARCH PROPOSAL: THE EFFECT OF AN EIGHT-WEEK BAREFOOT NEUROMUSCULAR WARM-UP PROGRAMME ON DYNAMIC POSTURAL STABILITY, LOWER LIMB SYMMETRY, AND REACTIVE STRENGTH IN FEMALE ADOLESCENT HOCKEY PLAYERS.

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **10 November 2021 till 30 June 2022.**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Mr M Kanzi at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

    The Director: Research Services
    Western Cape Education Department
    Private Bag X9114
    CAPE TOWN
    8000

We wish you success in your research.

Kind regards,
Meshack Kanzi
Directorate: Research
DATE: 10 November 2021

Lower Parliament Street, Cape Town, 8001
tel: +27 21 467 9272 fax: 0865902282
Safe Schools: 0800 45 46 47
Private Bag X9114, Cape Town, 8000
Employment and salary enquiries: 0861 92 33 22
www.westerncape.gov.za

Appendix 6 – Parents Informed Consent Form

Parents' informed consent form, sent out electronically to the parents by HMS Bloemhof's Sport Manager.

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

Please see Section 8 of our Health Research Ethics Committee (HREC) Standard Operating Procedures (SOPs) for more detailed information about requirements for Informed Consent (IC). You will find the SOPs here: http://www.sun.ac.za/english/faculty/healthsciences/rdsd/Pages/Ethics/SOP.aspx. (Please delete this paragraph before submitting your Informed Consent Form (ICF) to the HREC)

TITLE OF RESEARCH PROJECT:	
The effect of an eight-week barefoot neuromuscular warm-up programme on dynamic postural stability, lower limb symmetry and reactive strength in female high-school field hockey players	
DETAILS OF PRINCIPAL INVESTIGATOR (PI):	
Title, first name, surname: **Mr Jannick Schlewing**	**Ethics reference number:** **S21/07/131**
Full postal address: **Villa Al Sole, Polkadraai, 7600 Stellenbosch**	**PI Contact number:** **0720810022**

We would like to invite your child to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the principal investigator any questions about any part of this project that you do not fully understand. It is very important that you are completely satisfied that you clearly understand what this research entails and how your child could be involved. Also, your child's participation is **entirely voluntary**, and you are free to decline your child to participate. In other words, you may allow your child to participate, and your child may choose to take part, or not to take part. Nothing bad will come of it if you or your child says no: it will not affect you or your child negatively in any way whatsoever. Refusal to participate will involve no penalty or loss of benefits or reduction in the level of care to which your child is otherwise entitled. You are also free to withdraw your child from the study at any point, even if you and your child do agree to take part initially.

The Health Research Ethics Committee at Stellenbosch University has approved this study**.** The study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

What is this research study all about?

- The study will be conducted at HMS Bloemhof as part of your child's regular hockey practice. The total number of participants will be 35-50 under-18 and under-16 hockey players. The pre- and post-testing will be conducted at HMS Bloemhof during regular hockey training times.

- The study aims to examine whether a structured warm-up prior to hockey practice will have a positive effect on specific injury risk- and performance factors. The warm-up will include bodyweight exercises that are common in conditioning sessions with the aim to improve strength, quickness, and balance. Since the school is already running conditioning sessions for the hockey teams, your child will already be familiar with most exercises. Previous research showed that the number of lower leg injuries can be reduced with such warm-up programs. The study also wants to examine whether the effects of the warm-up program will be different when one group performs the intervention barefoot compared to shod. There has been a recent trend of barefoot distance running, but little is known about the effects of different styles of training, such as jumping and balance, which is part of the warm-up program. Your child will be asked to fill out a barefoot habits questionnaire. This is important, because being habitually barefoot may impact the results of the study.

- Before we start the eight-week warm-up program at the school, your child will be asked to attend a testing session with four tests, which will be conducted during regular hockey training times at HMS Bloemhof. These tests are a balance, single leg jumping power, speed, and agility. The eight-week warm-up program will be part of the regular hockey practice at school. In the week after the eight-week intervention, your child will be asked to attend a second round of testing following the same procedure as mentioned above. The testing procedures for each test are outlined below. Study assistants will be on site to instruct your child on the exact procedures and guidelines for each test and are available for any questions your child may have during the testing process.

- Testing Procedures: Star Excursion Balance Test & Single-leg Hop for distance, 40-m Sprint, and Illinois Agility Test

  Upon arriving at hockey practice, a study assistant will conduct a standardized warm-up. The first test is the Star Excursion Balance Test. Your child will be asked to stand on one leg in the middle of a grid with three lines pointing away forward and backwards. Your child will then reach with the non-stance foot as far forward as possible and touch the lines. This process will be completed with both legs. Then, the Single-leg Hop for distance will be conducted. Your child will be asked to jump as far forward as possible with each leg and 'stick the landing'. The furthest distance of three trials will be recorded as the score. Practice trials will be afforded for each test. The following test is the 40-m sprint test. Your child will be asked to sprint through light gates as fast as possible for a distance of 40-m. Two trials are afforded from which the fastest time will be recorded. The last test is the Illinois agility test, which assesses change-of-direction speed and manoeuvrability. The fastest time of two attempts will be recorded. All four test will be completed within 45-minutes during regular hockey practice times.

- Personal and descriptive information/anthropometric assessments

  Your child's personal information will be kept safe on a password-protected hard-drive at the researcher's home. The descriptive information will be used to determine if your child fulfils the requirements for inclusion in the study. Your child's name and surname is also required to be able to document compliance to the programme. For analyses of data, your child will be assigned a numerical code plus initials to maintain anonymity. Limb length measurements are required to normalize the test scores for the Star Excursion Balance test.

- After the pre-testing, your child will be randomly assigned to either barefoot or shod group.

Why do we invite your child to participate?*.*

- Your child is an under-18 hockey player at HMS Bloemhof, which is the target group for this intervention.

What will your child's responsibilities be?

- Your child's responsibilities will be to attend the pre- and post-intervention testing sessions and complete at least 80% of all warm-up sessions within the eight-week intervention period (i.e. attend at least 80% of hockey training sessions).

Will your child benefit from taking part in this research?

- The intervention programme has the potential to improve your child's strength, quickness (agility) and balance. Should the warm-up program prove to be successful in improving the testing measurements, the warm-up program could be implemented by other hockey teams at HMS Bloemhof. This may lead to possible injury-reducing and performance-enhancing benefits for players in the long-term.

Are there any risks involved in your child taking part in this research?

- Most of the exercises that form part of the warm-up program are already familiar to the players, as the exercises or variations thereof are part of the current conditioning sessions that your child is already participating in at Bloemhof. Further, the intervention sessions will be supervised by trained professionals (Sport Science Honours students from Stellenbosch University) who have been instructed in appropriate and safe exercise techniques.

There is an inherent risk to experience discomfort and soreness during and after exercises. Although measures will be taken to create a safe training environment and procedures, performing physical exercise has an inherent risk of potential injury. If your child does not agree to take part, what alternatives does your child have?

- Your child will not be excluded from hockey training. She will perform the typical warm-up routines that are implemented currently at hockey practice.

Who will have access to your child's information?

All personal data and test results will be treated as confidential and will be password-protected on a secure hard drive at the PI home. Only the PI and study supervisors will have access to the data. Participants will be assigned a numerical value to provide anonymity during analyses of data. When results are published in the thesis and possibly a journal article, only group results will be reported. It will not be possible to identify your child. **Even though it is unlikely, what will happen if your child gets injured somehow because you took part in this research study?**

- Stellenbosch University will provide comprehensive no-fault insurance and will pay for any medical costs that came about because your child took part in the research. You will not need to prove that the researchers were at fault.

Will your child be paid to take part in this study and are there any costs involved?

- Your child will not receive any specific compensation for their participation. If your child completed the intervention, as well as pre- and post-testing, they would stand the chance to enter a lucky draw of R250 for one participant from each group (barefoot and shod). Furthermore, your child will be informed of the overall study results and will be allowed to view their own results. Individual results will not be shared with third parties, but just with your child themselves.

Please see Section 9 of HREC SOPs on Participant Insurance, Appendices IX and X on Compensation for Injury.

Is there anything else that you should know or do?

- You can phone Jannick Schlewing (072 081 0022) or contact Prof Ranel Venter (083 309 2894; rev@sun.ac.za) if you have any further queries or encounter any problems.

➢ You can phone the Health Research Ethics Committee at 021 938 9677/9819 if there still is something that your study doctor has not explained to you, or if you have a complaint.

➢ You will receive a copy of this information and consent form for you to keep safe.

Declaration by parent or guardian

By signing below, I …………………………………..…………. agree that my child may take part in a research study entitled **The effect of an eight-week barefoot neuromuscular warm-up programme on dynamic postural stability, lower limb symmetry and reactive strength in female high-school field hockey players**.

I declare that:

- I have read this information and consent form and it is written in a language in which I am fluent and with which I am comfortable.
- I have had a chance to ask questions and I am satisfied that all my questions have been answered.
- I understand that taking part in this study is **voluntary,** and I have not been pressurised to consent
- My child may choose to leave the study at any time and nothing bad will come of it – she will not be penalised or prejudiced in any way.
- My child may be asked to leave the study before it has finished, if the s researchers feels it is in her best interests, or if she does not follow the study plan that we have agreed on.

Signed at (*place*) ....…........……………... on (*date*) …………....……….. 2021.

....	....
Signature of parent / guardian	**Signature of witness**

Declaration by investigator

I **Jannick Schlewing** declare that:

- I explained the information in this document in a simple and clear manner to …………………………………..
- I encouraged him/her to ask questions and took enough time to answer them.

- I am satisfied that he/she completely understands all aspects of the research, as discussed above.

  I did not use an interpreter.

Signed at (*place*) Stellenbosch on (*date*) 01 February 2022.

……………………………….. ………………………………….

Signature of investigator **Signature of witness**

Permission to have all anonymous data shared with journals:

Please carefully read the statements below and think about your choice. No matter what you decide, it will not affect whether your child can be in the research study.

When this study is finished, we would like to publish results of the study in journals. Most journals require us to share your anonymous data with them before they publish the results. Therefore, we would like to obtain your permission to have your child's anonymous data shared with journals.

Permission for sharing information with other investigators:

Please carefully read the statements below (or have them read to you) and think about your choice. No matter what you decide, it will not affect whether your child can be in the research study

In order to do the research we have discussed, we must collect and store data relating to your child's performance on the pre- and post-intervention tests. We will do some of the analyses right away. Other tests and analyses may be done in the future. Once we have done the research that we are planning for this research project, we would like to store your child's information and data. Other investigators from all over the world can ask to use the data in future research. To protect your child's privacy, we will replace her name with a unique study number. We will only use this code for her results and information about her. We will do our best to keep the code private. It is however always possible that someone could find out about her name, but this is very unlikely to happen. Therefore, we would like to ask for your permission to share your child's results with other investigators.

Tick the Option you choose for anonymous data sharing with journals:

I agree to have my child's anonymous data shared with journals during publication of results of this study

☐ Signature____________

OR

I do not agree to have my child's anonymous data shared with journals during publication of results of this study

☐ Signature____________

Tick the Option you choose for sharing samples and/or information with other investigators:

I do not want my child's tests results and/or information to be shared with other investigators

☐ Signature______________

OR

My child's test results and/or information may be shared with other investigators for further analysis and future research in a field related to neuromuscular training interventions and barefoot training.

☐ Signature______________

Appendix 7 – Child Assent Form

Child assent form handed out in-print by the principal investigator one week prior to the pre-intervention testing of the study.

	STELLENBOSCH UNIVERSITY **FACULTY OF HEALTH SCIENCES**	

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM

TITLE OF THE RESEARCH PROJECT:

The effect of an eight-week barefoot neuromuscular warm-up programme on dynamic postural stability, lower limb symmetry and reactive strength in female high-school field hockey players

RESEARCHERS NAME(S):
Jannick Schlewing

ADDRESS:
Villa Al Sole, Polkadraai, 7600 Stellenbosch

CONTACT NUMBER:
072 081 0022

What is this research project all about?

This research project aims to determine whether a structured warm-up before your hockey practice will have a positive effect on your balance, jump power with each leg, speed, and agility. The 20-minute warm-up will include bodyweight exercises, like hopping, balancing, and running drills that are similar to the conditioning sessions that you participate in at HMS Bloemhof. That means that you will already be familiar with many of the exercises.

Why a warm-up program? Other researchers have shown that the type of warm-up programme we want to implement could decrease the risk of injury in sports like hockey, but we do not know yet which specific factors they improve. That is why we will measure your balance, jump power, speed, and agility. We also want to examine whether the effects of the warm-up program will be different when one group performs the warm-up program barefoot and the other group in their regular training shoes. This is because there is a recent trend of barefoot distance running, but little is known about the effects of barefoot training on different styles of training, such as jumping and balance. You will be randomly placed in either the barefoot or training shoe group, but everyone will do the same warm-up program. You will be asked to fill out a barefoot habits questionnaire. This information is important for us, because it might effect the results of our study, if you spend lots of time barefoot.

Why have I been invited to take part in this research project?

We specifically want to measure the effect of the warm-up program for under-18 hockey players. Since you are playing in an under-18 hockey team at HMS Bloemhof, you are invited to take part. There are some criteria that each participant has to fulfil to be included in the study. You will be asked to fill out some personal information about your sporting- and injury history, etc. This information will be kept confidential and only myself and my supervisors have access to it.

Who is doing the research?

I am a Masters student in Sport Science at the Department of Sport Science, Faculty of Medicine and Health Sciences, Stellenbosch University. This research is part of my thesis to complete my degree. My biggest field of interest is youth sport development, which is why I chose this topic.

What will happen to me in this study?

Before we start the eight-week warm-up program at the school, we need to measure your balance, jump power with each leg, speed, and agility. All four tests will be conducted in one session before and after the eight-week intervention. These testing sessions will fall within your regular hockey training times at HMS Bloemhof and will take no longer than 45-minutes. The eight-week warm-up program will also be part of your regular hockey practice at school. In the week after the eight-week program, you will be asked to attend a second round of testing following the same procedure as detailed below. That way we can measure how much each participant improved throughout the eight-week period. The research assistants will explain to you the details of each test and you can ask them questions at any point in time.

The procedure for the four tests will go as follows. When you arrive at training, a female assistant will take measurements of your height, weight, and leg length. Another assistant will then go through a warm-up with you. For the first test you will be asked to stand in the middle of a grid with 3 lines pointing away from you in different directions. You will then balance on one leg and reach as far forward as possible with the other leg in each direction. After that you perform the single leg hop test, where you will jump as far as possible with each leg. You will have three trials per leg with short rest periods. After that you will complete a 40-m sprint test, with two attempts to sprint the 40-m as fast as possible. The last test is an agility course that you will also attempt twice to complete as fast as possible. Your fastest times will be recorded for each test.

During the two testing sessions, myself and all study assistance will follow the Covid-19 health and safety protocols. This includes wearing of masks, providing sanitization stations and maintaining appropriate social distancing rules. During the eight-week warm-up program at HMS Bloemhof, myself and all assistants will follow the school's designated Covid-19 health and safety protocols for sport activities.

Can anything bad happen to me?

There is a possibility that you will experience discomfort or muscle soreness after the initial start of the warm-up program. This is a normal response to training, and it will go away after one or two days. There is also always a possibility to injure yourself when performing physical activities. However, qualified coaches will supervise the warm-ups and will instruct you on the correct exercise technique. You can always ask questions at any point if you are unsure of the execution or need clarifications. If you feel discomfort during some exercises, you can also speak to the coaches, and they will adapt the movements for you.

Can anything good happen to me?

The results of the test scores and between the barefoot- and shod-group after the eight-week program, will help to advance scientific research. This knowledge might also help coaches to improve the sport warm-ups that you are already used to and make them more beneficial.
After the completion of the study, you can ask to view your individual test results to see if you have improved after the second round of testing.
If you have completed at least 80% of all warm-up sessions, as well as completed the first- and second round of testing, you are standing a chance to win R250. One participant from the barefoot- and one participant from the shod group will be selected as the winner.

Will anyone know I am in the study?

All of your personal information will be kept confidential and only myself, Jannick, and the study supervisors, my professors, will have access to it. Your testing results will be made anonymous as well, so that anybody reading my thesis will not be able to identify you or anyone else that participated. Further, we would like to store the data for possible studies in the future. All your information will be kept confidential to other researchers as well that may use the data for further analysis in other studies.

Who can I talk to about the study?

You can always contact myself, Jannick, (072 081 0022; 21115036@sun.ac.za), or Prof Ranel Venter (083 309 2894; rev@sun.ac.za) should you have any questions or concerns.

What if I do not want to do this?

You have no obligation to participate in the study, even if your parents have agreed. You can also stop being in the study at any time without getting into trouble. Your participation is entirely voluntary, and you should not feel pressured into participating by anyone.

Do you understand this research study and are you willing to take part in it?

YES	NO

Has the researcher answered all your questions?

YES	NO

Do you understand that you can pull out of the study at any time?

YES	NO

Signature of Participant   Date

Appendix 8 – Participant Questionnaire

Participant questionnaire handed out in-print by the principal investigator one week prior to the pre-intervention testing of the study.

Participant Questionnaire

1. Personal Information:

1.1 What is your full name and surname? ……………………………………………………

1.2 What is your date of birth? yyyy/mm/dd…………………………………………

1.3 Which leg is your dominant leg (that you would kick a ball with or jump off)? Left [ ] Right [ ]

2. School Sport Participation:

2.1 Do you confirm that you are medically suited to participate in organized school sport at HMS Bloemhof?

I confirm [ ] I do not confirm [ ]

2.2 At what age did you start playing hockey? ………… years old

2.3 In which Bloemhof hockey team are you currently playing? (u18A, U18B, u16A) …………

2.4 What is your current playing position? (Defender, Midfielder, Striker)………………………

2.4 What was/is your highest level of hockey participation? (e.g., Boland U16 in 2019)

……………………………………………………

2.5.1 Do you participate in any other sport or exercise at Bloemhof? (e.g., athletics sprinting, netball, etc.)

Yes [ ] No [ ]

2.5.2 If yes, what are you doing? ……………………………………………………

2.5.3 How many hours per week? ……………………………………………………

2.5.4 At what level? ……………………………………………………

2.6.1 Do you participate in any other sport or exercise outside of Bloemhof?

Yes [ ] No [ ]

2.6.2 If yes, what are you doing? ……………………………………………………

2.6.3 How many hours per week? ……………………………………………………

2.6.4 At what level? ……………………………………………………

3. Injury History:

3.1 Do you currently have a lower-limb injury that prevents you from training?

Yes [ ] No [ ]

3.1.2 If yes, what type of injury?……………………………………………………

3.2 Have you had a lower-limb injury in the past 3 months that prevented you from training for more than 2 weeks?

Yes [ ] No [ ]

3.2.2 If yes, what type of injury?……………………………………………………

3.3 Have you had a lower-limb injury last year (2021) that prevented you from training for more than 2 weeks?

Yes [ ] No [ ]

3.2.2 If yes, what type of injury?……………………………………………………

I hereby declare that all information provided above is accurate and give permission to the researcher, Jannick Schlewing, to store my information safely for analysis purposes. **I agree [ ]** **I disagree [ ]**

Appendix 9 – Barefoot Questionnaire

Barefoot questionnaire (Hollander et al., 2016; de Villiers et al., 2017) handed out in-print by the principal investigator one week prior to the pre-intervention testing of the study.

Name:

Vraelys oor hoe gereeld jy kaalvoet is
Questionnaire on how often you are barefoot

Omkring hoe baie jy kaalvoet loop by die skool:
Circle how often you are barefoot at school:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet is tydens sport:
Circle how often you are barefoot during sport activities:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet is in en om die huis:
Circle how often you are barefoot in and around the home:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet was toe jy in die laerskool was:
Circle how often you were barefoot while at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was tydens sport in die laerskool:
Circle how often you were barefoot during sport activities at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was in en om die huis toe jy in die laerskool was:
Circle how often you were barefoot in and around the home while you were at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Baie dankie! Thank you!

Appendix 10 – Scoring Sheet

Scoring sheet for pre-intervention testing, handed out to the participants on the days of testing and carried to each testing station. The research assistants filled out the achieved scores.

Name: ____________________ **Team:** __________ **Date:** __________

Birthday: __________ **Height:** _____ cm **Leg Length** **Right:** _____ cm **Left:** _____ cm

1. Y-Balance

	Right 1.	Right 2.	Right 3.	Left 1.	Left 2.	Left 3.
Anterior	cm	cm	cm	cm	cm	cm
Posteromedial	cm	cm	cm	cm	cm	cm
Posterolateral	cm	cm	cm	cm	cm	cm

2. Single-leg Hop

Right			Left		
1. cm	2. cm	3. cm	1. cm	2. cm	3. cm

3. Counter-Movement Jump

1. cm	2. cm	3. cm

4. 40-m Sprint

1. 10-m: sec 40-m: sec	2. 10-m: sec 40-m: sec

5. Illinois Agility

1. sec	2. sec

Athlete Number:

P

Bloemhof Hockey
Pre-Testing: 7/8/9/10 March

Scoring sheet for post-intervention testing

Name: ____________________ **Team:** __________ **Date:** __________

1. Y-Balance

	Right 1.	Right 2.	Right 3.	Left 1.	Left 2.	Left 3.
Anterior	cm	cm	cm	cm	cm	cm
Posteromedial	cm	cm	cm	cm	cm	cm
Posterolateral	cm	cm	cm	cm	cm	cm

2. Single-leg Hop

Right			Left		
1. cm	2. cm	3. cm	1. cm	2. cm	3. cm

3. Counter-Movement Jump

1. cm	2. cm	3. cm

4. 40-m Sprint

1. 10-m: sec 40-m: sec	2. 10-m: sec 40-m: sec

5. Illinois Agility

1. sec	2. sec

Athlete Number:

P

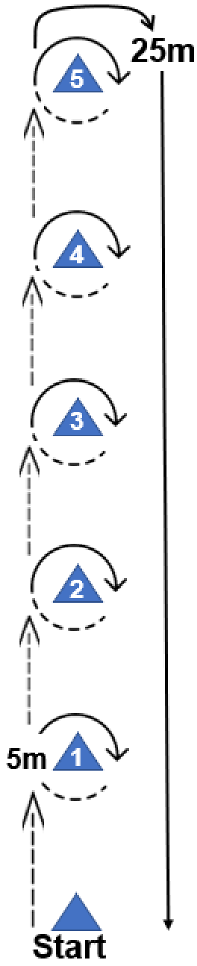
Bloemhof Hockey
Post-Testing: 16/17/18 May

Appendix 11 – Standardized Warm-up

Standardized 6 min warm-up protocol that was followed for both pre- and post-intervention testing.

- 25m lane, 1 cone at every 5m

1. **1 warm-up lane 25m up and down at 50% intensity**
2. **Run towards first cone, shuffle around facing forwards, run to next cone, etc.**
   → 2 sets: 1x shuffle right, 1x shuffle left
   → accelerate on the way back
3. **2 fast accelerations to 25m, walk back → to prepare for sprints & agility!**
4. **"Chase the chickens" (dynamic hamstring stretch) to first 5m cone**
   → at cone: 1x Y-Balance technique in each direction with each foot
5. **"Chase the chickens" (dynamic hamstring stretch) to second 5m cone**
   → at cone: 10 pogo hops and 2 single-leg hops per leg (technique, "stick the landing")
6. **"Walk on toes" (dynamic calf activation) to third 5m cone**
   → at cone: 3 counter-movement jumps (technique)
7. **"Walk on toes" (dynamic calf activation) to fourth 5m cone**
   → at cone: 6 reverse lunges per side
8. **Jog around fifth 5m cone and back to start line**
9. **Send group to Y-Balance Station, repeat with next group of 4**



Appendix 12 – Y-Balance Test Platform

Y-Balance test specialized equipment platform (Shaffer *et al.*, 2013).

This equipment is available in the United States at https://www.functionalmovement.com/store/23/y-balance_test_kit.

FIGURE 3. Posteromedial reach Y-balance test.

Appendix 13 – Author's Guidelines IJSS

Author's guidelines for the submission of article one from the International Journal of Sport Sciences and Coaching (https://journals.sagepub.com/author-instructions/SPO).

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Manuscript Submission Guidelines: *International Journal of Sports Science & Coaching*

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Appendix 14 – Author's Guidelines JSS

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