Universidad Miguel Hernández de Elche

Programa de Doctorado en Deporte y Salud

Effects of injury prevention programs on physical performance and neuromuscular control in youth soccer

Doctoral Thesis

A dissertation presented by

Carlos Pomares Noguera

Directed by

Dr. José Luis López Elvira and codirected by Dr. Francisco Ayala Rodríguez

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AUTORIZA:

Que el trabajo de investigación titulado: *"Effects of injury prevention programs on physical performance and neuromuscular control in youth soccer"* realizado por D. Carlos Pomares Noguera bajo la dirección del Dr. José Luis López Elvira y la codirección del Dr. Francisco Ayala Rodríguez, sea defendido como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

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Coordinador del programa de doctorado

Universidad Miguel Hernández de Elche

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Título de la Tesis:

EFFECTS OF INJURY PREVENTION PROGRAMS ON PHYSICAL PERFORMANCE AND NEUROMUSCULAR CONTROL IN YOUTH SOCCER

Tesis Doctoral presentada por:

D. Carlos Pomares Noguera

Dirigida por el Dr. Francisco Ayala Rodríguez y del Dr. Jose Luis López Elvira

El director	**El codirector**	**El doctorando**
Fdo.: Jose Luis López Elvira	Fdo.: Francisco Ayala Rodríguez	Fdo.: Carlos Pomares Noguera

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A mi yaya, María.

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PREFACE

The doctoral thesis that the reader is holding in his/her hands is the result of the last five years of research on the exciting topic of injury risk mitigation in youth soccer by some members of the research group Biomechanics for Health and Sport Performance purposes (BIOMEC) (code: 10/0062E) based at Miguel Hernández University of Elche.

The thesis presented here is divided into four main parts. Part I provides an overview of the available standardized warm-up programs designed with the aim of reducing soccer-related injuries in youth players, the issues that this thesis seeks to address, and the research objectives and hypotheses. Part II includes the three studies developed to address the research questions mentioned in Part I. This part is further divided into three chapters (numbers 3 to 5) which present each of the studies separately to the reader. Part III presents the main conclusions drawn from this thesis and sets out future lines of research. Finally, Part IV provides the reference list of the studies cited throughout the different chapters.

However, the scientific production of this research project is not limited to this document. During the five years up to the completion of this thesis, the author has also collaborated in other research projects and has presented the main findings of this thesis in different International and National Congresses. This period has enabled the author to complete also one international research stay in United Kingdom (one month in the University of Gloucestershire) to improve his scientific skills. Finally, the author and his research group have been awarded with some mentions and distinctions during these years thanks to their contributions to this line of investigation.

I hope you enjoy reading this thesis as much as I have enjoyed these years of work.

ABSTRACT

The practice of sports on a regular basis has proven to be a vital component for maintaining an active and healthy lifestyle that lasts a lifetime, reducing the risk of suffering from numerous non-communicable diseases (e.g., cardiovascular disease [atherosclerosis], certain types of cancer [breast and colon], metabolic disorders [diabetes mellitus] and respiratory disease [chronic obstructive pulmonary disease]) and helps maintain an optimal state of physical, psychological and social well-being in children and adolescents.

In this sense, given that soccer (i.e., associate football) is the most popular sport in the world, being most of its practitioners under the age of 18, it could have great potential to induce the aforementioned effects in young people. However, the high physical demands of the game of soccer alongside the decline in essential motor performance that often occurs during the years of maximal rate of growth and maturation may place young players at high risk of suffering an injury in comparison with their non-athlete counterparts. Thus, soccer-related injuries can counter the health-related beneficial effects of sports participation at a young age if a child or adolescent is unable to continue to participate because of the residual effects of injury.

Within the last years, a number of neuromuscular training programs have been designed with the aim of preventing and reducing the number and severity of soccer-related injuries in children and adolescents. The effectiveness of these neuromuscular training programs to reduce non-contact and overuse injuries in young soccer players has been documented in systematic reviews and meta-analyses. Although the main purpose of these neuromuscular training programs is injury prevention, knowing the effects (acute and chronic) elicited by them on physical performance and neuromuscular control measures could help identify the potential mechanism underlying the reported reduction in the incidence of injuries. Therefore, the main objective of this doctoral thesis was to analyze the acute and chronic effects of some neuromuscular training programs on parameters of physical performance and neuromuscular control in youth soccer players. In order to achieve this objective, three randomized controlled studies were carried out in a sample of 83 young soccer players.

On the one hand, the results of these studies report that neither the FIFA 11+ nor the Harmoknee programs elicit superior acute effects on measures of physical performance

(with the exception of the 10 and 20 m sprint time) and neuromuscular control to the dynamic warm-up routines currently performed by most soccer players prior to training sessions and matches. On the other hand, the studies that comprise this doctoral thesis also show that, unlike traditional dynamic warm-up routines, when the FIFA 11+ Kids and FIFA 11+ programs are systematically performed at the start of training sessions and matches produce clinically relevant and statistically significant chronic improvements in some measures of physical performance (10 and 20 m sprint time and jump height) and neuromuscular control (unilateral dynamic balance, bilateral strength ratios) in children and adolescent soccer players, respectively.

Therefore, the main findings of this doctoral thesis suggest that the mechanisms behind the promising reduction in injury risk by adhering to the FIFA 11+ kids and FIFA 11+ programs in young soccer players might be particularly associated with enhancements in tendon stiffness, balance, coordination and physical competency.

Keywords: injury, injury prevention, children, adolescents, motor competence, warm-up, agility, dynamic stability, performance, jumping height.

RESUMEN

La práctica deportiva de manera regular ha demostrado ser un componente de vital importancia para mantener un estilo de vida activo y saludable que perdure toda la vida, que reduzca el riesgo de sufrir numerosas enfermedades crónicas no trasmisibles (ej., enfermedad cardiovascular [aterosclerosis], determinados tipos de cáncer [mama y colon], trastornos metabólicos [diabetes mellitus] y enfermedades respiratorias y pulmonares) y ayude a mantener un estado óptimo de bienestar físico, psíquico y social en niños y adolescentes.

En este sentido, y dado que el fútbol es el deporte más popular en todo el mundo, siendo la mayor parte de sus practicantes menores de 18 años, éste podría poseer un gran potencial para inducir los efectos anteriormente citados en los jóvenes. Sin embargo, las altas demandas físicas que el fútbol impone a sus practicantes, unido a los desajustes en el control motor propios del proceso de crecimiento y maduración, colocan a los jóvenes jugadores en una situación más vulnerable para sufrir una lesión en comparación con sus homólogos no deportistas. Así, las lesiones podrían contrarrestar los efectos positivos que la práctica del fútbol presenta sobre la salud si un niño o adolescente no es capaz de continuar adherido a la misma como consecuencia de los efectos residuales derivados de estas.

En los últimos años, numerosos programas de entrenamiento neuromuscular (ej., FIFA 11+ y Harmoknee) han sido diseñados con el propósito de prevenir y reducir el número y la severidad de las lesiones asociadas a la práctica del fútbol en niños y adolescentes. La efectividad de estos programas de entrenamiento neuromuscular para reducir las tasas de lesiones por no contacto y sobreuso ha sido documentada en jóvenes jugadores por estudios de revisión y meta-análisis. Aunque el principal propósito de los programas de entrenamiento neuromuscular es la prevención de lesiones, conocer los efectos (agudos y crónicos) ocasionados por estos programas sobre el rendimiento físico y control neuromuscular podría ayudar a identificar el mecanismo potencial que subyace a la evidenciada reducción en la incidencia de lesiones. Por lo tanto, el objetivo principal de esta tesis doctoral fue analizar los efectos agudos y crónicos de ciertos programas de entrenamiento neuromuscular sobre parámetros de rendimiento físico y control neuromuscular en jugadores jóvenes de fútbol. Con el fin de conseguir estos objetivos, se

realizaron tres estudios experimentales controlados y aleatorizados en una muestra de 83 jugadores jóvenes de fútbol.

Los resultados de los estudios experimentales informan, por un lado, de que los programas FIFA 11+ y Harmoknee no producen efectos agudos sobre medidas de rendimiento físico (con excepción del tiempo en el sprint de 10 y 20 m) y control neuromuscular distintos a los observados por los programas tradicionales de ejercicios dinámicos que muchos jugadores adolescentes de fútbol llevan a cabo al inicio de las sesiones de entrenamiento y los partidos. Por otro lado, estos estudios también muestran que la realización sistemática de los programas FIFA 11+ Kids y FIFA 11+ al inicio de las sesiones de entrenamiento y en sustitución de las tradicionales rutinas de calentamiento dinámico produce una mejora clínicamente relevante y estadísticamente significativa en ciertas medidas de rendimiento físico (tiempo en el sprint de 10 y 20 m y altura de salto) y control neuromuscular (estabilidad dinámica unipodal, ratios bilaterales de fuerza) en niños y adolescentes jugadores de fútbol, respectivamente.

Por lo tanto, los principales hallazgos de la presente tesis doctoral sugieren que el mecanismo que podría estar detrás de la reducción en el riesgo de lesión que la adherencia a los programas FIFA 11+ Kids y FIFA 11+ produce en jugadores jóvenes de fútbol podría estar particularmente asociado a mejoras en la rigidez tendinosa, estabilidad, coordinación y competencia física.

Palabras clave: lesión, prevención de lesiones, niños, adolescentes, competencia motriz, calentamiento, agilidad, estabilidad dinámica, rendimiento, altura de salto.

ABBREVIATIONS

3G: Third generation

ACL: Anterior cruciate ligament

ASIS: Anterior superior iliac spine

CI: Confidence interval

CG: Control group

CMJ: Countermovement jump

CON: Concentric

COP: Center of pressure

CV: Coefficient of variation

DJ: Drop jump

DWU: Dynamic warm-up

ECC: Eccentric

F-MARC: FIFA Medical Assessment and Research Centre

FIFA: Fédération Internationale de Football Association

H/Q: Hamstring to quadriceps strength ratio

H/Q_{CONV}: Conventional hamstring to quadriceps strength ratio

H/Q_{CONV60}: Conventional hamstring to quadriceps strength ratio at 60º/s

$H/Q_{CONV180}$: Conventional hamstring to quadriceps strength ratio at 180º/s

H/Q_{FUNCT}: Functional hamstring to quadriceps strength ratio

H/Q_{FUNC60}: Functional hamstring to quadriceps strength ratio at 60º/s

$H/Q_{FUNC180}$: Functional hamstring to quadriceps strength ratio at 180º/s

$H/Q_{FUNC30/240}$: Functional hamstring to quadriceps strength ratio between the torques 30º/s (eccentrically) and 240º/s (concentrically)

IG: Intervention group

KIPP: Knee injury prevention program

LESS: Landing error scoring system

LSI: Limb symmetry index

PAP: Post-activation potentiation

PEP: Prevent injury and enhance performance program

PHV: Peak height velocity

RCT: Randomized control trial

ROM: Range of motion

RR: Relative risk

RSA: Repeated sprint ability

SD: Standard deviation

SEM: Standard error of measure

SLJ: Standing long jump

SSC: Stretch-shortening cycle

TE: Typical error of measure

VJ: Vertical jump

WHO: World Health Organization

CHAPTER 1

General Introduction

1

GENERAL INTRODUCTION

1.1 HEALTH BENEFITS OF REGULAR PHYSICAL ACTIVITY AND SPORT PARTICIPATION IN CHILDREN AND ADOLESCENTS

Both regular physical activity and physical fitness are considered to be important prerequisites for the health of children (5-14 years) and adolescents (>14-18 years) [1–3]. Thus, the benefits provided by regular physical activity for both children and adolescents have been observed in several health domains (table 1.1) that include physiology, neuroimmune functioning, recovery from disease and disability, increased muscular strength and cardiorespiratory fitness, angiogenesis and neurogenesis, reduced risk for chronic disease, improved self-esteem and psychological well-being as well as reduced stress, anxiety and depression [4]. Regular physical activity may also reduce the cost of managing common noncommunicable diseases that are associated with inadequate physical activity in youth population (e.g., obesity, low-back pain) and fosters better performance in schools (World Health Organization [WHO] [5]).

Therefore, promoting a physically active lifestyle across youth is not only an imperative for public health but also vitally important for the social and economic development of the countries [1]. In this sense, the new WHO 2020 guidelines on physical activity and sedentary behavior strongly recommend that children and adolescents:

- Should do at least an average of 60 min per day of moderate-to-vigorous intensity, mostly aerobic, physical activity, across the week.
- Vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone should be incorporated at least 3 days a week.

Sport may serve as a suitable and enjoyable physical activity setting for achieving these recommended levels of practice for health in youth population. Furthermore, participation in organized youth sport has been positively associated with higher levels of physical activity in adulthood [6,7].

Table 1.1: Summary of the major benefits of childhood and adolescence physical activity.

1. Health benefits during childhood and adolescence
▪ Maintenance of energy balance and prevention of overweight and obesity.
▪ Promoted healthy growth and development of the musculoskeletal and cardiovascular system.
▪ Reduced risk factors for: - Cardiovascular disease. - Type 2 diabetes. - Hypertension. - Hypercholesterolemia.
▪ Improved mental health and psychological well-being through: - Reduced anxiety and stress. - Reduced depression. - Higher self-esteem. - Improved cognitive function.
▪ Improved social interaction.
2. Improved health during adulthood
▪ Reduced probability of becoming obese during adulthood.
▪ Reduced morbidity and mortality from chronic disease during adulthood.
▪ Improved bone mass reduces likelihood of osteoporosis in later life.
3. Establishment of lifetime activity patterns
▪ Improved likelihood of becoming an active adult.

In this sense, as soccer (i.e., associated football) is the world's most popular sport with more than 270 million registered players (at amateur and elite levels) in 2006 [8], most of them male younger than 18 years, it might have a great potential to induce beneficial health effects and to support an active and healthy lifestyle during the life-course [9]. However, sport (including soccer) has been considered a double-edged sword [10] as it may have also some negative aspects (mainly at elite levels) associated. These negative aspects should be mitigated to avoid that its health benefits elicited in children and adolescents could be dramatically dismissed or even overwhelmed by them (e.g., risk of failure leading to poor mental health [11,12], risk of injury [13,14], sudden death [15–17], eating disorders [18], burnout [19], and exercise-induced gastrointestinal tract discomfort [20]). Among the most frequently reported negative aspects associated with youth soccer it can be found an elevated risk of injury [21]. This heighten injury risk, but particularly the standardized strategies designed to mitigate it, is the object of study of the present doctoral thesis. Although soccer practice increases the risk of injury in both male and female players (independently of their age and level of play), the current thesis is focused on youth male soccer players.

1.2 EPIDEMIOLOGY OF INJURIES IN YOUTH SOCCER

Soccer requires players to perform a substantive number of repeated high intensity movements such as sudden accelerations and decelerations, rapid changes of direction, tackling, jumping and landing tasks [22,23]. These high-intensity situations result in a notable increase in injury risk and are especially relevant in children where individual growth and maturation may predispose youth players to a higher risk [24–27].

In this sense, Rössler et al. [28], in a two-season descriptive epidemiological study carried out in players aged from 7 to 12 years, documented injury incidence rates of 0.6 (95% confidence interval [CI] = 0.5 - 0.7) and 4.6 (95% CI = 4.0 - 5.2) injuries per 1000 hour of soccer exposure during training sessions and match play, respectively. In addition, this study found that most (76.3%) injuries were located in the lower limbs and the most common types of injuries were joint and ligament injuries (mainly in the knee and ankle joints) (30.5%), contusions (22.5%), muscle and tendon injuries (mainly thigh [hamstrings, abductors and quadriceps] muscles) (18.5%), and fractures and bone injuries (15.4%). These authors also noticed a positive relationship between injury incidence and players´ age.

For its part, a recently conducted systematic review and meta-analysis on epidemiology of injuries in youth soccer (under 19 years old) reported for male adolescent players (12 to 19 years) training and match injury incidence rates of 2.8 (95%CI = 2.0 – 3.5) and 14.4 (95%CI = 11.0 – 17.8) per 1000 hours of exposure, respectively. In addition, lower extremity injuries had the highest incidence rates (4.1 injuries/1000 hours of exposure) and the most common types of injuries were muscle/tendon (1.9 injuries/1000 hours of exposure) and joint (non-bone) and ligament injuries (1.0 injuries/1000 hours of exposure) [29].

From the epidemiological data just described, it might be stated that injury incidence rates are higher during the adolescence compared to the pre-pubertal stage [30]. In particular, injury incidence seems to be aligned to peak height velocity (adolescence), when rapid disproportional growth is evident [31]. Likewise, the injury pattern seems to be different in children and adolescents, whereby younger soccer players seem to have more fractures and bone stress, fewer strains and sprains, and more injuries of the upper body than adolescent players (12-18 years).

The most frequently diagnosed soft tissue injuries (muscle, tendon and ligament) in youth male soccer players (i.e., thigh muscle strains, knee and ankle ligaments sprains and tears) may: a) lead to moderate absence from sport participation, b) negatively impact on short and long-term athlete development, c) cause long-term disability (development of knee osteoarthritis in adulthood) and d) increase medical costs [32,33]. Thus, soccer-related injuries can counter the health- related beneficial effects of sports participation at a young age if the child or adolescent is unable to continue to participate because of the residual effects of injuries [24].

Consequently, there is a clear need for implementing appropriated measures to prevent and reduce the number and severity of soccer-related injuries in youth male players.

1.3 STRUCTURED WARM-UP PROGRAMS FOR INJURY PREVENTION IN YOUTH SOCCER

Within the last decade, a substantive number of studies have been published describing different warm-up programs (e.g., FIFA 11 [34], FIFA 11+ [35], FIFA 11+ Kids [28], Harmoknee [36], Knäkontroll [37], KIPP [38] and PEP [39]) aimed at reducing the number and severity of sport-related injuries in children but mainly adolescent players. All of these programs include running exercises and specific dynamic movements focusing on enhancing physical competence and performance, as it has been suggested as a primary injury risk factor in youth team sport athletes [40,41] and are based on the injury profile and biological status (i.e., maturation phase) of the target population (children [<12 years] and adolescents [from 12 to 18 years]).

The three most popular standardized injury prevention programs that have been specifically developed to be implemented as pre-exercise warm-ups in youth soccer are described as follow.

FIFA 11+

The FIFA 11+ was developed in 2006 by the FIFA Medical Assessment and Research Centre (F -MARC) together with the Oslo Sports Trauma Research Centre and the Santa Monica Orthopaedic and Sports Medicine Research Foundation. FIFA 11+ is a complete warm-up program with running exercises at the beginning and end to activate the cardiovascular system. It features specific preventive exercises focusing on core and leg strength, balance and agility, each of them at three levels of increasing difficulty to provide variation and progression (figure 1.1). It takes about 20 to 25 minutes to complete and requires minimal equipment (a set of cones and balls). FIFA 11+ is encouraged to replace usual warm-ups for a few sessions (two or three) each week in amateur adolescent soccer.

Figure 1.1. FIFA 11+ program.

Harmoknee

The Harmoknee injury prevention program, designed by Kiani et al. [36], aims to reduce knee injury incidence rates in youth soccer players. It is focused on improving the main modifiable risk factors for knee injuries but mainly those related to anterior cruciate ligament (ACL) tears and ruptures (e.g., global dynamic stability of the lower limb, knee control during jump and fall actions, eccentric strength, joints range of motion). It is a multi-component program, consisting of five well-defined sections or blocks of exercises: warm up, muscle activation, balance, strength and core stability. These blocks of exercises were designed according to the existing scientific evidence regarding non-contact knee injury risk factors and were also supported by several experienced soccer practitioners (table 1.2).

Table 1.2. Harmoknee warm-up program*.

Exercise	Duration
Part 1: Warm up	10 minutes
1. Jogging	4 minutes
2. Backward jogging on the toes	1 minute
3. High-knee skipping	30 s
4. Defensive pressure technique	30 s
5. One and one	2 minutes
Part 2: Muscle activation	2 minutes
6. Calf	4 s each leg/side
7. Quadriceps	
8. Hamstrings	
9. Hip flexor muscles	
10. Groin muscles	
11. Hip and lower back muscles	
Part 3: Balance	2 minutes
12. Forward and backward double leg jumps	30 s
13. Lateral single leg jumps	
14. Forward and backward single leg jumps	
15. Double leg jump with or without ball	
Part 4: Strength	4 minutes (1 min each exercise)

16. Walking lunges in place	15 repetitions each leg
17. Hamstring curl	12 repetitions
18. Single-knee squat with toe raises	12 repetitions
Part 5: Core stability	4 minutes (1 min each exercise)
19. Sit-ups	2 sets x 12 repetitions
20. Plank on elbows and toes	2 sets x 20 s
21. Bridging	2 sets x 12 repetitions

*: for more details see http://www.harmoknee.com

FIFA 11+ Kids

As with the FIFA 11+ program, the Kids' version was designed by a panel of international experts from the FIFA Medical Assessment and Research Centre (F-MARC), the Department of Sport, Exercise and Health (DSBG) in Basel (Switzerland), the University of Amsterdam (Netherlands), the University of Cincinnati (USA), the Charles University and Na Bulovce Hospital (Czech Republic), the University of Applied Science in Sion (Switzerland) and the Institute of Sport and Preventive Medicine of Saarland University.

The FIFA 11+ for Kids has been specially developed for children's soccer, and the program is aimed at 7 to 13-year-olds. There is a focus on:

- Spatial orientation, anticipation, and attention particularly while dual-tasking (to avoid unintended contact with other players or objects).
- Body stability and movement coordination (more general than specific).
- Learning appropriate fall techniques (to minimize the consequences of unavoidable falls).

Accordingly, this warm-up program may contribute to achieving the aims of the earlier stages (1. Active Start, 2. FUNdamentals, and 3. Learn to Train) of the long-term athletic development conceptual model for late specialization sports [42–44].

The program consists of seven exercises that should be performed in the specified order at the beginning of every training session (figure 1.2). Every exercise has five levels that become progressively harder (levels 1 to 5). It should take around 15 minutes to complete the program.

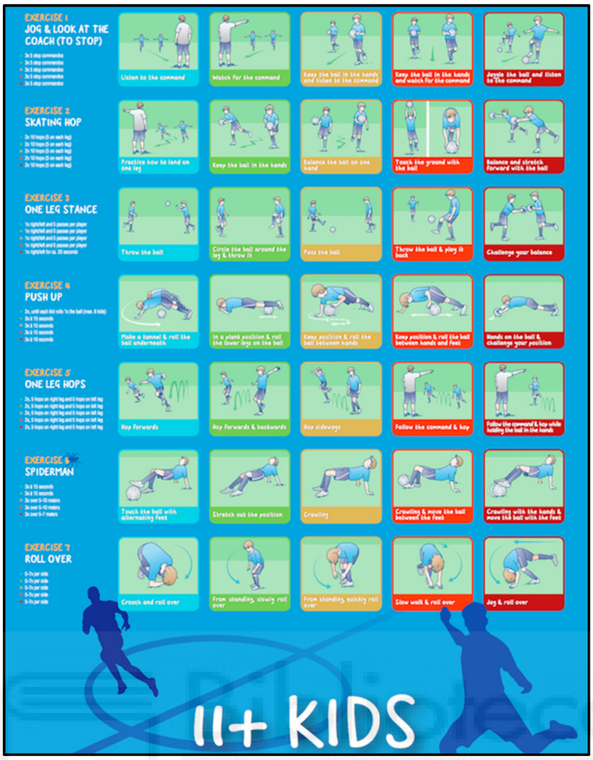


Figure 1.2. FIFA 11+ Kids program.

1.3.1 Evidence of injury prevention for FIFA 11+, Harmoknee and FIFA 11+ Kids programs in youth soccer

In the last decade, a substantive number of prospective studies have been conducted to explore the injury-preventing effect of FIFA 11+ in youth soccer (table 1.3). Epidemiological data from these individual studies has been also pooled into different meta-analyses with the aim of increasing statistical power and assess with a higher level of evidence whether the FIFA 11+ program when systematically performed during training is associated with injury reduction in adolescent soccer players [45]. In this sense, the FIFA 11+ program has demonstrated a substantial injury-preventing effect by reducing soccer injuries in recreational/subelite soccer by 39% [45]. Furthermore, this program has been able to reduce the top four most prevalent soccer injuries: hamstring, hip/groin, knee and ankle injuries by 60%, 41%, 48% and 32%, respectively. However, it should be highlighted that in order to achieve the desired injury-preventing effect, the FIFA 11+ must be performed at least twice a week during training sessions and/or match play for 16-24 weeks.

Only Kiani et al. [36] have assessed the efficacy of the Harmoknee program to reduce the number of knee injuries in a large cohort (n = 1506) of adolescent female soccer players (from 13 to 19 years old). In particular, this study documented a significant reduction in non-contact knee injury rates for the intervention (i.e., Harmoknee) group (0.01 injuries per 1000 hours of exposure) in comparison with the control group (0.15 injuries per 1000 hours of exposure), which performed the usual warm-up.

Despite the fact that both the FIFA 11+ and FIFA 11+ Kids have been designed by the same international group of experts, the efficacy of the latter program to reduce injury incidence rates in children soccer players has not been explored with the equal vigor that the FIFA 11+ (table 1.3). In this sense, the evidence available in this regard suggests that the implementation of the FIFA 11+ Kids as pre-exercise warm-up in training sessions and match play may result in a notable reduction of injury risk [42,43] and its associated health care costs [46] in children younger than 14 years. In particular, a major study of over 4,000 children in four countries showed that players who used the FIFA 11+ Kids program suffered 38% fewer injuries than children in the group that used a normal warm-up program, and where serious injuries were concerned (i.e., those involving a period of over 28 days without playing) the figure even exceeded 50% [42].

Therefore, the current scientific evidence available allows to state, but with different degree of certainty, that the FIFA 11+, Harmoknee and FIFA 11+ Kids, when performed systematically during everyday training sessions (2-3 times per week for at least 16 weeks) as standard warm-up, may present powerful injury-preventing effects in youth soccer players. Despite these injury-preventing effects, the implementations of the FIFA 11+, Harmoknee and FIFA 11+ Kids programs in applied youth soccer settings remains a challenging task.

Grass-root coaches have been identified as the key instigators in performing injury prevention programs with their players. What are the performance benefits of such exercises? is one of the most common questions by soccer coaches, when exposed to an injury prevention program. Therefore, if these three injury prevention programs also demonstrated direct performance benefits it would help motivate grass-root coaches and players to implement them (as alternatives to traditional warm-ups) in their training sessions and match play.

Table 1.3. Summary of studies investigating the injury-preventing effects of FIFA 11+, FIFA 11+ Kids and Harmoknee programs.

Reference / Country	Participants	Weekly frequency	Duration	Total exposure	Nº of injuries	Conclusions
FIFA 11+						
Soligard et al. [35] Norway	A total of 1892 female players (12-17 years) belonging to 93 teams - IG: 41 teams and 837 players - CG: 52 teams and 1055 players	Twice	36 weeks	- IG: 49899 h - CG: 45428 h	- IG: 161 - CG: 215	In the IG, there was a significantly lower risk of injury in general (RR = 0.68 [95%; CI = 0.48-0.98]), lower risk of overuse / fatigue injuries (RR = 0.47 [95%CI = 0.26-0.85]) and lower risk of serious injury (RR = 0.55 [95% CI = 0.36-0.83]) compared to the CG.
Steffen et al. [47] Canada	A total of 2020 female players (13-17 years belonging to 109 teams - IG: 58 teams and 1073 players - CG: 51 teams and 947 players	1	32 weeks	- IG: 66423 h - CG: 65725 h	- IG: 242 - CG: 241	There was no difference in the overall injury rate between the IG (3.6 injuries/1000h [95%CI: 3.2-4.1]) and CG (3.7 injuries/1000h [95%Cl = 3.2-4.1] (RR = 1.00 [95%CI = 0.8-1.2]) or in the incidence of any type of injury.
Longo et al. [48] Italy	A total of 121 male players (13-17 years) belonging to 11 teams - IG: 7 teams and 80 players - CG: 4 teams and 41 players	3-4	36 weeks	- IG: 23640 h - CG: 12648 h	- IG: 14 - CG: 17	FIFA 11+, unlike CG, showed a significant reduction in the overall (0.9 vs 2.2 injuries/1000h) and lower extremity (0.7 vs 1.4 injuries/1000h) injury incidence rates. Severe injuries were also reduced (0 vs 0.5 injury/1000h).
Steffen et al. [49] Canada	A total of 226 female players (13-18 years) belonging to 29 teams	2-3	16 weeks	- IG1: 2230,4 h - IG2: 2698,8 h	- IG1: 16 - IG2: 14	No significant inter-group differences in injury incidence rates were reported. However, a sub-

	- IG1 (Regular): 10 teams and 68 players - IG2 (Comprehensive): 10 teams and 78 players - CG: 9 teams and 80 players			- CG: 2496 h	- CG: 16	analysis revealed that compared to players with low adherence, players with high adherence to FIFA 11+ had a 57% lower risk injury (RR = 0.43 [95% CI = 0.19-1.00]).
Owoeye et al. [50] Nigeria	A total of 416 male players (14-19 years) belonging to 20 teams - IG: 10 teams and 204 players - CG: 10 teams and 212 players	Twice	24 weeks	- IG: 51017 h - CG: 61045 h	- IG: 36 - CG: 94	The FIFA 11+ program significantly reduced the overall injury rate in the IG by 41% (RR = 0.59 [95% CI: 0.40-0.86; p = 0.006]) and injuries in lower limbs 48% (RR = 0.52 [95% CI: 0.34-0.82; p = 0.004]).
Rahlf & Zech et al. [51] Germany	A total of 185 players (14-17 years) belonging to 13 teams - IG1 (10 min): 6 teams and 77 players - IG2 (20 min): 7 teams and 108 players	Twice	40 weeks	- IG2: 12499 h - IG1: 8633 h	- IG2: 90 - IG1: 55	No significant differences between groups were found. Injury incidence in the group performing the program 10 min was 6.37/1000h compared to 7.20/1000h in the group performing the program 20 min.
			FIFA 11+ Kids			
Rössler et al. [42] Switzerland Czech Republic Germany Holland	A total of 3895 male and female players (9-12 years) belonging to 243 teams - IG: 128 teams and 2066 players - CG: 115 teams and 1829 players	Twice	36 weeks	- IG: 140716 h - CG: 152033 h	- IG: 139 - CG: 235	Compared to CG, IG reported 48% reduction in overall injury rate, 74% reduction in severe injury rate and 55% reduction in lower extremity injury rate (RR = 0.52 [95%CI = 0.32-0.86]).

Rössler et al. [46] Switzerland Czech Republic Germany Holland	A total of 1002 male and female players (7-12 years) belonging to 62 teams - IG: 37 teams and 2066 players - CG: 25 teams and 1829 players	Twice	44 weeks	- IG: 43777 h - CG: 32596 h	- IG: 42 - CG: 57	This exercise-based injury prevention program was efficacious in reducing the number of soccer injuries by 50% (RR = 0.50 [95%CI = 0.29-0.86]).
Beaudouin et al. [43] Switzerland Czech Republic Germany Holland	A total of 3895 male and female players (7-13 years) belonging to - teams - IG: - teams and 2066players - CG: - teams and 1829 players	Twice	36 weeks	- IG: 140659 h - CG: 152089 h	- IG: 21 - CG: 50	There was a reduction of severe overall (RR = 0.42 [95% CI = 0.24 to 0.72]), match (RR = 0.41 [95%CI = 0.17 to 0.95]) and training injuries (RR = 0.42 [95% CI = 0.21 to 0.86]) in IG.
Zarei et al. [52] Iran	A total of 962 male players (7-14 years) belonging to 32 teams - IG: 15 teams and 443 players - CG: 17 teams and 519 players	Twice	32 weeks	- IG: 31934 h - CG: 32113 h	- IG: 30 - CG: 60	Injuries were reduced by half (RR = 0.50 [95%CI = 0.32- 0.78]).
			Harmoknee			
Kiani et al. [36] Sweden	A total of 1506 female players (13-19 years) belonging to 97 teams - CG: 49 teams and 729 players - IG: 48 teams and 777 players	1-2	36 weeks	- IG: 66981 h - CG: 66505 h	- IG: 3 - CG: 13	Harmoknee presented a high reduction in the knee injury incidence (0.04 vs 0.2 injury/1000h) and specifically, on non-contact injuries in this joint (0.01 vs 0.15 injury/1000h) (RR = 0.06 [95%CI = 0.01-0.46]).

CG: control group; IG: intervention group; RR: relative risk; CI: confidence interval

1.4 EFFECTS OF FIFA 11+, HARMOKNEE AND FIFA 11+ KIDS PROGRAMS ON PHYSICAL PERFORMANCE AND NEUROMUSCULAR RISK FACTORS

Meta-analytical evidence shows that exercise-based injury prevention programs (including FIFA 11+, FIFA 11+ Kids and Harmoknee) are efficacious in reducing injuries in young athletes when they are systematically performed [45,53–56]. However, often it is difficult to stimulate club managers and coaches to perform such training programs just for the prevention of injuries [57]. As stated before, one important argument to convince manager, coaches, and players for the implementation of these exercise-based injury prevention programs might be the fact that they are able to simultaneously elicit positive (acute and chronic) effect on athletes' performance [32]. In addition, the knowledge of the effects elicited by these exercise-based injury prevention programs on physical and neuromuscular performance measures can help in identifying the potential mechanisms behind the documented reduction in injury incidence.

Acute and chronic physical performance and neuromuscular control adaptations resulting from the application of the FIFA 11+, Harmoknee and FIFA 11+ Kids in organized child and adolescent soccer are presented as follow.

1.4.1 Post-exercise (acute) effects of the FIFA 11+, FIFA 11+ Kids and Harmoknee programs on measures of physical and neuromuscular performance youth soccer

It is widely accepted that a "good" or "appropriate" warm-up program should be able to improve performance (via post activation potentiation, decrease in stiffness, rise in core temperature and resting oxygen consumption [58]) but should not be too demanding to cause detrimental effects due to fatigue related factors [59]. Therefore, the FIFA 11+, FIFA 11+ Kids and Harmoknee must demonstrate that they are able to elicit physiological acute changes (post-exercise effects) to positively affect the major physical and neuromuscular performance measures (i.e., sprinting, jumping, range of motion, etc.) before being considered as appropriate warm-up program to be performed prior to formal training and competition.

Furthermore, if the use of the FIFA 11+, FIFA 11+ Kids and/or Harmoknee is to be promoted at the expense of dynamic warm-up programs currently performed by most amateur young soccer teams, the magnitude of their hypothetical positive effects on physical and neuromuscular performance measures should be at least similar to those reported by the latter mentioned warm-up programs [28,52,60–64]. Otherwise, the FIFA 11+, FIFA 11+ Kids and Harmoknee should be implemented in everyday soccer sessions as training components (i.e., placed in the main part of the training sessions), based on their demonstrated superior positive effects on injury incidence rates in comparison with traditional practices, rather than being used as a pre-exercise warm-up routine.

However, analyzing the body of literature regarding the acute effects of the FIFA 11+, FIFA 11+ Kids and Harmoknee on sports performance, a smaller evidence base supporting their use as "good warm-up programs" appears to be available in comparison with the number of studies that have documented their efficacy as long-term interventions to reduce the injury incidence (table 1.3). To the best of the candidate knowledge, only Bizzini et al. [59], Silva et al. [61], Chen et al. [65], Akbari et al. [62], Pardos-Mainer et al. [66], Parsons et al. [67], and Trajkovic et al. [64] have examined the pre-exercise effects of the FIFA 11+ on various physical and neuromuscular performance variables in young (males and females) soccer players, showing improvements in 20 m sprint time, jump height, agility, balance (static and dynamic) and maximal strength comparable with those obtained with other dynamic warm-up routines reported in the literature. In addition, Bizzini et al. [59] also reported that the FIFA 11+ induced similar improvement in resting oxygen uptake, core temperature and lactate as those obtained with other warm-up routines.

However, no studies (to the candidate´ knowledge) have analyzed the acute effects of the Harmoknee on physical and neuromuscular performance measures in young soccer players.

For its part, only Rössler et al. [28] have examined the pre-exercise effects of the FIFA 11+ kids on various physical performance variables in children soccer players, showing possibly beneficial effects in static and dynamic balance, jumping performance, and slalom dribbling.

Therefore, there is a clear need of studies aimed at exploring the acute (post-exercise) effects of these three programs on physical and neuromuscular performance measures in order to elucidate whether (or not) the FIFA 11+, FIFA 11+ Kids and/or Harmoknee may be considered as appropriate warm-up routines.

1.4.2 Training (chronic) effects of the FIFA 11+, Harmoknee and FIFA 11+ Kids programs on measures of physical and neuromuscular performance youth soccer

Some studies, but not many, have explored the training effects of both FIFA 11+ (mainly) and Harmoknee on some measures of neuromuscular performance (lower extremity balance [60] and core stability [67], knee proprioception [60], knee strength [60]) and sprinting and jumping abilities [61–64,67], which form part of the athletic physical performance spectrum, in adult soccer players (table 1.4). However, only six studies (to the best of the candidate´s knowledge) have been published analyzing the training effects of these two injury prevention programs on measures of physical and neuromuscular performance in adolescent soccer players despite being the target population of both programs. For example, Zarei et al. [68] examined the long-term effects of the FIFA 11+ program on selected physical performance measures in adolescent male soccer players (n = 82). After 30 weeks of using the FIFA 11+ as a warm-up program, improvements in jump height, agility and sprint time were observed compared to a normal warm-up routine [68].

For its part, only one study has examined the pre-exercise effects of the FIFA 11+ Kids on various physical performance measures in children soccer players, showing possibly beneficial effects in static and dynamic balance, jumping performance and slalom dribbling [28].

Therefore, studies on the physical and neuromuscular performance effects of the FIFA 11+, Harmoknee and FIFA 11+ Kids in children and adolescent soccer players are clearly warranted. This knowledge would help convince club managers and coaches of the need to implement the FIFA 11+, Harmoknee and FIFA 11+ Kids in their daily training sessions with the aims of reducing the number and severity of injury and improving performance in youth soccer players.

Table 1.4. Training (chronic) effects of the FIFA 11+, Harmoknee and FIFA 11+ Kids programs on measures of physical and neuromuscular performance in youth soccer players.

Reference Country	Participants	Design	Interventions	Outcome measures Sprint	Jump	Balance	Agility	Others	Key findings
				FIFA 11+					
Daneshjoo et al. [60] Iran	36 male young soccer players IG = 12 (19.2 ± 0.9 y) CG = 12 (19.7 ± 1.6 y)	Cluster-RCT	FIFA 11+ 8 weeks 3 days per week	-	-	Y-Balance Static Balance open and closed eyes	-	Proprioception Isokinetic strength (knee)	Dynamic balance, proprioception and isokinetic strength improved in FIFA 11+ group compared with CG.
Silva et al. [61] Brazil	17 male young soccer players IG = 9 (18.3 ± 1.6 y) CG = 8 (18.3 ± 1.6 y)	Cluster-RCT	FIFA 11+ 9 weeks 3 days per week	-	SJ CMJ	-	-	-	IG showed significant improvements in both types of jumps (SJ and CMJ).
Akbari et al. [62] Iran	24 male elite-young soccer players IG = 12 (16.79 ± 1.18 y) CG = 12 (16.79 ± 1.18 y)	Cluster-RCT	FIFA 11+ 8 weeks 3 days per week	-	VJ	-	-	-	IG improves performance in the vertical jump test, but the improvement was not maintained after one month of halting training.
Zarei et al. [63] Iran	82 male adolescent soccer players IG = 34 (15.0 ± 0.7 y) CG = 32 (15.2 ± 0.6 y)	Cluster-RCT	FIFA 11+ 30 weeks At least 2 days per week	20 and 40 yards	VJ CMJ	-	Illinois agility Dribbling sprint	Yo-Yo IR Sit and reach	IG showed superior results compared to CG in sprint time (20 yards), jump height (VJ and CMJ) and agility (Illinois agility).
Parsons et al. [67]	43 female young soccer players	Cluster-RCT	FIFA 11+ 36 weeks		LESS	Y-Balance	T-test	Static plank	IG increased their mean static plank hold time compared with

Canada	IG = 25 (11.1 ± 1.6 y) CG = 18 (10.8 ± 2.2 y)		1-2 days per week		VJ				CG. Y-Balance scores worsened from pre- to postseason in both groups.
Trajkovic et al. [64] Serbia	36 male young soccer players IG = 19 (11.2 ± 0.8 y) CG = 17 (10.9 ± 0.8 y)	Cluster-RCT	FIFA 11+ 4 weeks 3 days per week	20 m	SLJ	-	Illinois agility	RSA Sit and reach	Agility and jump height improved in FIFA 11 group compared with control.
Harmoknee									
Daneshjoo et al. [60] Iran	36 male young soccer players IG = 12 (19.2 ± 0.9 y) CG = 12 (19.7 ± 1.6 y)	Cluster-RCT	Harmoknee 8 weeks 3 days per week	-	-	Y-Balance Static Balance open and closed eyes	-	Proprioception Isokinetic strength (knee)	Dynamic balance, proprioception and isokinetic strength improved in Harmoknee group compared with CG.
FIFA 11+ Kids									
Zarei et al. [52] Iran	31 male young soccer players IG = 16 (11.3 ± 0.9 y) CG = 15 (11.7 ± 0.7 y)	Cluster-RCT	FIFA 11+ Kids 10 weeks 2 days per week	-	-	-	-	Isokinetic strength (hip, knee and ankle)	The IG was beneficial compared to the CG regarding isokinetic strength of the hip adductors, knee flexors, as well as ankle evertors and invertors.
Zarei et al. [63] Iran	56 male adolescent soccer players IG = 19 (11.9 ± 1.9 y) CG = 23 (12.1 ± 1.1 y)	Cluster-RCT	FIFA 11+ Kids 10 weeks At least 2 days per week	20 and 40 yards	SLJ Hop	Y-Balance	Illinois agility Dribbling sprint	Plank Side plank	IG gained significantly better results in balance, jump height and sprint time compared to CG.

Rössler et al. [28] Switzerland	122 children soccer players IG = 56 (10.0 ± 1.8 y) CG = 66 (10.1 ± 1.6 y)	Cluster-RCT	FIFA 11+ Kids 10 weeks At least 2 days per week	20 m	DJ CMJ SLJ	Y-Balance	Slalom dribble	Wall volley	Beneficial improvements in favor of FIFA 11+ Kids were observed in jump height, balance, agility and wall volley performance.

IG: intervention group; CG: control group; RCT: randomized control trial; DJ: drop jump; CMJ: countermovement jump; SLJ: standing long jump; VJ: vertical jump; LESS: Landing error scoring system; RSA: repeated sprint ability.

1.5 LINES OF ACTION OF THE PRESENT PHD THESIS

The FIFA 11+, Harmoknee and FIFA 11+ Kids, when they are systematically performed as pre-exercise warm-ups (2-3 times a week) in training sessions and match play for at least 3 months, have demonstrated being powerful risk mitigation strategies in amateur youth soccer. However, despite their recognized injury-preventing effects, coaches and players do not usually embrace with enthusiasm these standardized warm-up programs as their adherence rates have been consistently reported as low in youth soccer. An argument that might help to persuade coaches and soccer players to incorporate these injury prevention programs in daily training sessions and matches is that they could be concurrently used to benefit sport performance. Furthermore, the knowledge of the effects elicited by these exercise-based injury prevention programs on physical and neuromuscular performance measures can help in identifying the potential mechanisms behind the documented reduction in injury incidence. However, very few studies have analyzed the effects of the FIFA 11+, Harmoknee and FIFA 11+ Kids programs on major physical performance measures and neuromuscular risk factors. Therefore, the aim of the present doctoral thesis focuses on analysing the acute (i.e., post-exercise) (study 1) and training (i.e., chronic) (studies 2 and 3) effects of the FIFA 11+, Harmoknee and FIFA 11+ Kids programs on measures of physical and neuromuscular performance in youth soccer players.

CHAPTER 2

Research Objectives and Hypothesis

2

RESEARCH OBJECTIVES AND HYPOTHESES

2.1 GENERAL OBJECTIVE

Based on the limitations of the literature presented in the previous chapter, the general objective of the current doctoral thesis was *to analyze the acute and chronic effects of three neuromuscular training programs on parameters of physical performance and neuromuscular control in male young soccer players.*

In order to achieve this objective, three randomized controlled (experimental) studies were carried out. The first study described the acute effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on several physical performance measures in amateur soccer players. The second study analyzed the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance in youth amateur soccer players. The last study examined the training effects of the FIFA 11+ Kids on several parameters of physical performance in male youth soccer players.

The titles of the three studies that comprised the current doctoral thesis are the following:

- **Study 1.** Acute effects of three neuromuscular warm-up strategies on several physical performance measures in football players.
- **Study 2.** Training effects of the FIFA 11+ and Harmoknee on several neuromuscular parameters of physical performance measures.
- **Study 3.** Training effects of the FIFA 11+ Kids on physical performance in youth football players: a randomized control trial.

2.2 SPECIFIC OBJECTIVES

The specific objectives have been structured depending on the three studies of this doctoral thesis:

Study 1. Acute effects of three neuromuscular warm-up strategies on several physical performance measures in football players.

1. To analyze the acute (post-exercise) effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on several physical performance measures in amateur soccer players.

Study 2. Training effects of the FIFA 11+ and Harmoknee on several neuromuscular parameters of physical performance measures.

2. To analyze the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance measures in youth amateur soccer players.

Study 3. Training effects of the FIFA 11+ Kids on physical performance in youth football players: a randomized control trial.

3. To analyze the training effects of the FIFA 11+ Kids on several parameters of physical performance in male youth soccer players.

2.3 RESEARCH HYPOTHESES

The following hypotheses were established for each of the three studies included in the current doctoral thesis:

Study 1. Acute effects of three neuromuscular warm-up strategies on several physical performance measures in football players.

1. The candidate hypothesizes that there would not be significant differences in the acute effects elicited by the three soccer-related warm-up protocols selected on the physical performance measures analyzed based on the fact that the duration (approximately 25 min) and type of exercises (neuromuscular exercises) in each routine are similar.

Study 2. Training effects of the FIFA 11+ and Harmoknee on several neuromuscular parameters of physical performance measures.

2. The candidate hypothesizes that FIFA 11+ and Harmoknee would show beneficial and superior effects on physical performance (particularly in balance, sprint and jumping measures) in comparison to the traditional practices as they include specific and novel exercises designated to improve these parameters (e.g., Nordic hamstring exercise, single-leg stance tasks, multidirectional [vertical, forward, backward, lateral] single leg jumps, running drills [alternate

leg bounds, sub-maximal speed lineal running]).

Study 3. Training effects of the FIFA 11+ Kids on physical performance in youth football players: a randomized control trial.

3. It was hypothesized that FIFA 11+ Kids would show beneficial and superior effects on physical performance (particularly in balance and agility measures) in comparison to the traditional practices as they include specific and novel exercises designed to improve physical competency.

CHAPTER 3

Study 1

3

STUDY 1

ACUTE EFFECTS OF THREE NEUROMUSCULAR WARM-UP STRATEGIES ON SEVERAL PHYSICAL PERFORMANCE MEASURES IN FOOTBALL PLAYERS

by

Ayala F, Calderón-López A, Delgado-Gosálbez JC, Parra-Sánchez S, Pomares-Noguera C, Hernández-Sánchez S, López-Valenciano A, & De Ste Croix M.

3.1 ABSTRACT

No studies have analyzed the acute effects of the FIFA 11+ and Harmoknee warm-up programs on major physical performance measures. The aim of this study was to analyze the acute (post-exercise) effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on several physical performance measures in amateur soccer players. A randomized, crossover and counterbalanced study design was used to address the purpose of this study. A total of sixteen amateur soccer players completed the following protocols in a randomized order on separate days: a) FIFA 11+; b) Harmoknee; and c) dynamic warm-up (DWU). In each experimental session, 19 physical performance measures (joint range of motion, hamstring to quadriceps [H/Q] strength ratios, dynamic postural control, 10 and 20 m sprint times, jump height and reactive strength index) were assessed. Measures were compared via a magnitude-based inference analysis. The results of this study showed no main effects between paired comparisons (FIFA 11+ vs. DWU, Harmoknee vs. DWU and Harmoknee vs. FIFA 11+) for joint range of motions, dynamic postural control, H/Q ratios, jumping height and reactive strength index measures. However, significant main effects (likely effects with a probability of >75–99%) were found for 10 (1.7%) and 20 (2.4%) m sprint times, demonstrating that both the FIFA 11+ and Harmoknee resulted in slower sprint times in comparison with the DWU. Therefore, neither the FIFA 11+ nor the Harmoknee routines appear to be preferable to dynamic warm-up routines currently performed by most soccer players prior to training sessions and matches.

Keywords: *soccer, acute effects, warm-up, neuromuscular control, injury prevention.*

3.2 INTRODUCTION

The FIFA 11+ [69] and Harmoknee [36] are two warm-up programs designed to prevent and reduce the number and severity of soccer-related injuries, particularly in amateur players. Both programs include running exercises and specific dynamic movements focusing on the major neuromuscular risk factors for lower extremity injuries (i.e., leg strength, balance, dynamic postural control, agility, knee control during cutting and landing, joint range of motion), based on scientific evidence and best practice [36,69]. In addition to the running and neuromuscular exercises, the FIFA 11+ and Harmoknee also include sprinting, multidirectional speed and plyometric exercises.

Recent cluster randomized controlled trials have demonstrated that the FIFA 11+ is effective in reducing lower extremity injury rates (mainly knee injuries) in teams practicing this warm-up at least twice a week for longer than three consecutive months [35,49,50,70–72]. Although with less rigor than the FIFA 11+, the effectiveness of the Harmoknee to reduce the incidence of lower extremity injuries (mainly knee injuries) has also been documented [36]. The potential training (chronic) effects behind the reported reduction in injury incidence produced by the FIFA 11+ and Harmoknee appear to be related to improvement in neuromuscular control of the trunk and lower extremities [60,73,74].These positive results in injury incidence rates in combination with the fact that no additional or specific equipment (for example balance boards) is required have led some research groups and institutions to develop countrywide campaigns to implement the FIFA 11+ and Harmoknee in the everyday soccer training routines (especially at amateur levels) [57,75].

It is widely accepted that a “good” or “appropriate” warm-up program should be able to improve performance (via post activation potentiation, decrease in stiffness, rise in core temperature and resting oxygen consumption [58]) but should not be too demanding to cause detrimental effects due to fatigue related factors [59]. Therefore, both, the FIFA 11+ and Harmoknee must demonstrate that they are able to elicit physiological acute changes (post- exercise effects) to positively affect the major physical performance measures (i.e., sprinting, jumping, range of motion, etc.) before being considered as appropriate warm-up programs to be performed prior to formal training and competition. Furthermore, if the use of the FIFA 11+ and/or Harmoknee is to be promoted at the expense of dynamic warm-up programs currently performed by most amateur soccer teams, the magnitude of their hypothetical positive effects on physical performance measures should be at least similar to those reported by the latter mentioned warm-up programs [76–84]. Otherwise, the FIFA 11+ and Harmoknee should be implemented in everyday soccer sessions as training components (i.e., placed in the main part of the training sessions), based on their demonstrated superior positive effects on injury incidence rates in comparison with traditional practices, rather than being used as a pre-exercise warm-up routine.

However, analyzing the body of literature regarding the acute effects of the FIFA 11+ and Harmoknee on sports performance, a smaller evidence base supporting their use as "good warm-up programs" appears to be available in comparison with the number of studies that have documented their efficacy as long-term interventions to reduce the injury incidence [35,49,50,57,70–72,75]. To the best of our knowledge, only Bizzini et al. [59] have examined the pre-exercise effects of the FIFA 11+ on various sports-performance variables, showing improvements in 20 m sprint time, jump height and agility comparable with those obtained with other dynamic warm-up routines reported in the literature. In addition, Bizzini et al. [59] reported that the FIFA 11+ induced similar improvement in resting oxygen uptake, core temperature and lactate as those obtained with other warm-up routines. However, no studies (to the authors´ knowledge) have analyzed the acute effects of the Harmoknee on physical performance measures.

Therefore, the main purpose of this study was to analyze the acute (post-exercise) effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on several physical performance measures in amateur soccer players. We hypothesize that there would not be significant differences in the acute effects elicited by the three soccer-related warm-up protocols selected on the physical performance measures analyzed based on the fact that the duration (approximately 25 min) and type of exercises (neuromuscular exercises) in each routine are similar.

3.3 MATERIALS AND METHODS

3.3.1 Design

A randomized, post-test only crossover and counterbalanced study design, in which participants performed all experimental conditions, was used to address the aims of this study. The use of a pre- and post-test crossover design, in which participants performed a pre- and post- warm up physical performance assessment was not adopted because in a pilot study (n = 4 males and 2 females) the participants consistently reported that the pre- and post- warm up assessment procedure used was too long and subsequently they felt less able or fatigued to undertake the post-warm up assessment and hence, bias the results.

The independent variables were the three different intervention routines (FIFA 11+, Harmoknee and dynamic warm-up). The dependent variables included 19 physical performance measures (range of motion, dynamic postural control, conventional and functional hamstring-to-quadriceps strength ratios, 10 and 20 m sprint times, jumping height and reactive strength index).

Participants visited our laboratory on four occasions, with a week's rest interval between sessions. Each testing session was carried out 48–72 hours after finishing the previous competitive match (i.e., Tuesday or Wednesday) so that the players could have enough time for recovery. Furthermore, players did not carry out any training session throughout this rest-interval. To minimize circadian variation and other similar effects on physical performance, each participant carried out all experimental sessions at the same time of day (in the late afternoon or early evening, depending on the participants availability) and under the same environmental conditions (room temperature at 25˚C).

The first visit was a practice/habituation session to the different testing procedures and warm-up exercises, and the following three visits were the experimental sessions. During each experimental session, participants began by completing one of the three interventions: the FIFA 11+, the Harmoknee or the dynamic warm-up. The order of interventions was randomized per person using a computer-based software program (www.randomizer.org) to avoid carry-over effects. The assessment of the physical performance measures was carried out 2–3 minutes (post-test) after the entire warm-up program was completed. This time elapse between the end of the warm-up and the start of the assessment of the physical performance measures was selected because: a) it reflects the typical period of time existing between the end of the warm-up and the start of a match in the amateur leagues; and b) to be consistent with similar previous studies [59,82].

The order of the tests was consistent throughout the experimental sessions and was established with the intention of minimizing any possible negative influence among variables (figure 3.1). The mean duration of each experimental session was 65.3 ± 8.6 min.

A priori, the overall duration of the post-warm up physical performance assessment (45 min approximately) carried out within each experimental session, although similar to previous studies [59,80,84–86], could appear to be enough to generate fatigue in the participants to bias the results (at least in the latter testing measures). However, the above-mentioned pilot study also showed that the order of the tests, the number of trials performed, as well as the rest intervals within trials and among tests were sufficient in order not to produce meaningful musculoskeletal fatigue in the participants. Furthermore, a "damping phenomenon" (i.e., the physical demands required by the test battery may offset the potential effects of an intervention) was not expected due to the fact that the sport-specific dynamic movement components of the three warm ups included activities with very similar neuromuscular and energetic requirements to those needed to successfully perform in the tests. In addition, Ayala et al. [85] reported that the time course of the effects elicited by a dynamic warm up with similar characteristics (duration, type of exercises, intensity) to those used in the current study on some physical performance measures (i.e., 10 and 20 m sprint, jumping height) lasted more than 30 minutes while participants engaged in a simulated tennis match. Therefore, a decline in the magnitude of the effects elicited by the three interventions on physical performance throughout the length of the post- warm up assessments was not expected. Each experimental session was carried out under the strict supervision of the researchers.

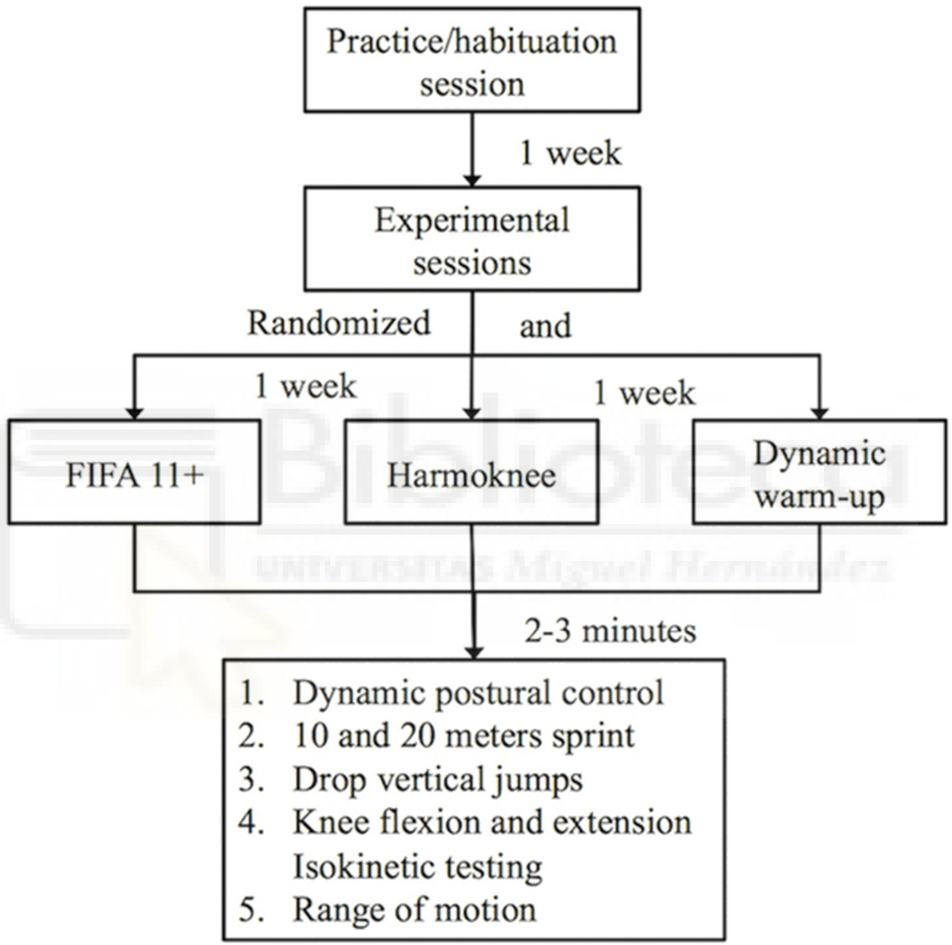


Figure 3.1. Schematic representation of the study design.

3.3.2 Participants

Twenty-two participants, consisting of 12 men and 10 women who were amateur soccer players, took part in the current study. Participants belonged to five different soccer teams that were engaged in the Official Amateur Championships of the Spanish Soccer Federation (fourth [regional] Spanish division). Although all participants reported taking part in regional soccer leagues, none was involved in a systematic and specific strength-training program. Likewise, their training frequency and duration through the study was 3 days per week, 1.5 hours per session. To reduce the interference of uncontrolled variables, all the participants were instructed to maintain their habitual lifestyle and normal dietary intake before and during the study. The participants were told not to exercise on the day before a test and to consume their last (caffeine-free) meal at least 3 hours before the scheduled test time.

Other exclusion criteria were: (1) histories of neuromuscular diseases or musculoskeletal injuries specific to the shoulder, ankle, knee, or hip joints over the past 6 months; (2) missing one testing session during the data collection phase; (3) and presence of self-reported delayed onset muscle soreness at any testing session. Before any participation, experimental procedures and potential risks were explained fully to the participants both verbally and in writing. Written informed consent was obtained from the players. The Institutional Research Ethics Committee approved the study participant information sheet, design and testing protocols prior data collection.

Eight men (age = 19.1 ± 1.3 y; stature = 177.2 ± 6.4 cm; body mass = 71.4 ± 8.8 kg) and eight women (age = 20.1 ± 1.8 y; stature = 164.9 ± 6.9 cm; body mass = 60.1 ± 6.6 kg) classified as amateur soccer players completed this study. Four men and two women were excluded from the study because they missed one or more of the testing sessions.

3.3.3 Interventions

FIFA 11+

The FIFA 11+ consisted of three parts (table 3.1), the first of which involved running exercises (part 1). The second part covered six exercises, all of which comprised three levels of difficulty and were aimed at improving strength, balance, muscle control and core stability (part 2). The third and final part consisted of advanced running exercises (part 3). All players were able to perform level II of difficulty for each exercise in part 2, which was confirmed during the familiarization session. However, no player was able to perform the level III of difficulty for each exercise. Therefore, the level II of difficulty was chosen for this study.

Table 3.1. FIFA 11+ warm-up program.

Exercise	Duration
Part 1: Running exercises	8 minutes
1. Straight ahead	2 sets over 30 m each exercise
2. Hip out	
3. Hip in	
4. Circling partner	
5. Shoulder contact	
6. Quick forward & backwards	
Part 2: Strength—Plyometric—Balance	10 minutes
7. The bench: alternate legs	3 sets x 40 s (lifting 2 s each leg in turn)
8. Sideways bench: raise and lower hip	3 sets x 20 repetitions each side
9. Hamstrings: intermediate	1 set x 7 repetitions
10. Single-leg stance: throwing ball with partner	2 set x 30 s each leg
11. Squats: walking lunges	2 set x 10 repetitions each leg
12. Jumping: lateral jumps	2 set x 15 jumps (30 s approximately)
Part 3: Running exercises	2 minutes
13. Across the pitch	2 sets x 30 m (70–80% maximum pace)
14. Bounding	2 sets x 30 m
15. Plant and cut	2 sets x 5 repetitions (80–90% maximum pace)

Harmoknee

The Harmoknee warm-up program included 5 parts: warm-up, muscle activation, balance, strength and core stability, all of which can be combined and performed in a regular soccer training session (table 1.2). Total program duration was 20 to 25 minutes.

Dynamic warm-up

Ten different cards showing dynamic warm-up routines were given to each participant. Seven of the dynamic warm-up routines were extracted from the studies selected in the meta-analysis carried out by Bizzini et al. [59] in the context of the acute effects of dynamic warm-ups [78–81,84,87,88]. The other three warm-up routines were selected because they reflect the warm-up structure and content that, according to our experience, might be the most widely used in soccer and which contain the following components chronologically ordered: a) some active aerobic activities (including running, light calisthenics); b) dynamic stretching exercises of the major muscle groups; and c) soccer-specific movements incorporating a various range of motion exercises with skill-based drills executed at, or just below game intensity [82,89,90].

Those published warm-up routines that required additional equipment (for example, balance boards, dumb-bells, weight vests or barbells) were not considered for the purpose of this study because they do not represent the reality of most amateur clubs and teams. After that, each participant picked up the three cards that most closely replicated his/her habitual warm-up routine. Three points were given to the most closely related warm-up routine, two points to the second and one point to the last warm-up routine. The dynamic warm-up routine considered the 'standard' must have been picked up and scores with two or three points by at least 70% of the participants. In the case of more than one dynamic warm-up routine meeting the above-mentioned criterion, the one with the highest summation of points was selected as standard. Two dynamic warm-up routines were picked up by at least 70% of the participants [82,89], these being the dynamic warm-up routine designed by Taylor et al. [82], which reached the highest score and hence was considered as the standard soccer-related warm-up routine (table 3.2).

Table 3.2. Dynamic warm-up program*.

Exercise		Duration
1.	High knees	3 set over 20 m
2.	Butt flicks	3 set over 20 m
3.	Carioca	3 set over 20 m each side
4.	Dynamic hamstring swings	10 repetitions each leg
5.	Dynamic groin swings	10 repetitions each leg
6.	Arm swings: forwards and backwards	10 repetitions each direction
7.	Faster high knees (shorter stride)	4 sets over 10 m
8.	Swerving	2 sets over 30 m at 70% of maximum pace
9.	Side stepping	2 sets over 30 m at 80% of maximum pace
10.	Spiderman walks	1 set over 20 m
11.	Sideways low squat walks	1 set x 10 steps each direction
12.	Upper body rotations	10 repetitions each leg
13.	Vertical jump	5 repetitions building in intensity
14.	Run through	2 sets x 20 m at 70% of maximum pace
		2 sets x 20 m at 80% of maximum pace
		1 set x 20 m at 90% of maximum pace
15.	Countermovement jump then 5 m sprint	2 sets x 5 m at 90% of maximum pace
		1 sets x 5 m at 95% of maximum pace
16.	Sprint for 5 m then countermovement jump	2 sets x 5 m

*: warm up program extracted from Taylor et al. [82]

3.3.4 Physical performance measures

Hip, knee and ankle range of motions

The passive hip flexion (passive straight leg raise test [figure a in supplementary file 3.1]), extension (Thomas test [figure b in supplementary file 3.1]) and abduction (passive hip abduction with knee flexed over the edge of the plinth test [figure c in supplementary file 3.1]); knee flexion (Modified Thomas test [figure d in supplementary file 3.1]) and ankle dorsiflexion (weightbearing lunge with knee extended [figure e in supplementary file 3.1] and flexed [figure f in supplementary file 3.1] tests) range of motions of the dominant and non-dominant extremities were assessed following the methodology previously described [91]. Participants were instructed to perform, in a randomized order, two maximal trials of each range of motion test for each extremity. The mean score for each test was used in the subsequent analyses. The same researchers performed the ROM testing at all testing sessions.

Conventional and functional hamstring-to-quadriceps strength ratios

The assessment of the H/Q_{CONV} and H/Q_{FUNCT} strength ratios was carried out following the methodology described by Ayala et al. [92]. Briefly, a Biodex System-4 isokinetic dynamometer (Biodex Corp., Shirley, NY, USA) and its respective manufacture software were used to determine isokinetic concentric and eccentric torques during knee extension and flexion actions. Only the dominant leg was tested, as no meaningful differences between legs have been previously reported for sedentary and recreationally active adults [93,94]. The dynamometer was calibrated according to the manufacturer's instructions immediately before each test session and verified immediately after to ensure that no changes occurred in sensitivity.

Participants were secured supine on the dynamometer with the hip passively flexed at 10˚– 20˚ (supplementary file 3.2). The axis of rotation of the dynamometer lever arm was aligned with the lateral epicondyle of the knee. The force pad was placed approximately 3 cm superior to the medial malleolus, with the foot in a relaxed position. Adjustable strapping across the pelvis, thigh proximal to the knee and foot localized the action of the musculature involved. The range of movement was set from 90˚ knee flexion (starting position) to 0˚ (0˚ was determined as maximal voluntary knee extension for each participant).

Before isokinetic testing, the participants performed a specific isokinetic warm-up consisting of three sub-maximal (self-perceived 50% effort) and two maximal concentric and eccentric knee extension and flexion actions at 120˚/s.

The isokinetic examination was separated into two parts. The first part of the examination was the assessment of the knee extensor and knee flexor muscles during concentric/concentric (CON/CON) cycles with extension undertaken first. After a 5 min rest period the eccentric/ eccentric (ECC/ECC) testing cycle was performed.

In both testing methods, three cycles of knee flexions and extensions were performed at three preset constant angular velocities in the following order: 60, 180 and 240˚/s for CON/ CON cycles; and 30, 60 and 180˚/s for ECC/ECC cycles (slow to fast). The two testing parts (CON/CON and ECC/ECC) were separated by a 5 min rest interval and a rest of 30 s was allowed between action cycles. The number of maximal muscle actions and the rest period durations were chosen to minimize musculoskeletal fatigue, which is unlikely to occur (based on the participants' perceptions reported in the pilot study) with only three muscle actions at three velocities and 30 s rest between muscle actions and velocities and 5 min rest between testing modes (concentric and eccentric). For both concentric and eccentric actions, participants were encouraged to push–pull/resist as hard and as fast as possible and to complete the full range of motion. Participants were instructed to abort the test if they felt any discomfort or pain. During the test, all participants were given visual feedback from the system monitor.

They were also verbally encouraged by the investigator to give their maximal effort, and the instructions were standardized by using key words such as 'resist', 'push' and 'hard and fast as possible'.

The peak torque was extracted for each of the three trials performed at each velocity during the CON/CON and ECC/ECC cycles of reciprocal knee extension and flexion movements through the three testing sessions. For each isokinetic peak torque variable, the average of the three trials at each velocity was used for the subsequent calculation of the conventional and functional hamstring-to-quadriceps strength ratios due to the magnitude of the error component decreasing with increased trials [95].

Thus, the H/Q_{CONV} ratios were calculated as the ratio between the torques produced concentrically by hamstrings and quadriceps during the isokinetic tests at 60 (H/Q_{CONV60}) and 180˚/s ($H/Q_{CONV180}$). H/Q_{FUNC} ratios were calculated as the ratio between the torques produced eccentrically by the hamstring and concentrically by the quadriceps muscles at 60 (H/Q_{FUNC60}) and 180˚/s ($H/Q_{FUNC180}$). Finally, the H/Q_{FUNC} proposed by Croisier et al. [96] was also calculated as the ratio between the torques produced eccentrically by the hamstring at 30˚/s and concentrically by the quadriceps muscles at 240˚/s ($H/Q_{FUNC30/240}$).

Dynamic postural control

Dynamic postural control was evaluated using the Y-Balance test and following the guidelines proposed by Shaffer et al. [97]. Players were allowed a maximum of five trials to obtain three successful trials for each reach direction (anterior [figure a in supplementary file 3.3], posteromedial [figure b in supplementary file 3.3] and posterolateral [figure c in supplementary file 3.3]). Trials were discarded if the player failed to maintain unilateral stance on the platform, failed to maintain reach foot contact with the reach indicator on the target area while the reach indicator is in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control [97]. Specifically, the testing order was completed as dominant anterior, non-dominant anterior, dominant posteromedial, non-dominant posteromedial, dominant posterolateral, and non-dominant posterolateral. The average of the three reaches was normalized by dividing by the previously measured leg length to standardize the maximum reach distance ([excursion distance/leg length] x100 = % maximum reach distance) [98]. Leg length was defined as the length measured in centimeters from the anterior superior iliac spine (ASIS) to the most distal portion of the medial tibial malleolus. To obtain a global measure of the balance test, data from each direction were averaged for calculating a composite score [99].

10- and 20-meters sprint time

Owing to their good reproducibility, linear sprint tests ranging from 10 to 20 m are used as general measures of linear acceleration and speed in soccer players. Time during a 20 m sprint in a straight line was measured by means of single beam photocell gates placed 1.0 m above the ground level (Time It; Eleiko Sport, Halmstad, Sweden). Each sprint was initiated from an individually chosen standing position, 50 cm behind the photocell gate, which started a digital timer. Each player performed three maximal 20 m sprints interspersed with 1 min of passive recovery, and the mean of the two fastest times achieved was retained.

Drop vertical jump height

A vertical drop jump (DJ) without arm swing was performed on a force platform (Kistler, Switzerland) according to Onate et al. [100]. Participants stood with feet shoulder-width apart on a 28 cm high step, 30 cm from the contact platform. They were instructed to lean forward and drop from the step as vertically as possible, in an attempt to standardize landing height. Participants were required to land with one foot on each of the force plates, then immediately perform a maximal vertical jump, finally landing back on the contact platform. Participants were asked to keep their hands on their hips to prevent the influence of arm movements on vertical jump performance. Each participant performed five maximal jumps starting from a standing position, with at least 30 s of recovery between jumps. Participants were asked to jump as high as possible. The mean jump height of the best three jumps was used for statistical analysis.

Reactive strength index

The reactive strength index was calculated using the data from the drop vertical jumps performed by the participants and following this formula [101,102]:

Reactive strength index = Jumping height (mm) / ground contact time (ms)

The mean reactive strength index of the best three jumps was used for statistical analysis.

3.3.5 Statistical analysis

Descriptive statistics (means ± standard deviations) were calculated for all physical performance measures at post warm-up interventions.

Dependent sample t-tests were carried out to assess differences between limbs (dominant versus non-dominant) in dynamic postural control and ROMs.

Magnitude-based inferences of differences between-groups were calculated for each variable using a spreadsheet designed by Hopkins [103]. Each participant's change score between paired sessions (dynamic warm-up vs. FIFA 11+; dynamic warm-up vs. Harmoknee; FIFA 11+ vs. Harmoknee) was expressed as a percentage of baseline score via analysis of log-transformed values, to reduce bias arising from non-uniformity of error. Errors of measurement and individual responses expressed as coefficients of variation were also estimated. In addition, the analysis determines the probability that the true effects are substantial or trivial when a value for the smallest substantial change is entered.

Coefficients of variation (CV) determined the smallest substantial change for each of the variables. The CV (standard error of measure [SEM] or typical error of measure [TE] expressed as percentage) data reported by previous inter-session reliability studies for each variable were used for the magnitude-based inference analyses. Thus, substantial is an absolute change > 2.5% for measures of range of motion [91], 18.5% for measures of H/Q strength ratios [92], 3.0% for measures of dynamic postural control [104], 1% for 10 and 20 m sprint times [105], 6% for DJ height [106] and 13.9% for measures of reactive strength index [107]. The qualitative descriptors proposed by Batterham and Hopkins [108] were used to interpret the probabilities (clinical inferences based on threshold chances of harm and benefit of 0.5% and 25%) that the true effects are harmful, trivial or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5–24%, unlikely or probably not; 25–74%, possibly or maybe; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly. This approach to qualitatively describe the inferences is based on where the confidence interval of the between-groups differences lies in relation to a 3-level (beneficial, trivial and harmful) scale of magnitudes. For example, whether a confidence interval is entirely within the beneficial range of the smallest substantial change, the effect is clearly beneficial (>99%, almost certainly). Contrarily, if the confident interval spans 2 levels; harmful and trivial or trivial and beneficial, then the inference is qualified with a descriptor that represents the likelihood that the true value will have the observed magnitude (probabilistic inference) [109]. The inference was deemed unclear when the 90% confidence interval of the pre-post change differences overlapped both beneficial and harmful levels.

This spreadsheet also provides estimates of the effect of an intervention adjusted to any chosen value of a covariate, thereby reducing the possibility for confounding effects (e.g., when a characteristic is unequal in the experimental and control groups). Thus, the sex of the participants was included as a covariate.

The current study considered a "substantial" main effect when a change was noted between paired-comparisons in physical performance measures that had reported a probability of the worthwhile differences of "likely" or higher (> 75% positive or negative).

3.4 RESULTS

The statistical analysis showed no significant differences (p values from 0.53 to 0.95) in joint range of motions (hip flexion, extension and abduction; knee flexion and ankle dorsiflexion with knee flexed and extended) and dynamic postural control (anterior, posteromedial and posterolateral directions) outcomes between the dominant and non-dominant limbs of the players. Consequently, the average score of both limbs for each unilateral variable was used for the subsequent statistical analysis. The post intervention results of variables are reported for descriptive purposes in table 3.3

Table 3.3. Post-intervention (Dynamic warm-up, Harmoknee and FIFA 11+) results (mean ± standard deviation [SD]) for physical performance outcomes.

Variable	Dynamic warm-up	Harmoknee	FIFA 11+
Y-Balance test (cm)^{T}			
- Anterior distance	64.9 ±5.7	63.5 ±4.3	63.6 ±5.1
- Posteromedial distance	101.7 ±8.6	103.9 ±7.8	104.4 ±8.4
- Posterolateral distance	96.8 ±7.4	95.4 ±6.1	97.2 ±7.8
- Composite	84.4 ±6.1	84.4 ±4.9	85.3 ±5.8
Sprint time (s)			
- 10 m	1.99 ±0.17	2.07 ±0.15	2.12 ±0.18
- 20 m	3.44 ±0.31	3.47 ±0.27	3.53 ±0.34
Vertical drop jump			
- Height (cm)	27.1 ±3.1	22.9 ±2.6	24.6 ±2.9
- Reactive strength index	1.04 ±0.29	1.07 ±0.27	1.05 ±0.28
Hamstring-to-quadriceps strength ratios			
- H/Q_{CONV60}	0.60 ±0.06	0.60 ±0.07	0.59 ± 0.08
- $H/Q_{CONV180}$	0.64 ±0.14	0.66 ±0.13	0.64 ±0.14
- $H/Q_{FUNCT60}$	1.33 ±0.34	1.23 ±0.29	1.29 ±0.18
- $H/Q_{FUNCT180}$	1.63 ±0.41	1.58 ±0.52	1.63 ±0.41
- $H/Q_{FUNCT30/240}$	1.99 ±0.62	1.92 ±0.65	2.06 ±0.47
Joint range of motion (˚)			
- Hip flexion	67.4 ±11.6	67.3 ±11.6	69.9 ±14.9
- Hip extension	17.1 ±5.1	17.6 ±5.8	16.1 ±4.4
- Hip abduction	50.4 ±8.7	51.4 ±8.5	48.7 ±8.6
- Knee flexion	123.4 ±14.9	124.7 ±13.1	124.2 ±11.6
- Ankle dorsiflexion knee extended	37.9 ±8.1	37.8 ±7.2	37.7 ±8.2
- Ankle dorsiflexion knee flexed	38.4 ±6.6	39.2 ±7.3	37.1 ±6.4

T: Normalized to limb length expressed as a percentage; s: seconds; cm: centimeter; º: degrees; H: hamstring; Q: quadriceps; CONV: conventional; FUNCT: functional

The paired inter-interventions percentage differences with the corresponding 90% confidence interval for the different physical performance measures are displayed in figure 3.2 (FIFA 11+ warm-up vs. Harmoknee warm-up), figure 3.3 (Dynamic warm-up vs. Harmoknee warm-up) and figure 3.4 (FIFA 11+ warm-up vs. dynamic warm-up). No substantial differences (likely differences with a probability > 75%) were found between paired-comparisons for most of the physical performance measures. Only substantial differences (with a probability of 77%) were found for the sprint time outcomes, so that the FIFA 11+ and Harmoknee warm-ups resulted in slower sprint times in comparison with the dynamic-warm up for 20m (2.4%) and 10m (1.7%) respectively.

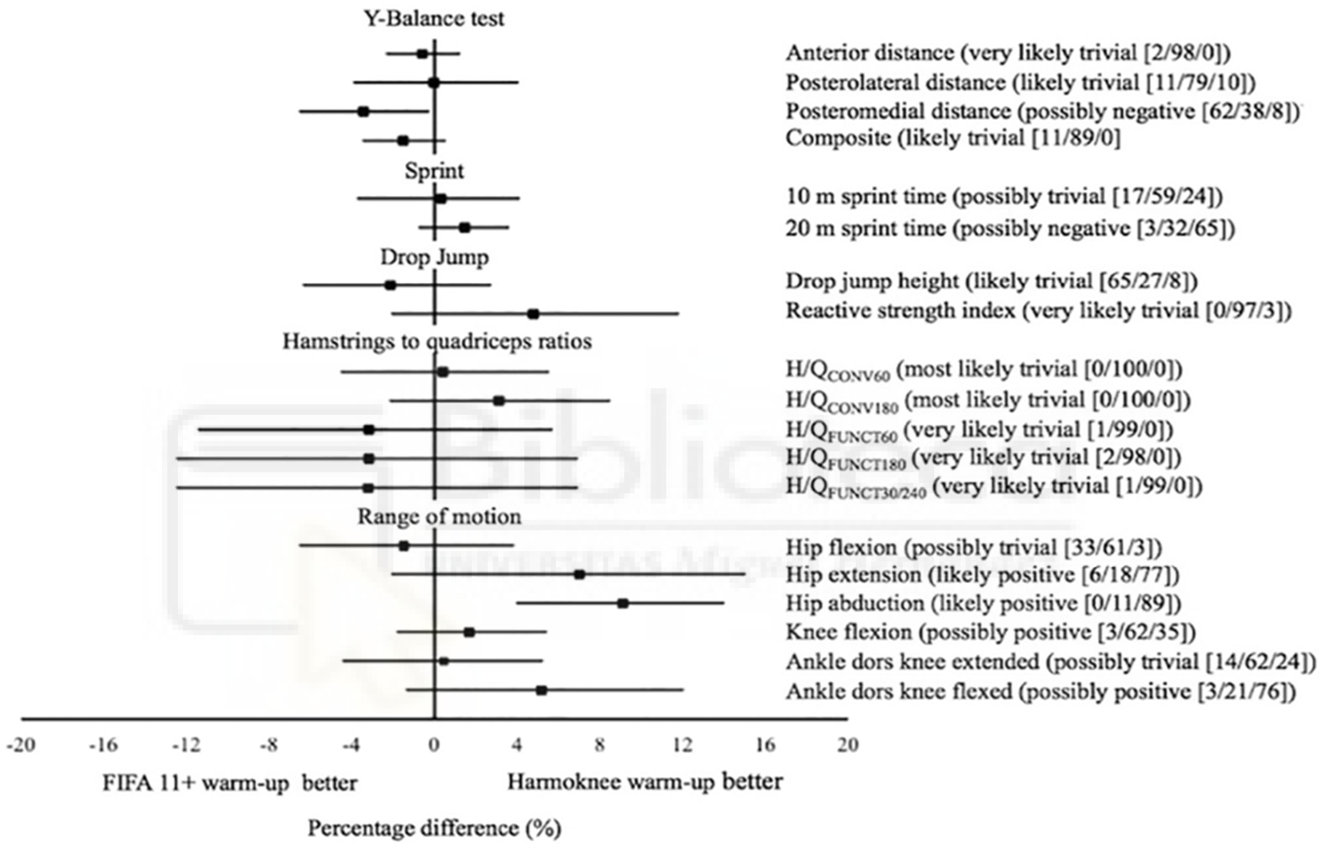


Figure 3.2. Net effects (expressed as percentage) of the interventions (paired comparisons) on the physical performance measures analyzed for the FIFA 11+ and Harmoknee. The probabilities of an effect being harmful/trivial/beneficial are expressed as percentage values. Clinical inference is provided.

3.5 DISCUSSION

The primary findings of the current study reported that the acute (post-exercise) effects elicited by both the FIFA 11+ and Harmoknee warm-ups on most physical performance measures (with the exception of the sprint times) were similar (not substantial: probabilities of worthwhile differences <75%) to those found by the standard soccer-related dynamic warm-up routine. However, it should be noted that although not substantial and with a practical significance that is unclear, there appears to exist a tendency showing that the Harmoknee elicits superior improvements in the ROM measures than the FIFA 11+ (figure 3.1). Perhaps a probable explanation for this positive tendency in ROM improvements in favor of the Harmoknee may be due to the fact that the Harmoknee, in contrast to the FIFA 11+, includes a specific element of stretching exercises (part number two: muscle activation). On the other hand, it should also be noted that another tendency appears to exist showing that the standard dynamic warm-up routine elicits higher improvements in the H/Q_{FUNC} ratios compared to those reported by both the FIFA 11+ and Harmoknee. Although speculative and based on the subjective perception verbally expressed by the participants, the specific eccentric exercise present in both the FIFA 11+ and Harmoknee, the Nordic curl, may have produced a certain degree of fatigue in this sample of players who were not used to performing eccentric exercises in their daily training sessions. As this is the first study (to the authors' knowledge) to explore the post-exercise effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on joint ROM measures, dynamic postural control and conventional and functional H/Q ratios, we are not able to make direct comparisons. Consequently, until future studies address this issue, the above-mentioned tendencies should be taken with a high degree of caution.

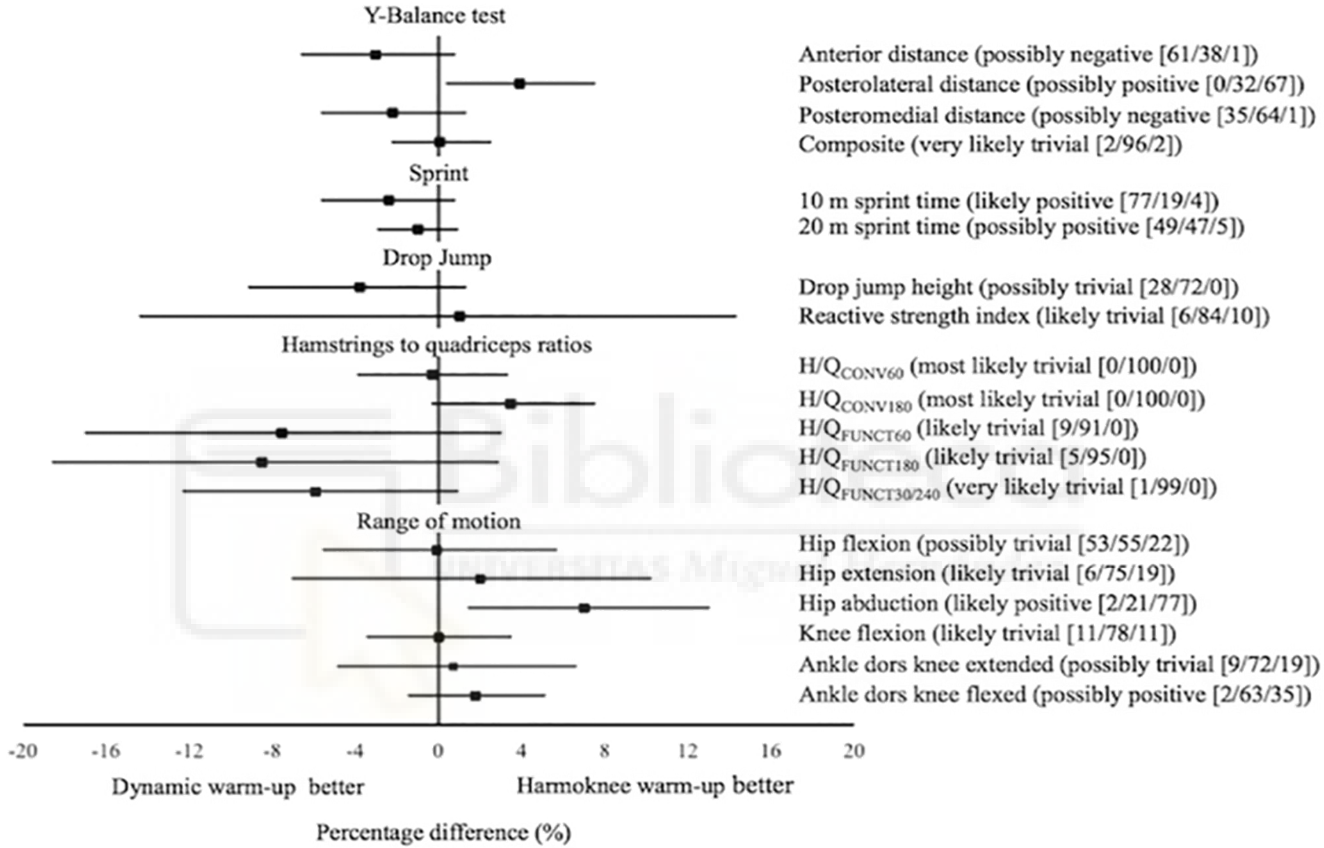


Figure 3.3. Net effects (expressed as percentage) of the interventions (paired comparisons) on the physical performance measures analyzed for the Dynamic warm-up and Harmoknee. The probabilities of an effect being harmful/trivial/beneficial are expressed as percentage values. Clinical inference is provided.

The current study also found that the standard dynamic warm-up routine elicited superior improvements in sprint times (1.7 and 2.4% for 10 and 20 m sprint times, respectively) when they were compared to those produced by the FIFA 11+ and Harmoknee routines (figures 3.2 and 3.3). These findings are not in agreement with the results reported by Bizzini et al. [59], who found that the magnitude of the effects elicited by the FIFA 11+ on sprint times (2.2%) were comparable with those reported in the literature for dynamic warm-up routines (≈1.8%). A possible explanation for this discrepancy may be attributed to the different research design used in each study; Bizzini et al. [59] carried out a meta-analysis to compare the effects elicited by the FIFA 11+ with other warm-up routines previously published regarding soccer players, while we directly compared the effects elicited by the FIFA 11+ with a standard soccer-related dynamic warm-up routine. The higher positive effects in the sprint and jump height measures reported by the dynamic warm-up routine in comparison with the FIFA 11+ and Harmoknee routines might be partially due to enhanced activation of the history-dependent neuromuscular factors such as post-activation potentiation (PAP) and stretch-shortening cycle (SSC), which have been found mainly after isometric or resistance/weight-based exercises completed immediately before the task [84,110–112]. Thus, the higher stimuli of resistance-based exercises presented in the exercises belonging to the final part of the dynamic warm-up routine (vertical and countermovement jumps, spiderman walks and sideways low squat walks) may have led to a higher post-activation potentiation in comparison to the FIFA 11+ and Harmoknee. In addition, the previously mentioned possible presence of muscle fatigue as a consequence of the specific and novel eccentric exercise (i.e., Nordic curl) for the participants in both the FIFA 11+ and Harmoknee routines may also have contributed to this finding.

Although the current study is novel in several aspects (testing procedures, statistical analyses and design), some limitations should be noted. One limitation was the small sample size used in each group (interventions or controls). However, the sample size that was enrolled in each group was similar to previous warm-up studies [59,78–82,84,87,89,90] and allowed main effects to be found.

Another possible limitation of the current study is the sampling frame. The age distribution of participants (19.1 ± 1.3 y) and their physical skills level (amateur) were narrow and so generalizability cannot be ascertained.

3.6 PRACTICAL APPLICATIONS

The main findings of the current study reported that the three interventions (FIFA 11+, Harmoknee and standard dynamic warm-up routines) elicited similar acute (post-exercise) effects on several physical performance measures. However, superior positive acute effects on sprint measures were found in favor of the dynamic warm-up routine compared to both the FIFA 11+ and Harmoknee routines. Therefore, and based on the above-mentioned findings, neither the FIFA 11+ nor the Harmoknee routines appear superior to the dynamic warm-up routines currently performed by most soccer players prior to training sessions and matches. However, the FIFA 11+ and Harmoknee should be implemented in everyday soccer sessions as training components (i.e., placed in the main part of the training sessions), based on their demonstrated superior positive effects on injury prevalence rates in comparison with traditional practices.

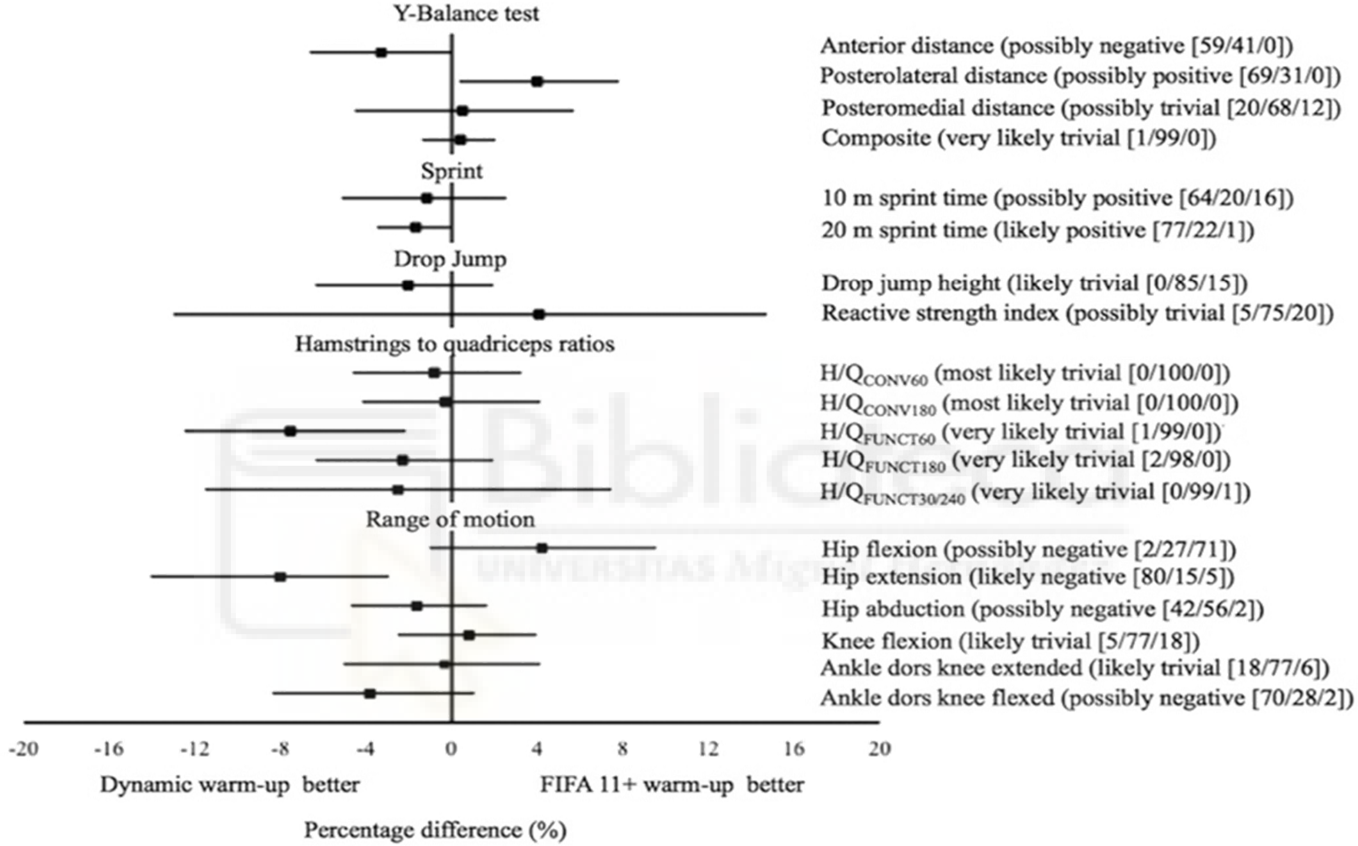
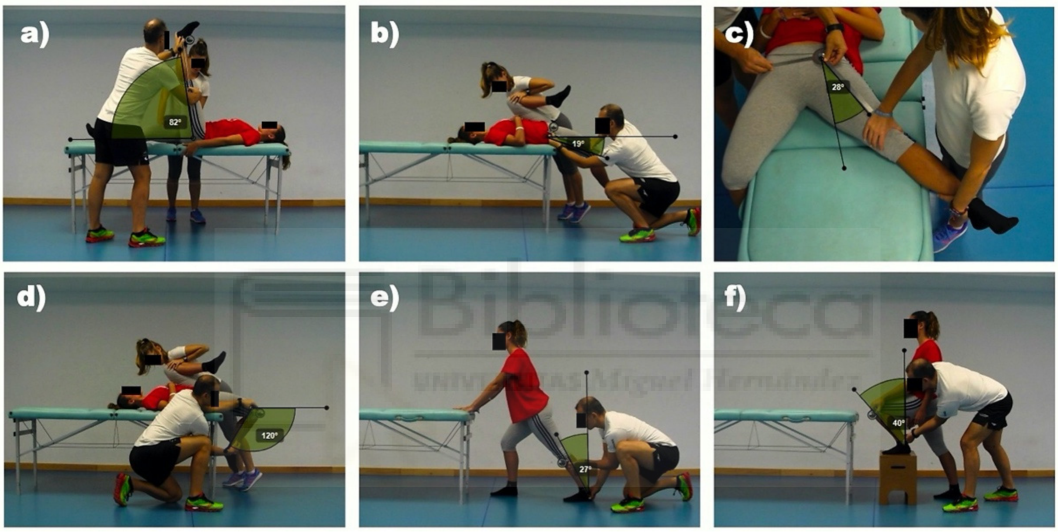


Figure 3.4. Net effects (expressed as percentage) of the interventions (paired comparisons) on the physical performance measures analyzed for the Dynamic warm-up and FIFA 11+. The probabilities of an effect being harmful/trivial/beneficial are expressed as percentage values. Clinical inference is provided.

3.7 SUPPLEMENTARY FILES

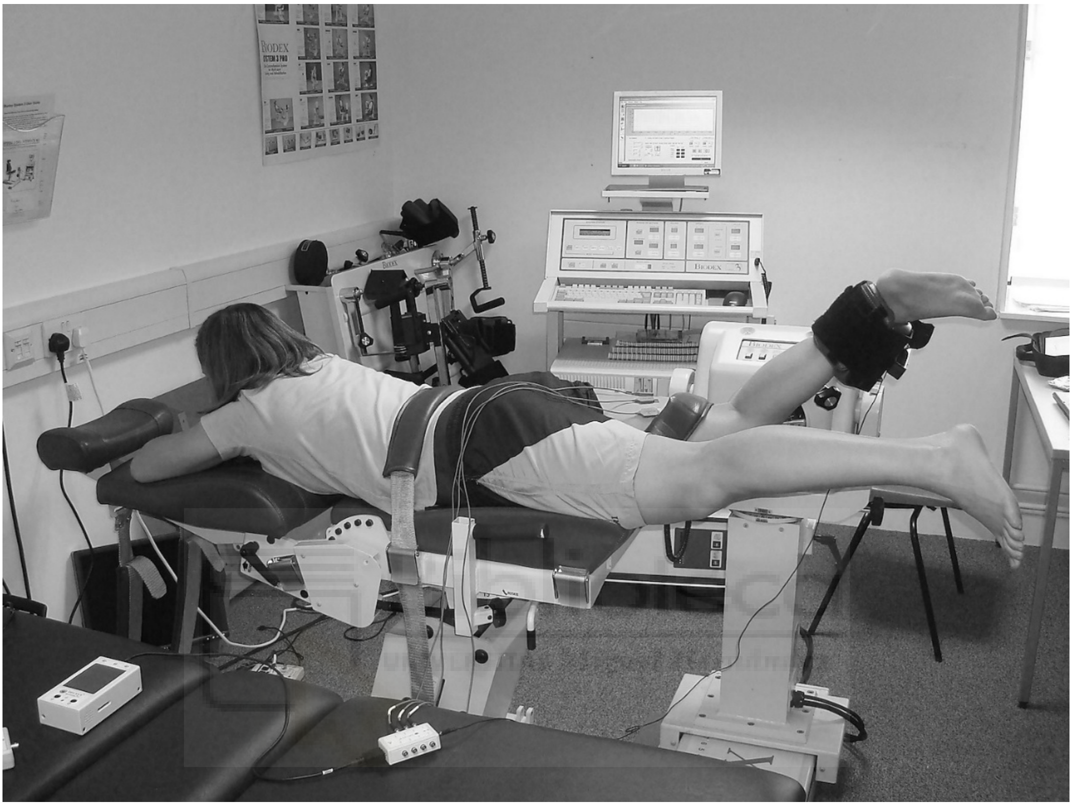
Supplementary file 3.1

The passive hip flexion (passive straight leg raise test [figure a]), extension (Thomas test [figure b]) and abduction (passive hip abduction with knee flexed over the edge of the plinth test [figure c]); knee flexion (Modified Thomas test [figure d]) and ankle dorsiflexion (weight-bearing lunge with knee extended [figure e] and flexed [figure f] tests) range of motions assessment.



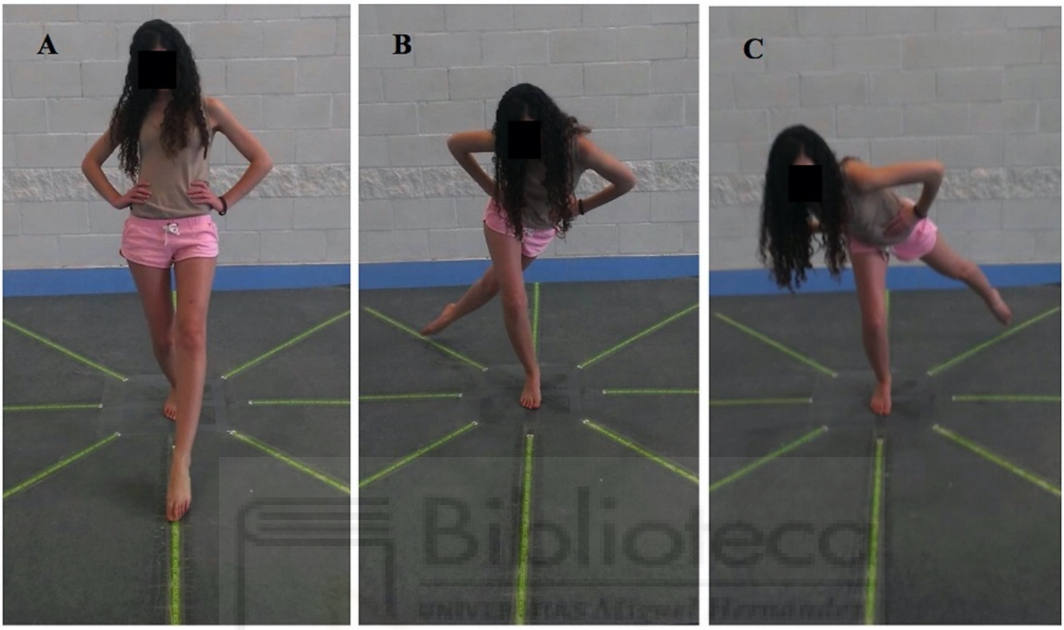
Supplementary file 3.2

Isokinetic testing position.



***Supplementary file** 3.3*

Dynamic postural control assessment (anterior [figure a], posteromedial [figure b] and posterolateral [figure c] directions).



CHAPTER 4

Study 2

4

STUDY 2

TRAINING EFFECTS OF THE FIFA 11+ AND HARMOKNEE ON SEVERAL NEUROMUSCULAR PARAMETERS OF PHYSICAL PERFORMANCE MEASURES

by

Ayala F, Pomares-Noguera C, Robles-Palazón FJ, García-Vaquero MP, Ruiz-Pérez I, Hernández-Sánchez S, & De Ste Croix M.

4.1 ABSTRACT

The main purpose of this study was to analyze the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance measures in youth amateur soccer players. 41 adolescent players were randomized within each team into 2 groups (team 1: control vs. FIFA 11+; team 2: control vs. Harmoknee). The FIFA 11+ and Harmoknee groups performed the program 3 times a week for 4 weeks; the control groups completed their usual warm-up routines. 13 physical performance measures (joint range of motion, dynamic postural control, single legged hop limb symmetry, sprint time, jumping height and agility) were assessed. All physical performance parameters were compared via a magnitude-based inference analysis. Significant between-group differences (in favor of the FIFA 11+ players) were found for dynamic postural control (anterior [2.5%] and posteromedial [7.2%] distances), single legged hop limb symmetry (side-to-side symmetry during a triple hop test [8.3%]), 10 (8.4%) and 20 (1.8%) m sprint times and jumping height (9.1%) neuromuscular outcomes. For the Harmoknee, significant differences (in comparison to its paired control group) were found only for 10 (2.7%) and 20 (2.9%) m sprint times and jumping height (9.7%). Therefore, the main findings of this study suggest exchanging traditional warm-up programs for the FIFA 11+ in male youth soccer players based on its superior effects on some neuromuscular parameters (sprinting, jumping and stability) of physical performance.

Keywords: *soccer, muscle, warm-up, neuromuscular control, sport-related injuries.*

4.2 INTRODUCTION

Soccer (associated football) is one of the most popular sports in the world. Despite the numerous health benefits, participation in a physically demanding sport such as soccer can lead to greater exposure to causal factors of injury [24,26]. The increased risk of injury (mainly in the lower extremities) produced by playing soccer is especially relevant in cases in which growth and maturation are not yet completely developed, such as in childhood and adolescence [113]. Specifically, injury incidence in adolescent populations has recently been aligned to peak height velocity, when rapid growth is evident [31,114]. Furthermore, recent epidemiology studies have reported that the frequency and severity of injuries among youth soccer players is striking in comparison to other sports [115–117]. Particularly, injury rates in youth soccer vary from 5.6 injuries per 1000 h of exposure [118] to 37.6 injuries per 1000 match hours [119]. Consequently, participation at a young age if a child or adolescent is unable to continue to participate because of the effects of injury [120].

Therefore, there is a clear necessity to develop and implement measures aimed at preventing and reducing the number and severity of soccer-related injuries in youth players. The FIFA 11+ [69] and Harmoknee [36] are 2 training programs designed to prevent injuries in youth soccer players. Both programs include running exercises and specific dynamic movements focusing on enhancing the most important and modifiable injury risk factors (e. g., poor physical performance in strength, power, balance, speed, proprioception and joint range of motion [53]) and based on scientific evidence and best practice [36,69]. Recent cluster randomized controlled trials have demonstrated that the FIFA 11+ is effective in reducing lower extremity injury rates in male [50,71] and female [35,72] youth players. Although with a smaller evidence base than the FIFA 11+, the effectiveness of the Harmoknee to reduce the incidence of lower extremity injuries (mainly knee injuries) has also been documented in female youth players [36].

Although the main purpose of both FIFA 11+ and Harmoknee is injury prevention, the knowledge of training effects elicited by these training programs on physical performance can help in identifying the potential mechanisms behind the reported reduction in injury incidence [121]. Although some studies have explored the training effects of both programs (mainly FIFA 11+) on some measures of neuromuscular performance (lower extremity balance [49,122] and core stability [121], knee proprioception

[122], knee strength [121,123,124]), and sprinting and jumping ability [121,125,126] (that form part of the athletic physical performance spectrum), none of them have used adolescents players as a sample despite being the target population of both programs.

Therefore, the main purpose of this study was to analyze the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance in youth amateur soccer players. We hypothesized that these 2 programs would show beneficial and superior effects on physical performance (particularly in balance, sprint and jumping measures) in comparison to the traditional practices as they include specific and novel exercises designated to improve these parameters (e. g.: Nordic hamstring exercise, single-leg stance tasks, multidirectional [vertical, forward, backward, lateral] single leg jumps, running drills [alternate leg bounds, sub- maximal speed lineal running]).

4.3 METHODS

4.3.1 Sample size estimation

The sampling package (sample size estimation, contrast of hypothesis, comparing groups means, independent groups) of the statistical software Epidat 4.1 was used to calculate the sample size needed to detect meaningful changes. The change in the hip flexion ROM was selected as the primary outcome variable for the sample size estimation as pilot studies carried out in our laboratory using different population cohorts suggested that this variable has high inter-session variability.

Thus, an estimation of the desired sample size was made based on the expected difference in the primary outcome variable (hip flexion ROM) of 1.5° (standard deviation of 0.95°) assuming equal variances, with confidence limits of 95 %, a statistical power of 80 % in a Student’s t-test for independent groups and an alpha level of 0.05. The analysis reported that a minimal sample size of 8 participants would be required. Considering the possible level of dropout in this type of intervention, an additional 25 % was added to the minimal sample size calculation (10 participants per group) to ensure an appropriate final sample size.

4.3.2 Participants

A total of 60 male youth amateur soccer players were contacted to take part in the study. Participants were recruited from 3 different soccer teams that were engaged in the Official Amateur Championships of the Spanish Soccer Federation (first national juvenile league). The participants met 4 inclusion/exclusion criteria: 1) had no history of impairments to the knee, thigh, hip, or lower back in the 6 months prior to the study; 2) all playing positions except goalkeepers; 3) all participants were free of delayed onset muscle soreness (DOMS) at any testing session; and 4) participated in 3 supervised training sessions per week (1.5–2 h per session). In addition, participants were excluded from the data analysis if they a) missed more than 2 consecutive or 3 non-consecutive training sessions and/or b) one testing session.

Before any participation, experimental procedures and potential risks were fully explained to the participants in verbal and written form, and written informed consent was obtained from players, their parent/guardian and coaches. The Institutional Research Ethics committee approved the study protocol prior data collection, conforming to the recommendations of the Declaration of Helsinki and the IJSM guidelines [127].

Of the 60 players contacted, all players (n = 20) who belonged to one team were excluded from the study because the post-test session was not completed. Therefore, 41 youth male amateur soccer players (age: 16.8 ± 0.7 y; body mass: 70.2 ± 3.5 kg; stature: 173.9 ± 6.7 cm; years playing soccer: 6.1 ± 2.2 y) from 2 different soccer teams completed this study.

4.3.3 Research design

A parallel, 2-group, pre-post, randomized controlled trial with double baseline (2 pre-test sessions) was used to address the purposes of this study.

The study was conducted in Spain and began in February 2015 and was completed in April 2015. In Spain, the first national juvenile league has 2 different rest periods (winter [2–3 weeks for Christmas holidays] and spring [2 weeks for Easter holidays] breaks) so the season is divided into 3 main terms/macrocycles. The 3 terms have approximately the same number of weeks (from 10 to 12 weeks) and matches (from 10 to 12 matches; one every weekend). The time frame of the study was selected so that the study could start after the winter break and could be completed before the play-off/play-out phases. The second term of the season was chosen rather than the first term in order to be sure that the players selected to each team was definitive and stable within the testing period. Further, the study was not carried out in the third term of the season with the aim of reducing the dropout rate of players' that could be expected due to the secondary school final exams (this decision was made based on coaches' experience).

The independent variables were the 3 different intervention programs (control [traditional or regular warm-up], FIFA 11+ and Harmoknee). The dependent variables included 13 physical performance measures (range of motion [hip, knee and ankle joints], dynamic postural control [measured throughout the Y-balance test], single legged hop limb symmetry, sprint times [10 and 20 m], jumping height and agility).

Prior to the intervention phase, the participants' baseline value for each dependent variable was determined using 2 identical testing sessions separated by a week rest-interval. Each testing session was carried out 48–72 h after finishing the previous competitive match (i.e., Tuesday or Wednesday) so that the players could have enough time for recovery. In addition, players did not carry out any training session throughout this rest-interval. Tests were conducted within the time frame of a regular training session at the same time of the day (in the late afternoon or early evening, depending on the team's training schedule). All the tests were carried out on an outdoor training pitch (3G artificial surface). The total testing procedure lasted approximately 2 h for one team. After these 2 pretest sessions were completed, participants were randomized within each team into 2 groups (team 1: control [n = 11] vs. FIFA 11+ [n = 10]; team 2: control [n = 10] vs. Harmoknee [n = 10]) using a computer-based software program. One of the researchers without any contact or knowledge of the players completed the allocation and randomization. Therefore, no allocation concealment mechanisms were necessary.

For the following 4 weeks (intervention phase), the participants completed only one of the 3 intervention programs 3 days a week as part of their weekly training sessions. As the FIFA 11+ and Harmoknee were initially proposed as training programs that should be performed during the pre-exercise warm-ups, the participants who were allocated in the intervention groups carried out the FIFA 11+ or the Harmoknee instead of their traditional or regular warm-up routines. However, prior to the matches played every single weekend (n = 4), all players performed their traditional warm-up routines (this situation was imposed by the coaches).

The training period of 4 weeks was selected: (a) to match the typical duration of each of the 2 mesocycle within each macrocycle of the regular season in this population; (b) to ensure that both the testing and intervention phases of this study were developed during the same period of the season in each team; and (c) it has been defined as the minimum period needed to find improvements in ROM [128], dynamic postural control [129], sprinting and jumping [103] after performing a specific training program.

A trained rehabilitation specialist was assigned to each team for administrating the FIFA 11+ (team 1) and Harmoknee (team 2), and for checking the warm-ups and assisting the coaches during the normal warm-up (control group). All players in the intervention groups attended a workshop designed to demonstrate how to perform the exercises correctly. In order to prevent contamination of the control groups the training pitch was divided into 2 equal parts, so that the players who belonged to the control group performed their regular warm-up in one part while the players who belonged to the intervention group (FIFA 11+ or Harmoknee) performed their new warm-up in another part of the pitch. Two days after the intervention phase, the post intervention assessments were carried out following the same procedure completed during the baseline-testing phase. The testers who conducted the baseline and post intervention assessments were blinded to group assignment.

4.3.4 Testing procedure

During each testing session, participants began by completing a standardized warm-up routine consisting of 4–5 min of self-paced low- to moderate-intensity running including forward/backwards movements, sidestepping and general mobilization (i.e., arm circles, leg kicks). After these participants performed 6–8 min of dynamic stretching (i.e., straight leg march, forward lunge with opposite arm reach, forward lunge with an elbow instep, lateral lunge, trunk rotations, multidirectional skippings) performing 3 sets, from low to high intensity, with a 15 s rest period between each set. Following this dynamic stretching routine, participants performed 3 sets of ballistic exercises with a 15 s rest period between each set. Exercises included single hop jumps (5 repetitions), alternate leg bounds (multidirectional x 5 repetitions) and short (5–15 m) accelerations and decelerations in different directions (3 repetitions forwards and 5 repetitions side to side). The assessment of the dependent variables was carried out 3–5 min after the standardized warm-up. The order of the tests was consistent through the experimental sessions and is displayed in figure 4.1.

Dynamic postural control

Dynamic postural control was evaluated using the Y-Balance test and following the guidelines proposed by Shaffer et al. [97]. Players were allowed a maximum of 5 trials to obtain 3 successful trials for each reach direction (anterior [supplementary file 4.1a], posteromedial [supplementary file 4.1b] and posterolateral [supplementary file 4.1c]). Trials were discarded if the player failed to maintain unilateral stance on the platform, failed to maintain reach foot contact with the reach indicator on the target area while the reach indicator is in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control [97]. Specifically, testing order was completed as dominant anterior, non-dominant anterior, dominant posteromedial, non-dominant posteromedial, dominant posterolateral, and non-dominant posterolateral. The average of the 3 reaches were normalized by dividing by the previously measured leg length to standardize the maximum reach distance ((excursion distance/leg length) x100 = % maximum reach distance) [98]. Leg length was defined as the length measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial tibial malleolus. To obtain a global measure of the balance test, data from each direction were averaged for calculating a composite score [99]. The dominant lower extremity was defined as the participant's kicking leg (self-reported).

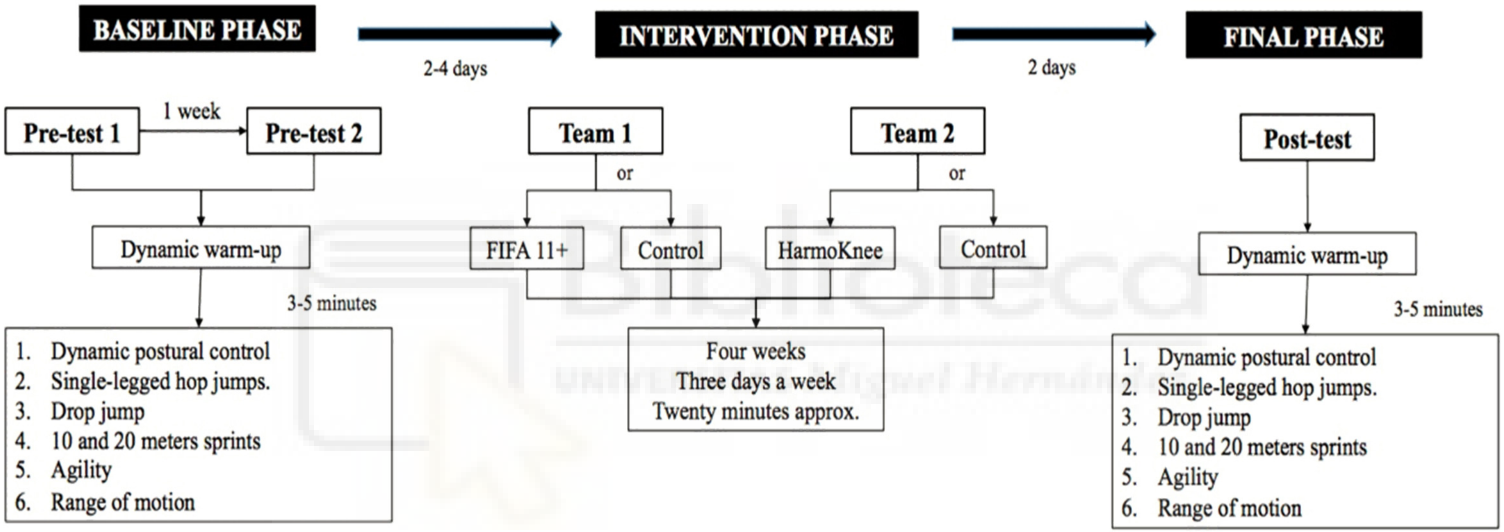


Figure 4.1. Schematic representation of the study design.

Hip, knee and ankle range of motions

The passive hip flexion (passive straight leg raise test [supplementary file 4.2a]), knee flexion (Modified Thomas test [supplementary file 4.2b]) and ankle dorsiflexion (weight-bearing lunge with knee extended test [supplementary file 4.2c]) range of motions of the dominant and non-dominant extremities were assessed following the methodology previously described [91,130]. Participants were barefoot and instructed to perform, in a randomized order, 2 maximal trials of each ROM test for each extremity. An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for all ROM measures. The mean score for each test was used in the subsequent analyses. The same researchers performed the ROM testing at all testing sessions.

Single legged hop limb symmetry

Side-to-side symmetry in jumping distance were evaluated using 2 single-legged hop tests: 1) the single hop for distance (single hop); and 2) triple hop for distance (triple hop).

The single hop was performed with the participant standing on the leg to be tested, hopping as far as possible, and landing on the same leg (supplementary file 4.3a). The triple hop for distance was performed with the participant standing on 1 leg and performing 3 consecutive hops as far as possible (supplementary file 4.3b). Both tests were considered successful if the landing was stable. To be considered a valid trial, the landing must be on one limb, under complete control of the participant. If the participant landed with early touchdown of the contralateral limb, had loss of balance, touched the wall, or had additional hops after landing, the hop was repeated. The hop distance was measured to the nearest centimeter from the starting line to the player's heel with a standard tape measure. Each player performed 3 practice trials and 3 test trials for each of the different hops. The single hop was performed first, followed by the triple hop. Players were instructed to rest between hops whenever needed. For the calculation of the limb symmetry index (LSI) during each of the hop tests, the average values of the 3 successful trials were used. We calculated LSI by using the following formula: (dominant lower extremity/non-dominant lower extremity) × 100 % [131].

10 and 20 m sprint

Owing to its good reproducibility, linear sprint tests ranging from 10 to 20 m are used as general measures of linear speed in soccer players [132]. Time during 10 and 20-m sprint in a straight line was measured by means of single beam photocell gates placed 1.0 m above ground level (Time It; Eleiko Sport, Halmstad, Sweden). Each sprint was initiated from an individually chosen standing position, 50 cm behind the photocell gate, which started a digital timer. Each player performed 2 maximal 10 and 20-m sprint trials interspersed with 3 min of passive recovery, and the fastest time achieved for each distance was recorded.

Vertical drop jump

A vertical drop jump (DJ) without arm swing was performed on a contact platform (Ergojump®, Finland) according to Onate et al. [100]. Participants stood with feet shoulder-width apart on a 28-cm- high step, 30 cm from the contact platform. They were instructed to lean forward and drop from the step as vertically as possible, in an attempt to standardize landing height. Participants were required to land with one foot on each of the contact platform, then immediately perform a maximal vertical jump, finally landing back on the contact platform. Participants were asked to keep their hands on their hips to prevent the influence of arm movements on vertical jump performance. Each participant performed at least 5 maximal jumps starting from a standing position, with at least 1 min of recovery between jumps. Participants were asked to jump as high as possible. The mean jump height of the best 3 jumps was used for statistical analysis.

Agility

The Illinois agility test is commonly used in measuring agility in soccer [126,133,134]. The length of the zone is 10 m, while the width (distance between the start and finish points) is 5 m. 4 cones were placed in the center of the testing area at a distance of 3.3 m from one another (supplementary file 4.4). The participants started the test lying face down, with their hands at shoulder level. The trial started on the “go” command, and the participants began to run as fast as possible. The trial was completed when the players crossed the finish line without having knocked any cones over. Time was measured using a photocell system (Time It; Eleiko Sport, Halmstad, Sweden). 3 trials were performed by each player with the best time used for analysis [126,133].

4.3.5 Interventions

Control group

Coaches were asked to administer their normal warm-up routines trying to match the duration of the FIFA 11+ and the Harmoknee (20–25 min). The traditional warm-up differed between teams but included a combination of running, stretching, technical exercises with the ball and small-sided games.

FIFA 11+

The FIFA 11+ consisted of 3 parts: the first of which involved running exercises (part 1); the second part covered 6 exercises, all of which comprised 3 levels of difficulty and were aimed at improving strength, balance, muscle control and core stability (part 2). The third and final part consisted of advanced running exercises (part 3). For more details see the manual and instructions freely available on the official website (FIFA-Medical and Assessment Research Centre [F-MARC], FIFA 11+, http://www.f-marc.com/11plus [accessed September 1, 2014]). The players completed The FIFA 11+ 3 times a week for 4 weeks substituting their normal warm-up routine. All players were able to perform level II of difficulty for each exercise in part 2, as confirmed during the introductory workshop. No player was able to perform the level III of difficulty for each exercise and therefore the level II of difficulty was chosen for this study.

Harmoknee

The Harmoknee warm-up program included 5 parts: warm-up, muscle activation, balance, strength and core stability, all of which can be combined and performed in a regular soccer training session (Kiani, Ashkan, Harmoknee, http://www.harmoknee.com/ [accessed June 7, 2014). Total program duration was 20–25 min [36]). Similar to the FIFA 11+, Harmoknee was also performed 3 times per week for 4 weeks substituting their normal warm-up routine.

4.3.6 Statistical analysis

The distribution of raw data sets was checked using the Kolmogorov-Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$).

Dependent sample t-tests were carried out to assess differences between limbs (dominant vs. non-dominant) in dynamic postural control and ROM in pre-test 1 and pre-test 2 measures. In cases where no significant differences were found, the mean value of both limbs was used for the subsequent analyses. Dependent t-tests were also carried out to assess baseline inter-session differences (pre-test 1 vs. pre-test 2) for each dependent variable. If no significant differences were found, the mean value of both testing sessions for each variable was used to assess the effects of the intervention programs. Independent sample t-tests were run to evaluate baseline differences between the groups belonging to the same team (paired comparison: team 1, control vs. FIFA 11+; team 2, control vs. Harmoknee) for each dependent variable (mean of the 2 baseline measures).

Magnitude-based inference analysis of the interventions (FIFA 11+, Harmoknee and control) were estimated using a spreadsheet designed by Hopkins [103] via Student t-test with unequal-variances computed for change scores between paired sessions (team 1: control vs. FIFA 11+; team 2: control vs. Harmoknee) at each testing moment (pre-test [baseline], post-test) for each variable. Alpha was set at $p < 0.05$. Each participant's change score between pre and post-tests was expressed as a percentage of baseline score via analysis of log-transformed values, to reduce bias arising from non-uniformity of error. In addition, the analysis determines the probability that the true effects are substantial or trivial when a value for the smallest substantial change is entered. This spreadsheet also provides estimates of the effect of an intervention adjusted to any chosen value of a covariate, thereby reducing the possibility for confounding effects (e.g., when a characteristic is unequal in the experimental and control groups). Thus, the baseline pre-test value (mean of the 2 pre-test measures) of each dependent variable was included as a covariate to avoid the phenomenon of regression to the mean and thereby obtaining a better estimation of the effects of the FIFA 11+ and Harmoknee interventions in comparison with their paired control groups.

Coefficients of variation (CV) determined the smallest substantial change for each of the variables. The CV (standard error of measure [SEM] or typical error of measure [TE] expressed as percentage) data reported by previous inter-session reliability studies for each variable were used for the magnitude-based inference analyses. Thus, substantial is an absolute change > 2.5% for measures of range of motion [91], 3% for measures of dynamic postural control [104], 1.0% for 10 and 20 m sprint times [105], 1.2% for Illinois agility [135] and 6% for DJ height [128]. For those variables (single and triple hop measures) where no studies have analyzed the inter-session reliability, 0.20 standardized units (that is a fraction of the between-participants standard deviation at baseline) was chosen as the substantial change [136]. The default of 0.20 gives chances that the true effect is at least small [109].

The qualitative descriptors proposed by Hopkins [109] were used to interpret the probabilities that the true affects are harmful, trivial or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5–24%, unlikely or probably not; 25–74%, possibly or may be; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly. This approach to qualitatively describe the inferences is based on where the confidence interval of the between-groups differences lies in relation to a 3-level (beneficial, trivial and harmful) scale of magnitudes. For example, whether a confidence interval is entirely within the beneficial range of the smallest substantial change, the effect is clearly beneficial (> 99%, almost certainly). Contrarily, if the confident interval spans 2 levels; harmful and trivial or trivial and beneficial, then the inference is qualified with a descriptor that represents the likelihood that the true value will have the observed magnitude (probabilistic inference) [109]. The inference was deemed unclear when the 90% confidence interval of the pre-post change differences overlapped both beneficial and harmful levels. Effect sizes, which are standardized values that permit the determination of the magnitude of differences between groups or experimental conditions [136], were also calculated for each of the variables using the method previously described by Cohen [136]. Cohen [136] assigned descriptors to the effect sizes (d) such that effect sizes less than 0.4 represented a small magnitude of change while 0.41–0.7 and greater than 0.7 represented moderate and large magnitudes of change, respectively. Analyses were completed using SPSS version 20 (SPSS Inc, Chicago, IL, USA) and an online spreadsheet (Hopkins, Will, "pre-post parallel groups trial spreadsheet", http://www.sportsci.org [accessed April 14, 2015]).

4.4 RESULTS

The statistical analysis showed no significant differences (p values from 0.43 to 0.87) in Y-balance test (anterior, posteromedial and posterolateral directions) and ROM (hip flexion, knee flexion and ankle dorsiflexion) outcomes between the dominant and non-dominant limbs of the players at either the pre-test 1 or the pre-test 2 sessions. Consequently, the average score of both limbs for each unilateral variable was used for the subsequent statistical analysis. No significant differences (p values from 0.22 to 0.93; $d < 0.4$) were found between the values obtained in both pre-test sessions in each variable so that the average score was used as criterion of reference (real baseline score). In addition, there were no paired inter-group differences at baseline for any dependent variable (p values ranging from 0.27 to 0.65).

The pre (baseline) and post intervention results of each group are reported for descriptive purposes in table 4.1 (FIFA 11+ and control) and table 4.2 (Harmoknee and control). The paired inter-group differences after the intervention phase (4 weeks) with the corresponding 90% confidence interval for the physical performance measures are displayed in figures 4.2 and 4.3 for the FIFA 11+ and Harmoknee respectively.

There were substantial (possible and likely substantial differences with a probability ranging from 60 to 91%; d 0.22 to 0.49), and significant ($p < 0.05$) pre-post change differences between control vs. FIFA 11+ (in favor of the latter) for LSI during triple hop (pre- post change differences ranging from −12.5 to −3.9%), anterior (pre-post change differences ranging from 0.9 to 13.8%) and posteromedial (pre-post change differences ranging from −1.2 to 6.5%) distances reached through the Y-balance test, 10 (pre-post change differences ranging from −18.5 to 3.0%) and 20 m (pre- post change differences ranging from −5.7 to 1 %) sprint times and DJ height (pre-post change differences ranging from −8.5 to 22 %) (figure 4.2). However, no main effects were observed ($p > 0.05$; trivial effect with a probability of 55–98%; $d < 0.2$) between control vs. FIFA 11 + for all the ROM measures, LSI during single hop, posterolateral distance, agility and composite score for the Y-balance test. Main effects of the Harmoknee in comparison to its paired control group (likely substantial differences with a probability ranging from 79 to 93%; d ranging from 0.33 to 0.55; $p < 0.05$) were found for knee flexion ROM (pre-post change differences ranging from −5.4 to −1.3%) 10 (pre-post change differences ranging from − 5.3 to − 0.1%) and 20 m (pre-post change differences ranging from −5.5 to −0.3%) sprint times and DJ height (pre-post change differences ranging from 1.9 to 18%) (figure 4.3).

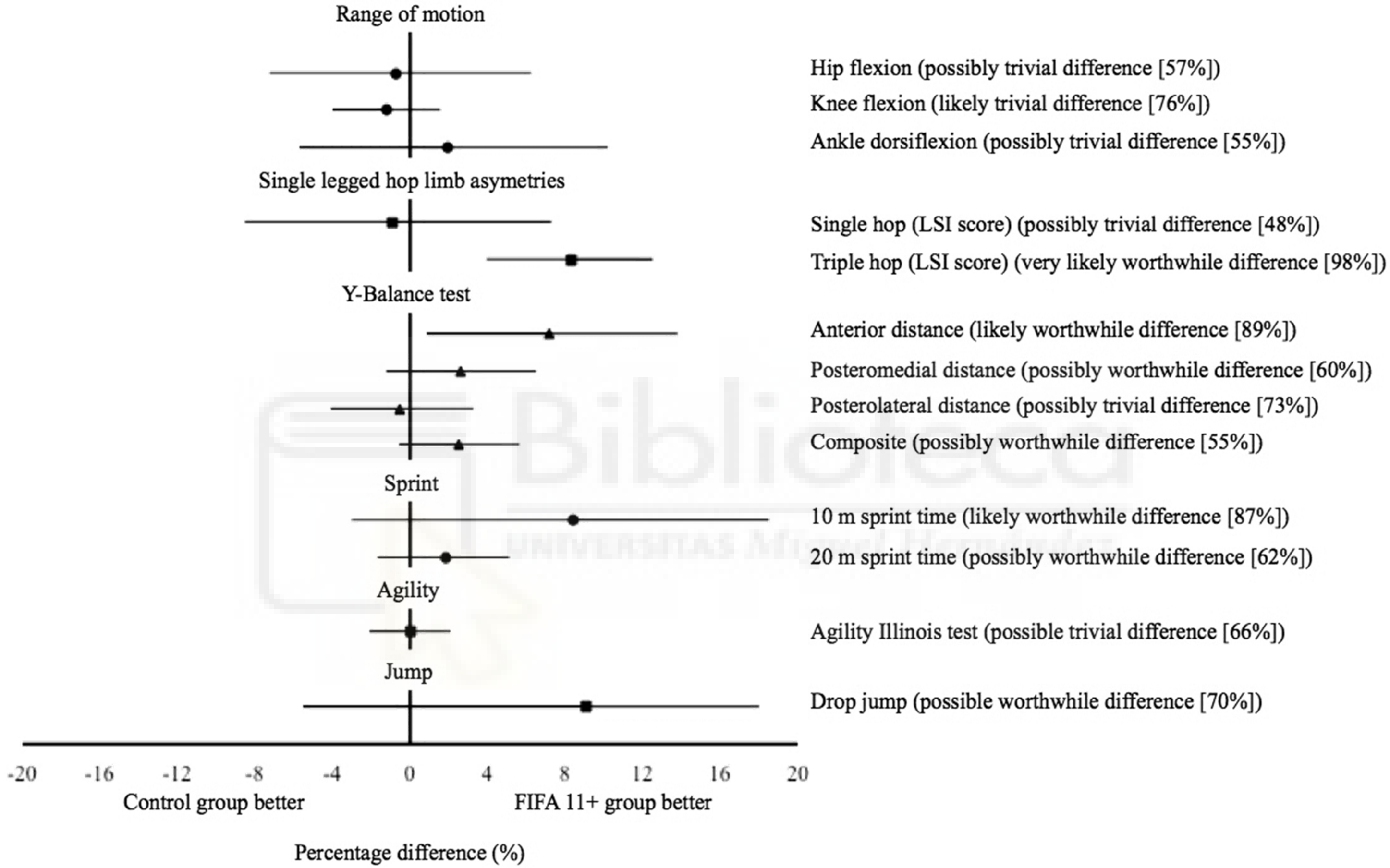


Figure 4.2. Net effects (expressed as percentage) of the intervention on neuromuscular parameters of physical performance for the "FIFA 11+" and control group.

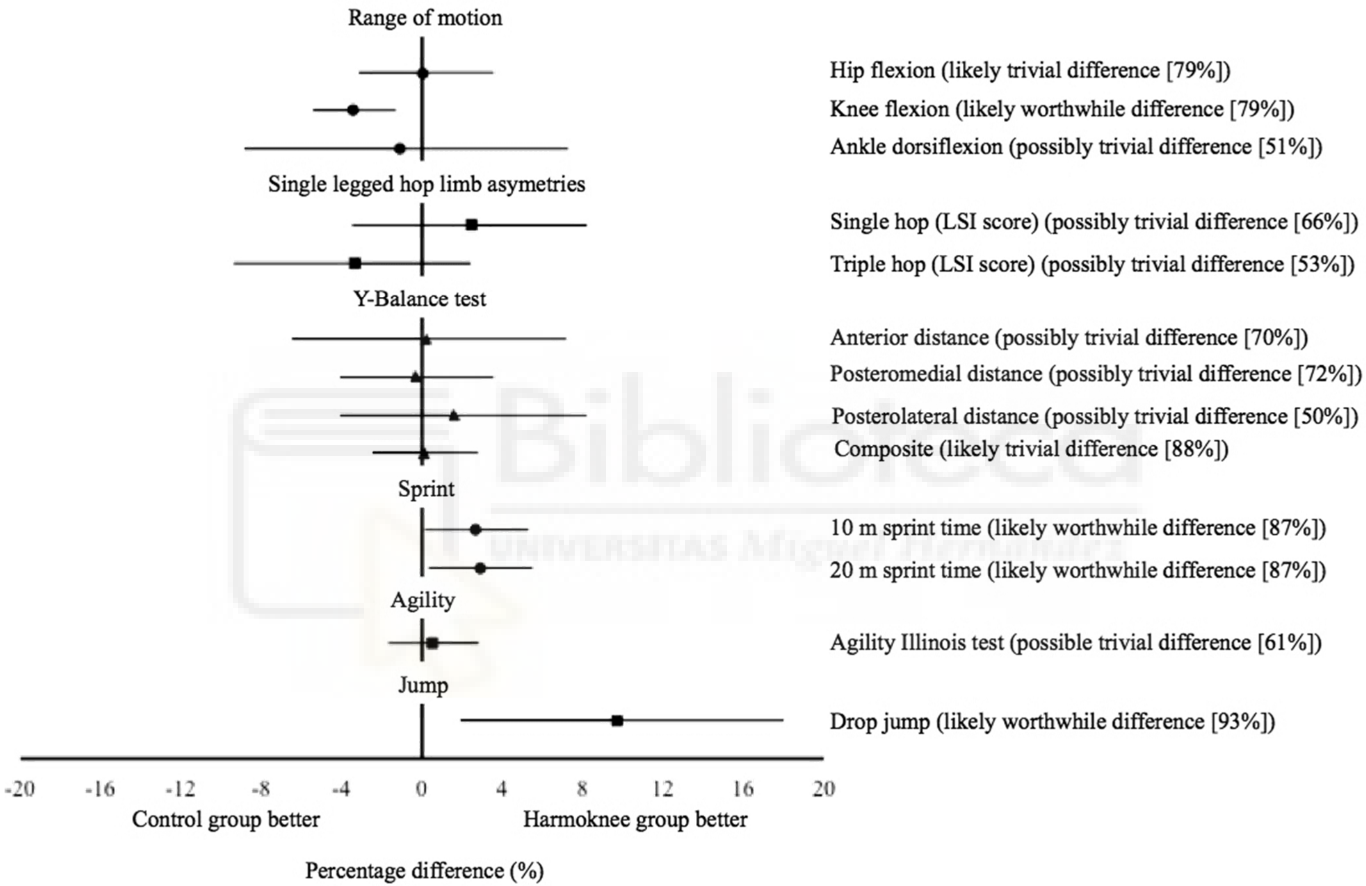


Figure 4.3. Net effects (expressed as percentage) of the intervention on neuromuscular parameters of physical performance for the Harmoknee and control group.

Table 4.1. Baseline and post-intervention (FIFA 11+ and Control) results (mean ± standard deviation [SD]) for physical performance outcomes. The percentage differences between pre and post-test average values are also reported.

Physical performance measure	FIFA 11+						Control					
	Baseline (pre-test)		Post-test		% Difference		Baseline (pre-test)		Post-test		% Difference	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Range of motion (º)												
▪ Hip flexion	79.3	± 4.5	77.8	± 6.7	-1.9	± 6.5	79.9	± 8.7	76.5	± 7.4	-4.3	± 6.9
▪ Knee flexion	136.1	± 7.7	134.6	± 7.6	-1.1	± 5.8	135.3	± 7.0	134.1	± 8.3	-0.9	± 4.3
▪ Ankle dorsiflexion	36.4	± 2.1	39.8	± 3.4	9.3	± 10.1	36.7	± 4.0	36.5	± 2.5	-0.5	± 2.1
Single legged hop limb symmetries												
▪ Single hop	91.6	± 11.1	92.7	± 8.7	1.2	± 3.4	98.6	± 8.3	98.8	± 2.3	0.2	± 2.7
▪ Triple hop	94.3	± 12.9	90.8	± 13.2	-3.7	± 7.8	97.3	± 4.6	102.7	± 6.6	5.5	± 9.5
Y-Balance test (cm) T												
▪ Anterior distance	67.5	± 6.1	67.3	± 6.3	-0.3	± 7.5	70.5	± 5.3	64.8	± 5.2	-8.1	± 10.3
▪ Posteromedial distance	112.9	± 4.8	115.3	± 2.8	2.1	± 4.3	112.0	± 7.8	109.2	± 6.3	-2.5	± 5.1
▪ Posterolateral distance	109.2	± 5.3	109.5	± 4.9	0.3	± 3.7	108.3	± 8.5	106.5	± 5.7	-1.7	± 5.4
▪ Composite	96.3	± 4.0	97.3	± 2.7	1.0	± 2.4	96.8	± 6.7	93.2	± 4.9	-3.7	± 5.9
Sprint time (s)												
▪ 10 m	1.93	± 0.13	2.03	± 0.23	5.20	± 7.80	1.82	± 0.28	2.09	± 0.33	14.80	± 21.10
▪ 20 m	3.30	± 0.18	3.24	± 0.15	-1.80	± 6.20	3.28	± 0.15	3.31	± 0.23	0.90	± 5.50
Agility (s)	16.7	± 1.2	16.3	± 0.8	-2.4	± 5.6	16.6	± 1.0	16.4	± 1.4	-1.0	± 3.0
Vertical drop jump (cm)	26.7	± 2.2	26.6	± 3.5	-0.4	± 7.3	24.1	± 2.2	22.4	± 5.5	-7.1	± 17.3

T: Normalized to limb length expressed as a percentage; s: seconds; cm: centimetre; º: degrees

Table 4.2. Baseline and post-intervention (Harmoknee and Control) results (mean ± standard deviation [SD]) for physical performance outcomes. The percentage differences between pre and post-test average values are also reported.

Physical performance measure	Harmoknee						Control					
	Baseline (pre-test)		Post-test		% Difference		Baseline (pre-test)		Post-test		% Difference	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Range of motion (º)												
▪ Hip flexion	68.5	± 6.2	69.7	± 6.4	1.8	± 3.6	66.4	± 4.0	67.5	± 3.6	1.7	± 3.1
▪ Knee flexion	131.6	± 8.8	130.6	± 8.5	-0.8	± 1.7	133.2	± 4.7	137.1	± 7.6	2.9	± 2.3
▪ Ankle dorsiflexion	41.9	± 2.1	41.9	± 2.0	0.0	± 3.5	41.3	± 1.8	41.9	± 4.0	1.5	± 7.8
Single legged hop limb symmetries												
▪ Single hop	100.9	± 6.6	98.0	± 6.1	-2.9	± 6.7	99.9	± 2.1	99.7	± 5.4	-0.2	± 2.9
▪ Triple hop	100.9	± 6.3	99.1	± 1.8	-1.8	± 4.7	98.8	± 4.9	94.0	± 5.5	-4.9	± 8.6
Y-Balance test (cm) T												
▪ Anterior distance	62.7	± 5.2	64.8	± 7	3.3	± 6.6	59.6	± 5.2	61.2	± 2.9	2.7	± 7.2
▪ Posteromedial distance	95.0	± 4.1	94.5	± 5.9	-0.5	± 4.7	91.4	± 4.6	91.2	± 3.8	-0.2	± 3.1
▪ Posterolateral distance	93.0	± 4.1	93.0	± 6.3	0.0	± 3.3	92.4	± 5.1	90.8	± 7.5	-1.7	± 7.1
▪ Composite	83.6	± 2.8	84.1	± 3.7	0.6	± 3.1	81.0	± 5.0	81.3	± 4.4	0.3	± 2.1
Sprint time (s)												
▪ 10 m	1.81	± 0.05	1.81	± 0.07	0.00	± 2.4	1.86	± 0.04	1.91	± 0.07	2.70	± 3.80
▪ 20 m	3.25	± 0.09	3.17	± 0.05	-2.50	± 2.1	3.34	± 0.05	3.36	± 0.13	0.60	± 3.10
Agility (s)	16.6	± 0.3	16.4	± 0.3	-1.1	± 1.4	17.2	± 0.4	17.1	± 0.5	-0.6	± 2.6
Vertical drop jump (cm)	23.7	± 3.6	26.1	± 4.1	10.1	± 9.1	24.4	± 1.2	24.5	± 2.0	0.4	± 6.7

T: Normalized to limb length expressed as a percentage; s: seconds; cm: centimetre; º: degrees

4.5 DISCUSSION

The findings of the current study indicate that the training stimuli provided by the implementation of the FIFA 11+ 3 times per week for 4 weeks (12 sessions) appear to be sufficient to elicit substantial improvements in several (dynamic postural control, single legged hop limb symmetry [triple hop], sprint times and jumping height), but not all (joint [hip and knee flexion and ankle dorsiflexion] range of motion and agility measures), of the physical performance parameters analyzed.

No studies appear to have examined the effectiveness of the FIFA 11+ on range of motion, dynamic postural control, sprint, agility and jump physical performance parameters in adolescent amateur soccer players and hence, direct comparisons are not possible. However, previous studies using different soccer player cohorts [121,125,126] have reported conflicting training effects of the FIFA 11+ on dynamic postural control, sprint, jump and agility measures. Thus, whereas Daneshjoo et al. [125], and Kilding et al. [126] reported benefits (compared to traditional warm-up) in jumping height and 20 m sprint time after performing the FIFA 11+ in young adults (age: 18.9 ± 1.4 years) and preadolescent (age: 10.4 ± 1.4 years) soccer players respectively; Impellizzeri et al. [121] did not find meaningful improvements in the dynamic postural control, sprint time (10 and 20 m), jumping height (countermovement jump) and agility in adult players (age: 23.7 ± 3.7 years). These differences in population could be a possible explanation for this discrepancy among the results reported. It is possible that the FIFA11+ is not rigorous enough for adult soccer players to reach a training effect and improve physical performance after implementing the FIFA11+ into their regular training. The timing of the interventions carried out in these studies [121,125,126] and also in our study was the same, (e.g., during the regular season) and hence this aspect may have very little influence on these conflicting results.

As this is the first study (to the authors' knowledge) to explore the effects of the FIFA 11+ on single legged hop limb symmetry and joint ROM measures, we are not able to make comparisons. The absence of improvements in the joint ROM measures after performing the FIFA 11+ was expected because this program does not include any specific group of exercises a priori designed to enhance joint ROM (i.e., passive hip flexion, knee flexion and ankle dorsiflexion ROMs). Consequently, our findings would appear to suggest that the inclusion of more specific dynamic stretching exercises, emphasizing major lower extremity joint movements, might be required if a major component of the FIFA 11+ is to improve joint ROM and reduce the likelihood of sustaining a muscle strain [137,138].

The current study also found that the Harmoknee injury prevention program only elicited positive training effects (in comparison with its paired control group) after being implemented for 4 weeks on sprint times (−2.7 to −2.9%) and jumping height (9.7%) measures. The magnitude of the above-mentioned improvements in the sprint time and jumping height after the Harmoknee program were higher than those previously reported by Daneshjoo et al. [125]. Daneshjoo et al. [125] reported an improvement of −0.5% and 1.9% for the sprint time and jumping height respectively after implementing the Harmoknee program 3 times per week for 8 weeks in a group of male professionals under 21y-old soccer players. Perhaps, a possible explanation for these conflicting results might be attributed to the different levels of sport performance of the population used in each study (amateurs vs. professionals). It can be argued that given the high level of professional under 21 players, the Harmoknee may not be challenging enough for them to see a training effect [139]. In addition, the results of the current study did not show meaningful improvements in the dynamic postural control, in contrast to the findings reported by Daneshjoo et al. [122], who showed a significant increase (approximately 5.6%) in dynamic postural control. Aside from the different populations used, and in contrast to the other neuromuscular performance variables (sprint and jumping), the training stimuli needed to achieve meaningful improvement in postural control after the implementation of the Harmoknee program might be higher. Thus, while Daneshjoo et al. [122] applied the Harmoknee program for 8 weeks (total number of sessions = 24), we implemented the Harmoknee for just 4 weeks (total number of sessions = 12). Thus, given the intensity and volume of the Harmoknee program used in the current study, 4 weeks (12 sessions) might not be enough to elicit a training response. We were not able to compare the effects of the Harmoknee on the rest of the physical performance parameters selected, as the current study was the first in addressing this issue.

The authors of the current study speculate that the reported improvements in physical performance elicited by the FIFA 11+ program may contribute to a reduction of injury risk in the long-term. Thus, the mechanisms behind the previously reported reduction in injury incidence by the FIFA 11+ in youth soccer players [35,49,50,71,72] might be particularly associated with enhancements in neuromuscular control and dynamic postural control. However, the mechanisms behind the effectiveness of the Harmoknee to reduce the incidence of lower extremity injuries [36] might be only related to enhancements in neuromuscular control. It has been suggested that for youth athletes, an effective plyometric training load should be approximately 74–88 feet contacts completed within each session, which should be performed through the combination of 4–6 exercises geared toward developing both safe jumping and landing mechanics and also to stress stretch-shortening cycle activity [140,141]. In addition, the training frequency should be at least 2–3 non-consecutive days per week [141]. However, despite the fact that the youth amateur players involved in the current study undertake less plyometric training load e. g., within session (< 60 foot contacts completed through 2–3 exercises) and weekly (3 training session) compared with those competing at a higher level e.g., within session (> 74 foot contacts completed through 4–6 exercises and a weekly frequency of 5 training sessions), it appears that the training stimuli of the FIFA 11+ and Harmoknee may be enough to induce benefits in jumping and sprint performance.

Although the current study is novel in several aspects (testing procedures, statistical analyses and design), some limitations should be noted. One limitation is the lack of a placebo group, defined as a separate group, that in contrast to a typical control group, receives a new sham "placebo" intervention (e.g., upper limb strength training) which is specifically designed to have no real effects on the dependent variables analyzed. In fact, we only used paired control groups as in previous similar studies [121,122,124–126] but we could not control for potential effects of expectations generated by the enrolment in an experimental intervention. However, to avoid or minimizing the placebo effect in measures influenced by motivation or learning, a double baseline (2 pre-test sessions) design was used. Therefore, while we cannot exclude that the trends towards a better performance which can be observed from the inspection of the forest plots (mainly in the FIFA 11+ intervention) are partially or totally due to a placebo effect, the results of the tests were less likely influenced. Another important limitation was the small sample size used in each group (interventions or controls). However, the sample size that was enrolled in each group was similar to previous studies [122,124–126] and allowed main effects were identified. Another possible limitation of the current study is the sample used. The age distribution of participants (16.8 ± 0.7y) and their physical skills level (amateur) narrow the generalizability of these results. In order to minimize the error associated with the players who belonged to the control group copying and performing any new exercise included in the intervention groups during their regular warm-up, the players of the intervention groups performed their new warm-up in a separate part of the pitch. In addition, a trained rehabilitation specialist was assigned to each team for administrating the interventions and for checking that the control groups did not perform exercise that were not part of their normal warm-up. However, we cannot totally exclude the possibility that the players of the control groups might have performed exercise included in the interventions outside of their regular training sessions. In particular, although during the warm-up prior to the normal training sessions they were in a different part of the pitch, they might have been conscious (via eye contact) that their team mates belonging to the intervention groups were performing different warm-up exercises. In addition, it is possible that the players belonging to both groups in each team (control and intervention groups) might have spoken about the interventions during the rest periods of the training sessions or even in the locker room. Furthermore, it is also possible that the players of the control group might have felt less motivated to perform their traditional warm-up routine because they knew they were in the control group and not in the intervention group. Finally, comparison between intervention groups (FIFA 11+ and Harmoknee) were not carried out due the fact that it was impossible to reach an agreement between the coaches of the teams regarding the minutes spent in the different training components (technical-tactical, interval-training, intermittent training, small-sided games, …) in each training session. Future studies that investigate the effects of longer interventions than that conducted in the current study (> 4 weeks) on several physical performance variables using randomized control trial with placebo control group designs are needed to understand better potential mechanisms behind the reported reduction in injury incidence reported by the FIFA 11+ and Harmoknee programs. In addition, further research is needed to identify the exercises really necessary for preventing injuries in order to develop more time-efficient prevention programs which can be more easily implemented into daily routines.

In conclusion, the findings of the current study reinforce that even short-term adherence to an injury prevention program can have positive effects on performance variables. Thus, the results of this study showed that performing the FIFA 11+ 3 times per week for 4 weeks elicits substantial improvements (in comparison with its paired control group) in dynamic postural control, single legged hop limb symmetry, sprint time and jumping height. Thus, we can speculate that an enhancement in physical performance (neuromuscular control and dynamic postural control) is a possible key mechanism for explaining the injury prevention effect of FIFA 11+. In contrast to the FIFA 11+, the Harmoknee only reported meaningful effects on sprint and jumping ability suggesting improvements in neuromuscular control as the mechanism behind its documented effectiveness to reduce the incidence of lower extremity injuries. Our findings would suggest that the FIFA 11+ is more effective in reducing injury risk factors (poor physical performance in postural control and neuromuscular control) than the Harmoknee program in adolescent male amateur soccer players. We would therefore advocate exchanging traditional warm-up programs for the FIFA 11+ in male youth soccer players.

4.6 SUPPLEMENTARY FILES

Supplementary file 4.1

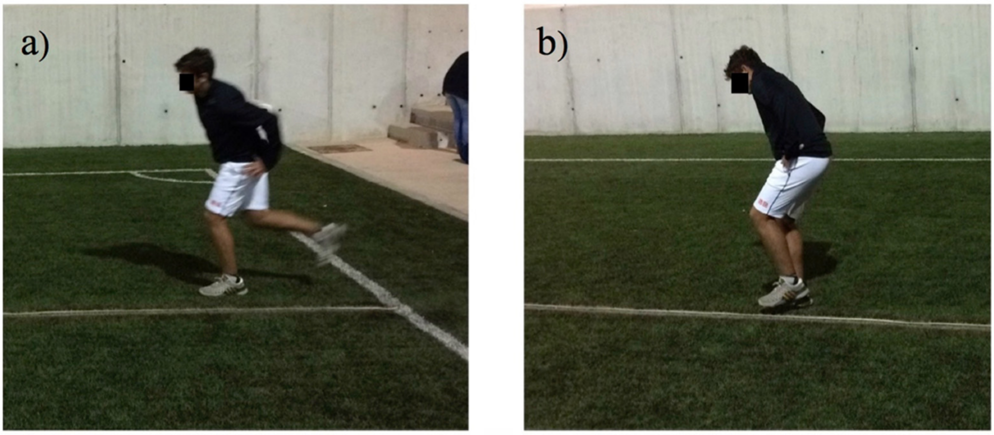
Dynamic postural control assessment (anterior [a], posteromedial [b] and posterolateral [c] directions).

***Supplementary file** 4.2*

The passive hip flexion (passive straight leg raise test [a]), knee flexion (Modified Thomas test [b]) and ankle dorsiflexion (weight-bearing lunge with knee extended test [c]) range of motion assessment.

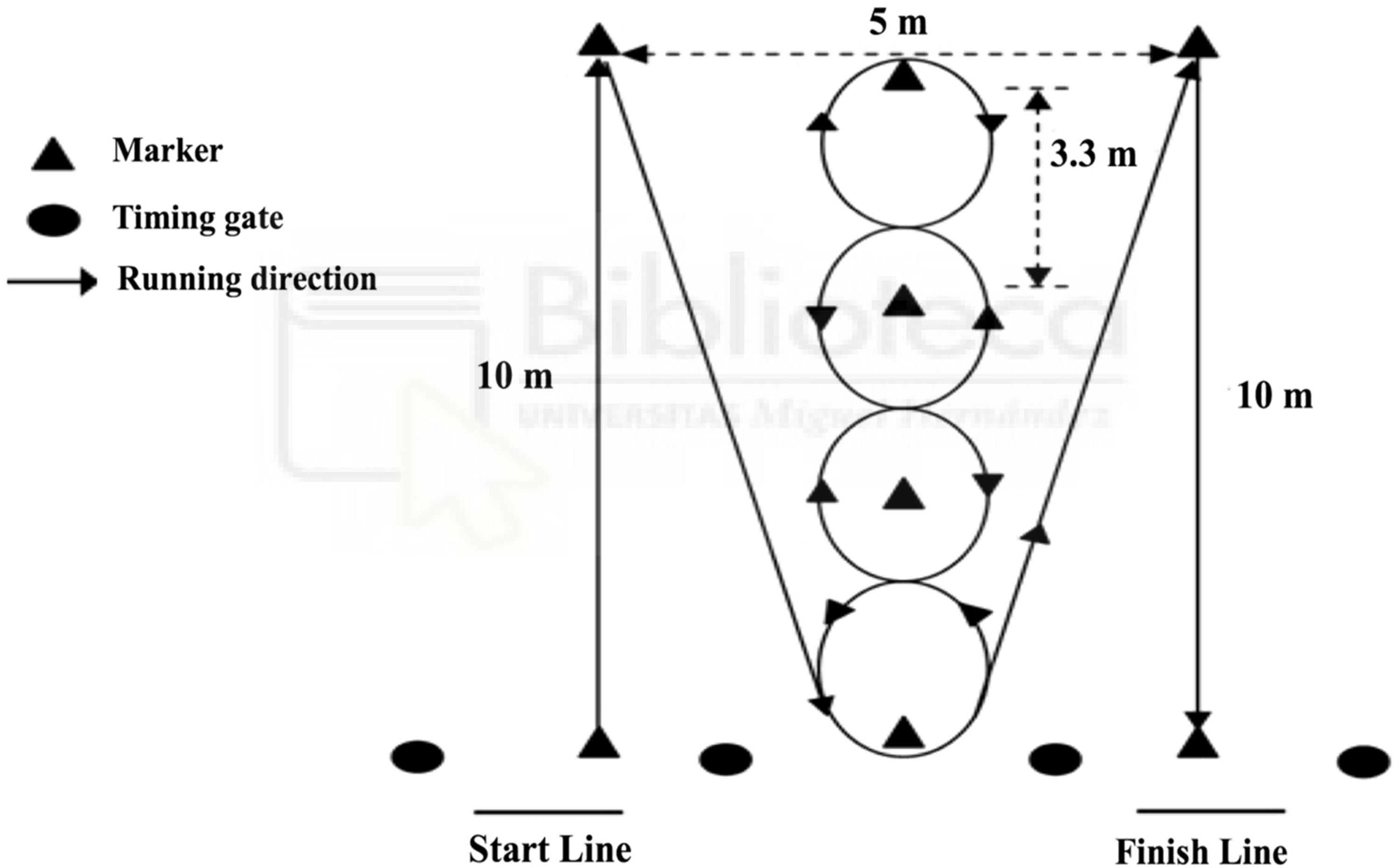
Supplementary file 4.3

Single legged hop limb symmetry assessment (single hop for distance [a]; and triple hop for distance [b]).



Supplementary file 4.4

Illinois agility run dimensions and completion route. m = meters.



CHAPTER 5

Study 3

5

STUDY 3

TRAINING EFFECTS OF THE FIFA 11+ KIDS ON PHYSICAL PERFORMANCE IN YOUTH SOCCER PLAYERS: A RANDOMIZED CONTROL TRIAL

by

Pomares-Noguera C, Ayala F, Robles-Palazón FJ, Alomoto-Burneo JF, López-Valenciano A, López-Elvira JL, Hernández-Sánchez S, & De Ste Croix M.

5.1 ABSTRACT

The objective of this study was to analyze the training effects of the FIFA 11+ Kids on several parameters of physical performance in male youth soccer players. Twenty-three youth players were randomized within each team into two groups (control vs. intervention). The intervention group performed the FIFA 11+ Kids program 2 times a week for 4 weeks; the control groups completed their normal warm-up routines. Thirteen physical performance measures {range of motion (hip, knee, and ankle joints), dynamic postural control (measured throughout the Y balance test), 20 m sprint time, slalom dribble with a ball, agility, vertical jumping height [counter movement jump (CMJ) and drop jump (DJ)], horizontal jump distance, accuracy when volleying a ball [measured throughout the Wall Volley test]} were assessed. All physical performance parameters were compared via magnitude-based inference analysis. Significant between-group differences in favor of the FIFA 11+ players were found for dynamic postural control {anterior [mean and 90% confidence intervals (CI) = 1 cm, from −1.6 to 3.5 cm] and posteromedial (mean and 90% CI = 5.1 cm, from −1.8 to 12 cm) and posterolateral (mean and 90% CI = 4.8 cm, from 0.6 to 9.0 cm) distances}, agility run (mean and 90% CI = 0.5 s, from −0.9 to 0 s), vertical jump height [CMJ (mean and 90% CI = 3.1 cm, from 0.2 to 6.1 cm) and DJ (mean and 90% CI = 1.7 cm, from −0.5 to 3.9 cm)], and horizontal jump distance (mean and 90% CI = 2.5 cm, from −8 to 15 cm). The control groups showed better performance in 20 m sprint time (mean and 90% CI = −0.05 s, from −0.11 to 0.07) and wall volley tests (mean and 90% CI = 0.2, from −0.2 to 0.6) compared to the intervention group. The main findings of this study suggest that

just 4 weeks of implementation of the FIFA 11+ Kids produce improved physical performance compared with traditional warm-up routines in youth soccer players.

Keywords: *youth athletes, agility, injury prevention, jumping, warm-up.*

5.2 INTRODUCTION

Soccer (associated football) is a physically demanding sport that entails sudden acceleration and deceleration, rapid changes of directions, jumping and landing tasks, as well as many situations in which players are involved in tackling to keep possession of or to win the ball [22,23]. These high-intensity situations result in a notable increase in injury risk and are especially relevant in children where individual growth and maturation may predispose youth players to a higher risk [24,26,27]. Epidemiology studies have reported that the frequency and severity of injuries among youth soccer players is striking in comparison to other sports [115–117]. In particular, a recent epidemiological study of young children (7–12 years of age) reported injury incidence rates of 0.61 per 1,000 h of exposure and an increase in the incidence rate with age [142]. While some studies have explored position-related differences in injury incidence [143], it should be noted that there may be differing movement demands based on soccer position; however, no studies have directly explored this within youth soccer.

Therefore, it would appear important to implement effective injury prevention programs early to counter potential injury-related risks. Several injury prevention programs have been designed with the aim of preventing and reducing the number and severity of soccer-related injuries in adolescent players, such as the FIFA 11+, knee injury prevention program and preventing injury and enhancing performance program [36,38,69,144]. All of these programs include running exercises and specific dynamic movements focusing on enhancing physical competence and performance, as it has been suggested as a primary injury risk factors in youth athletes [145] and are based on the injury profile and biological status (i.e., maturation phase) of the target population (>14 years of age). The effectiveness in reducing non-contact overall and overuse lower extremity injury rates of these abovementioned injury prevention program have been documented in male and female youth (aged 13–19 years) players [146].

However, these injury prevention program may not be suitable for younger players (<13 years of age) since maturation seems to affect the incidence and characteristics of injury. Specifically, injury incidence in youth populations has been shown to be higher in adolescents than pre/early pubertal players [30]. Thus, injury incidence has recently been aligned to peak height velocity (adolescence), when rapid disproportional growth is evident [31]. Furthermore, younger soccer players seem to have more fractures and bone stress, fewer strains and sprains, and more injuries of the upper body than adolescent players [142]. These considerations have led some authors to develop a warm-up program designed to prevent injuries and reduce the number and severity of soccer-related injuries in children who take age-specific injury characteristics and physical maturity into account [28]. The warm-up program "FIFA 11+ Kids" is intended to prevent and reduce the number and severity of soccer-related injuries by enhancing children's fundamental and sport-specific motor skills through a range of evidence-based exercises. In particular, the FIFA 11+ Kids focus on: (a) spatial orientation, anticipation, and attention, particularly while dual-tasking (to avoid unintended contact with other players or objects); (b) body stability and movement coordination (more general than specific neuromuscular or proprioceptive training); and (c) learning appropriate fall techniques (to minimize the consequences of unavoidable falls). Accordingly, this warm-up program may contribute to achieving the aims of the earlier stages [(1) Active Start, (2) FUNdamentals, and (3) Learn to Train] of the long-term athletic development conceptual model for late specialization sports [147,148].

Only one large-scale cluster-randomized controlled trial has evaluated the effectiveness of the FIFA 11+ Kids showing a 38% reduction in injuries, with severe injuries reduced by more than 50%, compared to a control group (data available at https://www.fifamedicinediploma.com/lessons/prevention-fifa11-kids/).

However, the training effects elicited on movement skills and physical performance on the potential mechanisms behind the reported reduction in injury incidence remain to be elucidated. To the best of our knowledge, only some authors have examined the pre-exercise effects of the FIFA 11+ Kids on various physical performance variables in children soccer players, showing possibly beneficial effects in static and dynamic balance, jumping performance, and slalom dribbling [28].

Therefore, the main purpose of this study was to analyze the training effects of the FIFA 11+ Kids on several parameters of physical performance in young soccer players. We hypothesized that this new program would show beneficial and superior effects on physical performance (particularly in balance and agility measures) in comparison to the traditional practices as they include specific and novel exercises designed to improve physical competency.

5.3 MATERIALS AND METHODS

5.3.1 Research design and participants

A total of 26 male youth soccer players (age: 11.8 ± 0.3 years; stature: 144.7 ± 5.1 cm; body mass: 39.4 ± 5.5 kg) took part in the current study. Participants were recruited from two different soccer teams that were engaged in the Official Amateur Championships of the Spanish Soccer Federation (under 12 years regional league). All participants were classified as pre-peak height velocity (PHV) (−3 years to −1 years from PHV) and met three inclusion criteria: (1) had no history of impairments to the knee, thigh, hip, or lower back in the 6 months prior to the study; (2) all participants were free of self-reported delayed onset muscle soreness at any testing session (self-reported); and (3) participated in two training sessions per week (1.5–2 h per session). In addition, two exclusion criteria were also established: (1) missed two consecutive or three non-consecutive training sessions and (2) missed one testing session [149].

All experimental procedures and potential risks were explained fully both verbally and in writing to the participants, and written informed consent was obtained from players, their parent/guardian, and coaches. The Institutional Research Ethics committee of the Miguel Hernandez University of Elche (DPS.FAR.01.14), conforming to the recommendations of the Declaration of Helsinki, approved the study protocol prior data collection.

Twenty-three young soccer players from two different soccer teams completed this study. Three players who belonged to one team were excluded from the study because they missed more than three non-consecutive training sessions. The participants' characteristics can be observed in table 5.1.

A parallel, two-group, pre-post, randomized controlled trial with double baseline (two pre-test sessions) was used to address the purposes of this study.

The study was conducted between February and April 2015. In Spain, the under 12 local league has two rest periods [winter (2–3 weeks for Christmas holidays) and spring (2 weeks for Easter holidays) breaks] so the season is divided into three main terms/macrocycles. The three terms have approximately the same number of weeks (8–10 weeks) and matches (8–10 matches; one every weekend). The time frame of the study was selected so that the study started after the winter break and could be completed before the Easter break. The second term of the season was chosen rather than the first term in order to be sure that the players selected to each team was definitive and stable within the testing period. Further, the study was not carried out in the third term of the season with the aim of reducing the dropout rate of players' that could be expected due to the primary school final exams.

Table 5.1. Demographic variables for the children soccer players*.

Age (years)	11.8 ± 0.3
Stature (cm)	144.7 ± 5.1
Body mass (kg)	39.4 ± 5.5
Body mass index (Kg/m^2)	18.7 ± 2.1
Maturation offset (years from PHV)	-2.4 ± 0.4

** All values are mean ± SD*

The independent variables were the two different warm-up programs [control (traditional or regular warm-up) and intervention (FIFA 11+ Kids)]. The dependent variables included 13 physical performance measures {range of motion (hip, knee, and ankle joints), dynamic postural control (measured throughout the Y balance test), 20 m sprint time, vertical jump height [counter movement jump (CMJ) and drop jump (DJ)], horizontal jump distance, accuracy when volleying a ball (measured throughout the wall volley test), slalom dribble and agility}.

Prior to the intervention phase, the participants' baseline value for each dependent variable was determined using two identical testing sessions separated by a week rest-interval. Each testing session was carried out 48–72 h after finishing the previous competitive match (i.e., Tuesday or Wednesday) so that the players had enough time for recovery. In addition, players did not carry out any training session throughout this rest-interval. Tests were conducted within the time frame of a regular training session at the same time of the day (in the late afternoon). All the tests were carried out on an outdoor training pitch (3G artificial surface). The total testing procedure lasted approximately 2 h for one team. After the two pre-test sessions were completed, participants were randomized within each team into two groups [team 1: control (n = 6) vs. FIFA 11+ Kids (n = 6); team 2: control (n = 4) vs. FIFA 11+ Kids (n = 7)] using a computer-based software program. One of the researchers without any contact or knowledge of the players completed the allocation and randomization. Therefore, no allocation concealment mechanisms were necessary.

For the following 4 weeks (intervention phase), the participants completed only one of the two intervention programs 2 days a week as part of their weekly training sessions. Prior to competitive matches, all players performed their normal warm-up routines (this was imposed by the coaches of both teams).

The training period of 4 weeks was selected (a) to match the typical duration of each of the two mesocycle that make up the three macrocycles of the regular season and (b) to ensure that both the testing and intervention phases of the study were completed during the same period of the season in each team.

A Master in Sports Science student was assigned to both teams for administrating the FIFA 11+ Kids and for checking that the coaches delivered their normal warm-ups in the control group. All players in the intervention groups attended a workshop designed to demonstrate how to perform the exercises correctly. In order to prevent contamination of the control groups, the training pitch was divided into two equal parts, so that the players who belonged to the control group performed their regular warm-up in one part while the players who belonged to the intervention group performed their new warm-up in another part of the pitch. Two days after the intervention phase, the post-intervention assessments were carried out following the same procedure completed during the baseline-testing phase. Due to organizational reasons, the same two testers (one tester conducted the tests while the other tester recorded the data) who conducted the baseline and post-intervention assessments were not blinded to group assignment.

5.3.2 Testing procedure

During each testing session, participants began by completing a standardized warm-up routine consisting of 4–5 min of self-paced low- to moderate-intensity running including forward/backward movements, sidestepping, and general mobilization (i.e., arm circles, leg kicks). After this, participants performed 6–8 min of dynamic stretching (i.e., straight leg march, forward lunge with opposite arm reach, forward lunge with an elbow instep, lateral lunge, trunk rotations, multidirectional skippings) performing three sets, from low to high intensity, with a 15 s rest period between each set. The assessments of the dependent variables were carried out 3–5 min after the standardized warm-up. The order of the tests was consistent through the experimental sessions and is displayed in figure 5.1.

Dynamic Postural Control

Dynamic postural control was evaluated using the Y balance test. Players were allowed a maximum of five trials to obtain three successful trials for each reach direction (anterior, posteromedial, and posterolateral). Trials were discarded if the player failed to maintain unilateral stance on the platform, failed to maintain reach foot contact with the reach indicator on the target area while the reach indicator is in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control [97]. Specifically, testing order was completed as dominant anterior, non-dominant anterior, dominant posteromedial, non-dominant posteromedial, dominant posterolateral, and non-dominant posterolateral. The best of the three reaches was normalized by dividing by leg length to standardize the maximum reach distance ((excursion distance/leg length) × 100 = % maximum reach distance) [98]. Leg length was defined as the length measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial tibial malleolus. To obtain a global measure of the balance performance, data from each direction was averaged to determine a composite score [98].

20-m Sprint

Time during a 20-m sprint in a straight line was measured by means of single beam photocell gates placed 0.3 m above the ground level (Time It; Eleiko Sport, Halmstad, Sweden). Each sprint was initiated from an individually chosen standing position, 30 cm behind the photocell gate, which started a digital timer. Each player performed three maximal 20 m sprints interspersed with 3 min of passive recovery, and the fastest time achieved was retained [150].

Agility

The Illinois agility test is commonly used in measuring agility in soccer [28,76,126]. The length of the zone is 10 m, while the width (distance between the start and finish points) is 5 m. Four cones were placed in the center of the testing area at a distance of 3.3 m from one another. Four cones were used to mark the start, finish, and two turning points. The participants started the test lying face down, with their hands at shoulder level. The trial started on the "go" command, and the participants began to run as fast as possible.

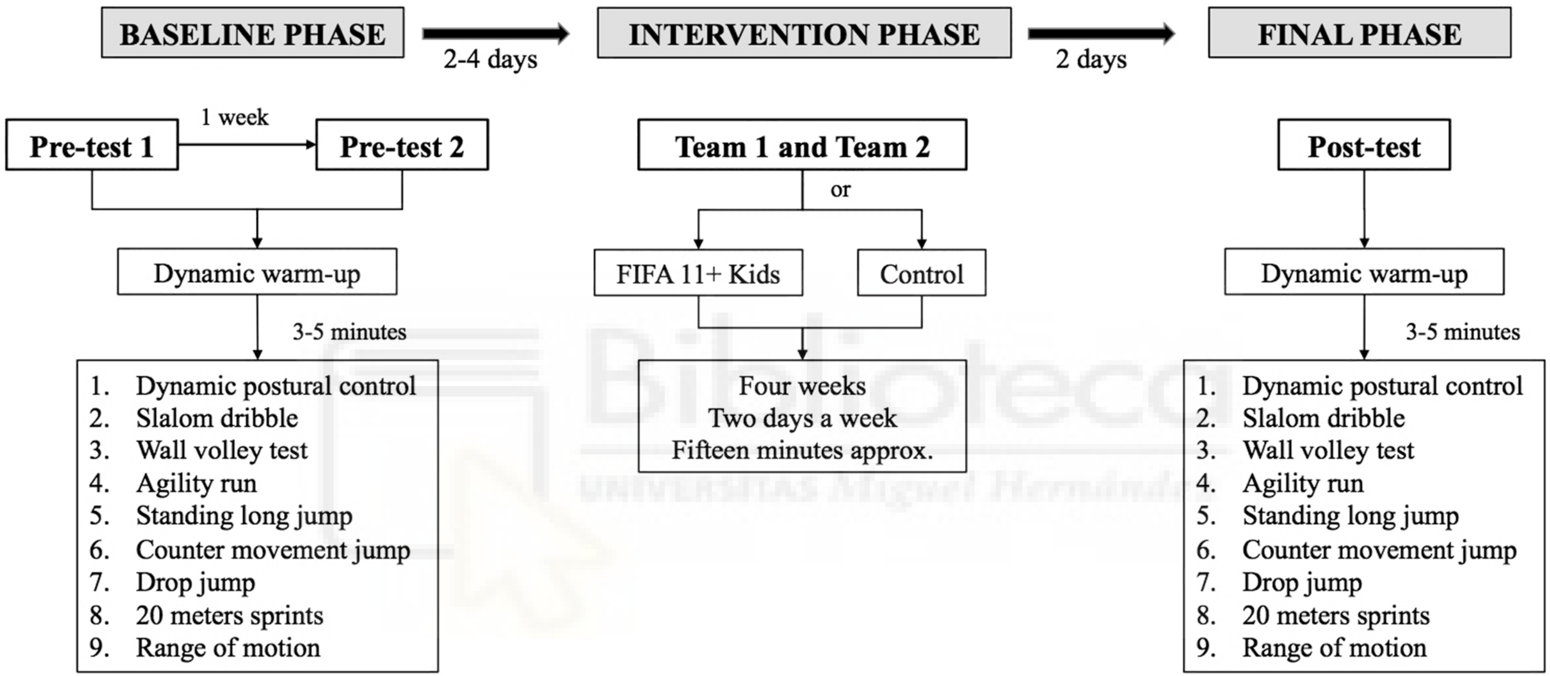


Figure 5.1. Schematic representation of the study design.

The trial was completed when the players crossed the finish line without having knocked any cones over. Time was measured using a photocell system (Time It; Eleiko Sport, Halmstad, Sweden). Each player performed three trials with the best score (time) used for analysis.

Slalom Dribble

The slalom dribble course was 20 m in length. Participants ran with the ball in a zig-zag fashion around five cones placed in a straight line 4.5 m away from one another. The run time was measured using two photoelectric timing gates. Participants started 0.3 m in front of the starting line and performed four repetitions with the best score (time) used for analysis.

Wall Volley Test

The wall volley test required players to pass the ball through the air against a wall, control the rebound, and make as many direct air-borne passes against the wall as possible, within a time limit of 30 s. The outcome was the absolute number of correct rebounds [151]. The player was placed in a field which was 2 m wide and 0.5 m away from the wall. Only rebounds accomplished while standing in the sector were counted. After two familiarization tests, participants completed two repetitions and the best score was used for analysis.

Standing Long Jump

The participant stood behind the starting line and was instructed to push off vigorously and jump as far as possible. The participant had to land with the feet together and to stay upright. Arm swing was not permitted. Jump distance was measured from the take off line to the back of the heel. After two familiarization tests, participants performed three repetitions. The best score of the three repetitions was selected for the subsequent analysis.

Counter Movement Jump

A CMJ without arm swing was performed on a contact platform (Ergojump1, Finland) [152]. During the CMJ, the participants first stood upright, then squatted to a self-selected depth of approximately 90° knee flexion, and jumped immediately as high as possible. Players were asked to keep their hands on their hips to prevent the influence of arm movements on vertical jump performance. In addition, players were allowed to perform a countermovement with the lower limbs before jumping. Each player performed five maximal CMJs interspersed with 45 s of passive recovery, and the best jump height was recorded.

Drop Jump

A vertical DJ without arm swing was performed on a contact platform (Ergojump®, Finland) [100]. Participants stood with feet shoulder-width apart on a 28-cm-high step, 30 cm from the contact platform. They were instructed to lean forward and drop from the step as vertically as possible, in an attempt to standardize landing height. Participants were required to land with one foot on each of the force plates, then immediately perform a maximal vertical jump, finally landing back on the contact platform. Participants were asked to keep their hands on their hips to prevent the influence of arm movements on vertical jump performance. Each participant performed at least five maximal jumps starting from a standing position, with at least 1 min of recovery between jumps. Participants were asked to jump as high as possible with the shortest contact time with the ground. The best jump height was used for statistical analysis.

Hip, Knee, and Ankle Range of Motions

Passive hip flexion [passive straight leg raise test], knee flexion [Modified Thomas test], and ankle dorsiflexion [weight-bearing lunge with knee extended test] range of motion of the dominant and non-dominant extremities were assessed [91]. Participants were barefoot and instructed to perform in a randomized order and two maximal trials of each range of motion test for each extremity. The best score for each test was used in the subsequent analyses. The same researchers performed the ROM testing at all testing sessions.

5.3.3 Interventions

Control Group

Coaches were asked to administer their normal warm-up routines trying to match the duration of the FIFA 11+ Kids (15–20 min). The traditional warm-up differed slightly between teams but included a combination of running, stretching, technical exercises with the ball and games.

FIFA 11+ Kids

The FIFA 11+ Kids consisted of seven different exercises: a running game, two jumping exercises, a balance/coordination task, two exercises targeting body stability, and an exercise to improve falling technique [28]. The program has a modular structure and consists of three skill levels with progressive load. The players completed the FIFA 11+ Kids two times a week for 4 weeks substituting their normal warm-up routine. All players were able to perform the level II of difficulty for each exercise in part 2 properly as confirmed during the habituation workshop. However, no player was able to perform the level III of difficulty for each exercise, and therefore, the level II of difficulty was used.

5.3.4 Statistical analysis

The distribution of raw data sets was checked using the Kolmogorov–Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$).

Dependent sample *t*-tests were carried out to assess differences between limbs (dominant vs. non-dominant) in dynamic postural control and range of motion pre-test 1 and pre-test 2. In cases where no significant differences were found, the mean value of both limbs was used for the subsequent analyses. Dependent *t*-tests were also carried out to assess baseline intersession differences (pre-test 1 vs. pre-test 2) for each dependent variable. If no significant differences were found, the mean value of both testing sessions for each variable was used to assess the effects of the intervention programs. Contrarily, if significant differences were found, the highest value of both testing sessions for each variable was used for the magnitude-based inference analysis of the interventions. Independent sample t-tests were run to evaluate baseline differences between the groups (intervention vs. control) for each dependent variable (mean of the two baseline measures). Magnitude-based inference analysis of the warm-up programs (intervention and control) were estimated using a spreadsheet via Student's t-test with unequal variances computed for change scores between paired sessions (intervention vs. control) at each testing time [pre-test (baseline), post-test] for each variable [103]. Alpha was set at $p < 0.05$. Each participant's change score between pre- and post-tests was expressed as a percentage of baseline score via analysis of log-transformed values, to reduce bias arising from non-uniformity of error.

This approach of data analysis uses confidence intervals (CI) to calculate the probability that a difference is of practical relevance or trivial when a value for the smallest worthwhile change is entered. A difference score of at least 0.2 of the between-participant SD (representing a small effect) was considered to be practically worthwhile [153]. The qualitative descriptors were used to interpret the probabilities that the true affects are harmful, trivial, or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5–24%, unlikely or probably not; 25–74%, possibly or may be; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly [109]. This spreadsheet also provides estimates of the effect of an intervention adjusted to any chosen value of the covariate, thereby reducing the possibility for confounding of the effect when a characteristic is unequal in the experimental and control groups: thus, the baseline pre-test value (mean of the two pre-test measures) of each dependent variable was included to avoid the phenomenon of regression to the mean and thereby obtaining a better estimation of the effects of the warm-up programs in comparison with their paired control groups.

5.4 RESULTS

t-Tests demonstrated no significant differences (p values from 0.06 to 0.97) in Y balance test (anterior, posteromedial, and posterolateral directions and composite score) and ROM (hip flexion, knee flexion, and ankle dorsiflexion) outcomes between the dominant and non-dominant limbs of the players at either pre-test 1 or pre-test 2. Consequently, the average score of both limbs for each unilateral variable was used for the subsequent statistical analysis. No significant differences (p values from 0.08 to 0.97) were found between the scores obtained in both pre-test sessions in each variable (with the exception of the Illinois test [mean pre-test 1 vs. pre-test 2 difference = 0.24 ± 0.42 s; p = 0.01]) so the average score was used as criterion of reference (baseline score) (table 5.2). In addition, there were no paired inter-group differences at baseline for any dependent variable (p values ranging from 0.24 to 0.89). The pre (baseline) and post-intervention results of each group are reported for descriptive purposes in table 5.3 (FIFA 11+ Kids and control).

The inter-groups differences after the intervention phase (4 weeks) with the corresponding 90% CI for the physical performance measures are displayed in figure 5.2. Very likely and likely beneficial effects favoring the intervention group were observed in CMJ height and DJ height, respectively. Possibly beneficial effects in favor of the intervention group were observed in Y balance test (anterior, posteromedial, and posterolateral distances and composite score), agility run, standing long jump, and knee flexion ROM measures. Likely trivial effects were found for Slalom dribble and for hip flexion and ankle dorsiflexion ROM measures. The control group showed better performance in 20 m sprint time and wall volley tests compared to the intervention group.

5.5 DISCUSSION

The findings of the current study indicate that the training stimuli provided by the implementation of the FIFA 11+ Kids two times per week for 4 weeks (8 sessions) appears to be sufficient to elicit small to moderate improvements in some [dynamic postural control, agility run, and jumping (standing long jump, CMJ, and DJ) measures] but not all [20 m sprint time, slalom dribble, wall volley, and ROMs (with the exception of the knee flexion ROM) measures] of the physical performance parameters analyzed.

Similar improvements in dynamic postural control (Y balance anterior distance), agility run and jumping measures have been reported after the implementation of the FIFA 11+ Kids twice a week for 10 weeks in a large cohort of young soccer players [28]. However, and in contract to our results, same authors found improvements in slalom dribble and wall volley measures. Perhaps, a possible explanation for these conflicting results might be attributed to the different duration of the intervention phases (10 vs. 4 weeks). Therefore, given the intensity and volume of the FIFA 11+ Kids program used in the current study, 4 weeks (8 sessions) might not be enough to elicit training responses in sprinting times and soccer-specific coordinative tasks measures (slalom dribble and wall volley).

Table 5.2. Descriptive pre-tests statistics (mean ± standard deviation) and differences between pre-test 2 and pre-tests 1 (mean ± 95% confidence intervals).

Variable	**Pre-test 1**		**Pre-test 2**		**Differences**		***P* level**
Y balance test ^{T}							
▪ Anterior distance	75.1	± 12.1	75.8	± 10.7	0.7	(-2.5 to 3.9)	0.63
▪ Posteromedial distance	107.7	± 14.0	108.9	± 12.9	1.2	(-2.1 to 4.6)	0.44
▪ Posterolateral distance	110.5	± 17.9	111.5	± 15.6	1.0	(-2.3 to 4.4)	0.52
▪ Composite	97.8	± 13.3	98.8	± 12.2	1.0	(-1.2 to 3.2)	0.65
20 m sprint time (s)^{b}	3.83	± 0.18	3.81	± 0.18	-0.02	(-0.09 to 0.04)	0.51
Agility run (s)^{b}	20.0	± 0.8	19.8	± 0.8	-0.24	(-0.43 to 0.06)	0.01
Slalom dribble (s)^{b}	6.12	± 0.34	6.14	± 0.39	0.02	(-0.16 to 0.20)	0.82
Wall Volley (n)	3.0	± 0.9	2.7	± 0.4	-0.3	(-0.6 to 0.1)	0.08
Standing long jump (cm)	142.6	± 10.8	142.6	± 14.9	0.0	(-3,6 to 3.7)	0.97
Counter movement jump (cm)	23.2	± 3.4	22.9	± 2.5	-0.3	(-0.7 to 0.1)	0.59
Drop jump (cm)	19.7	± 2.9	20.5	± 3.3	0.8	(-0.2 to 1.9)	0.13
Range of motion (º)							
▪ Hip flexion	71.6	± 5.2	71.7	± 5.3	0.1	(-0.1 to 0.4)	0.27
▪ Knee flexion	129.8	± 5.9	129.9	± 6.1	0.1	(-0.2 to 0.5)	0.53
▪ Ankle dorsiflexion	31.3	± 3.9	31.3	± 3.8	0.0	(-0.4 to 0.4)	1.00

º: degrees; s: seconds; cm: centimeters; ^{b}: smaller values represent better results; ^{T}: normalized to limb length expressed as a percentage

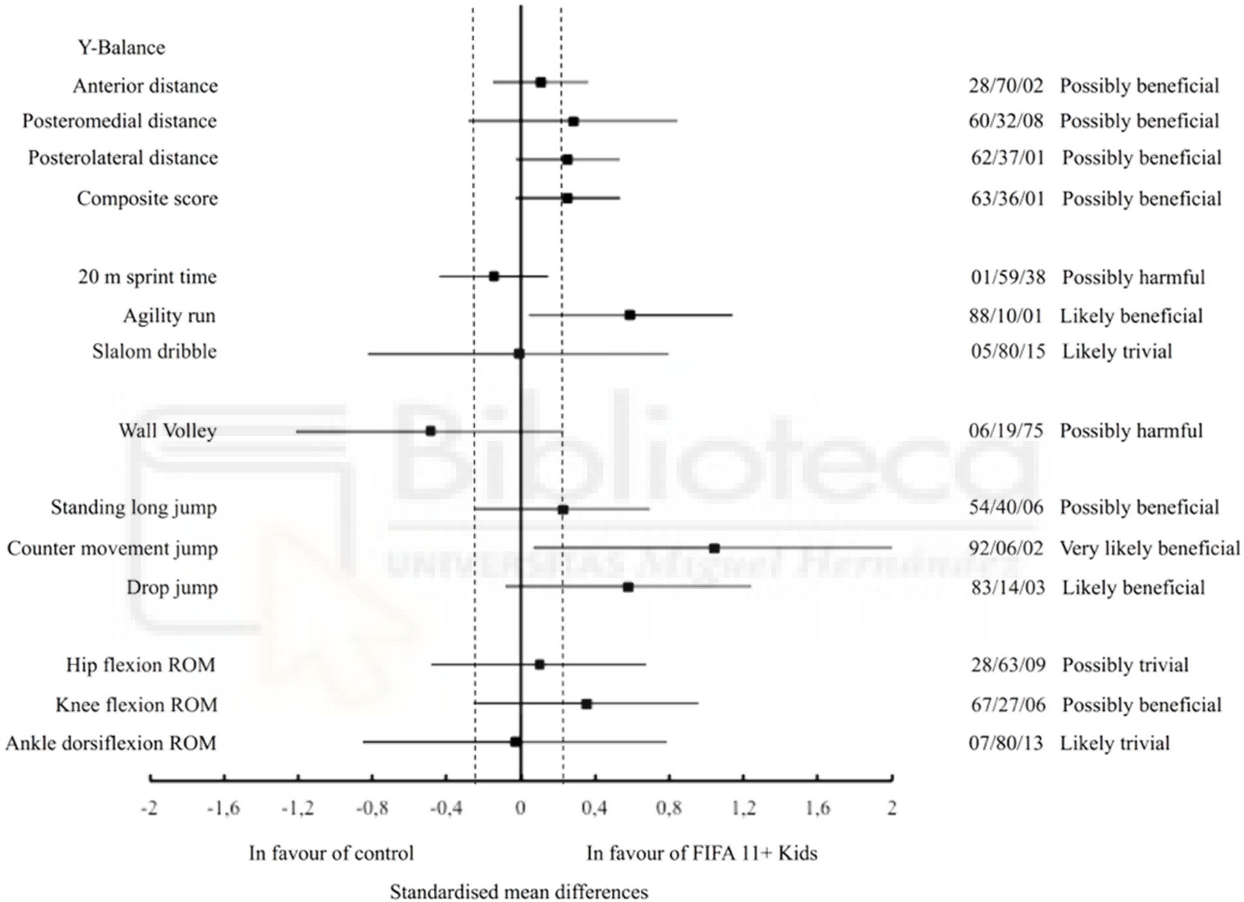


Figure 5.2. Standardized mean differences (90% confidence interval) between the FIFA 11+ Kids and control group in the physical performance parameters analyzed.

Table 5.3. Baseline (pre-test) and post-intervention (FIFA 11+ and Control) results (mean ± standard deviation [SD]) for physical performance outcomes. The differences between pre- and post-test average values are also reported (mean and 95% confidence intervals [CI]).

Physical performance measure	FIFA 11+ Kids						Control					
	Baseline		Post-test		Difference		Baseline		Post-test		Difference	
	Mean	SD	Mean	SD	Mean	95%CI	Mean	SD	Mean	SD	Mean	95%CI
Y Balance test ^{T}												
▪ Anterior distance	75.8	± 14.2	77.2	± 12.8	1.4	(-0.2 to 3.2)	75.1	± 14.2	75.6	± 5.6	0.5	(-1.5 to 2.7)
▪ Posteromedial distance	109.5	± 14.4	112.9	± 14.9	3.5	(-1.1 to 8.4)	106.9	± 11.3	106.3	± 9.9	-0.6	(-6.9 to 4.0)
▪ Posterolateral distance	113.1	± 19.8	116.2	± 17.6	3.1	(-0.1 to 7.1)	108.3	± 10.7	107.4	± 9.9	-0.9	(-3.7 to 1.2)
▪ Composite	99.5	± 15.5	102.1	± 14.3	2.7	(-0.1 to 5.7)	96.7	± 7.5	96.4	± 7.4	-0.3	(-3.3 to 2.1)
20 m sprint time (s)^b	3.79	± 0.21	3.78	± 0.25	-0.01	(-0.05 to 0.03)	3.87	± 0.06	3.83	± 0.11	-0.04	(-0.1 to -0.01)
Agility run (s)^b	20.0	± 0.8	19.5	± 0.8	-0.4	(-0.62 to -0.17)*	19.7	± 0.7	19.8	± 0.9	0.07	(-0.37 to 0.47)
Slalom dribble (s)^b	6.13	± 0.32	5.42	± 0.33	-0.71	(-0.86 to -0.56)*	6.13	± 0.29	5.43*	± 0.38	-0.07	(-0.9 to -0.5)
Wall Volley (n)	2.9	± 0.6	3.1	± 0.5	0.2	(-0.09 to 0.41)	2.8	± 0.6	3.2	± 0.7	0.4	(0.04 to 0.75)
Standing long jump (cm)	143.0	± 15.5	146.1	± 19.6	3.1	(-5.5 to 10.7)	142.1	± 6.8	141.7	± 10.2	-0.3	(-10.9 to 19.1)
Counter movement jump (cm)	22.7	± 2.9	24.5	± 5.3	1.8	(0.6 to 4.1)	23.5	± 2.7	21.8	± 3.2	-1.7	(-3.1 to 1.5)
Drop jump (cm)	19.8	± 3.2	21.6	± 4.2	1.8	(0.3 to 3.2)	20.5	± 2.4	20.4	± 3.2	-0.1	(-1.7 to 1.6)
Range of motion (º)												
▪ Hip flexion	72.1	± 6.0	73.8	± 6.6	1.7	(-1.1 to 4.9)	71.1	± 4.2	72.1	± 4.0	1.0	(-0.3 to 2.2)
▪ Knee flexion	129.7	± 6.8	131.1	± 6.8	1.4	(-0.7 to 3.4)	130.1	± 4.9	129.1	± 4.4	-1.0	(-3.5 to 1.9)
▪ Ankle dorsiflexion	30.9	± 3.9	32.5	± 4.5	2.6	(-0.4 to 3.3)	31.9	± 3.9	33.6	± 3.9	1.7	(-0.5 to 5.1)

^{T}: Normalized to limb length expressed as a percentage; s: seconds; cm: centimetres; º: degrees; ^{b}: smaller values represent better results; *: $p < 0.05$

Force platforms have been used as a criterion measure in scientific setting to assess postural control by interpretation of parameters derived from the center of pressure (COP) such as velocity and area of COP displacement [154]. However, because of its high cost and the need for sophisticated instruments, qualified technicians, and time constraints, the use of this method is limited in sports settings. Consequently, the field-based Y balance test has been recommended as an alternative to force platforms for estimating dynamic postural control in sports setting because: (a) it offers sufficient challenge for dynamic postural control as the subject must maintain balance on a single limb, whilst the other limb carries out a series of reaching tasks (operationally valid); (b) its procedure is simple to administer; (c) instructions are easy to follow; (d) scores are easy to explain; (e) the movements require minimal skills training; and (f) large numbers can be tested in a short period of time [98]. Furthermore, the Y balance test has been shown to be sensitive enough: (a) to detect dynamic postural control deficits in patients with chronic ankle instability [155], patellofemoral pain syndrome [156] and anterior cruciate ligament deficiency [157]; (b) to identify athletes at high risk of non-contact lower extremity injury [158,159]; and (c) to monitor the rehabilitation and return to play processes [160]. Furthermore, the test has also been shown to have high intra and inter-tester reliability [161]. Studies looking at the influence of the FIFA 11+ in adult males have reported improvements in dynamic postural control, agility run, jump performance, and balance [69]. The very likely positive effects of jump performance in the current study show probable improvements in power in this group of young children. The possibly beneficial effects of the FIFA 11+ Kids on balance and agility found in the current study are important as balance and coordination develop throughout maturation [162]. To our knowledge this is the first study to show improvements in balance and agility in prepubertal children following the introduction of a short, focused warm-up program for only 4 weeks. These findings highlight the benefits of such programs to development movement competency in young children, which is essential for athletic performance and which forms the foundation of the youth physical development model [163] and also for injury prevention.

As this is the first study (to the authors' knowledge) to explore the effects of the FIFA 11+ Kids on ROM measures, we are not able to make comparisons. The absence of improvements in the joint ROM measures for the ankle and hip, after performing the FIFA 11+ Kids was expected because this program does not include any specific group of exercises a priori designed to enhance their ROM. However, the possibly beneficial increase in knee ROM is encouraging, given that restricted knee flexion ROM on landing is a risk factor for high ligament loading.

The findings of the current study speculate that the reported improvements in physical performance elicited by the FIFA 11+ Kids program may contribute to a reduction of injury risk in the long-term application. Thus, the mechanisms behind the promising reduction in injury risk by adhering to the FIFA 11+ Kids in prepubertal soccer players might be particularly associated with enhancements in tendon stiffness, balance coordination and physical competency.

5.6 PERSPECTIVES AND LIMITATIONS

An important limitation was the small sample size used in each group (interventions or controls). However, despite the sample size that was enrolled in each group significant main effects were still found. In order to minimize the error associated with the players who belonged to the control group copying and performing any new exercise included in the intervention groups during their regular warm-up, the players of the intervention groups performed their new warm-up in a separate part of the pitch. In addition, a trained rehabilitation specialist was assigned to each team for administrating the interventions and for checking that the control groups did not perform exercise that were not part of their normal warm-up. However, we cannot totally exclude the possibility that the players of the control groups might have performed exercise included in the interventions outside of their regular training sessions. Likewise, and in order to avoid the possible expectation bias of the intervention and control groups, participants did not received information regarding which warm-up program (FIFA11+ Kids or traditional warm-up) was expected to achieve better results in the dependent variables. As we mentioned before, we can neither excluded the possibility that the participants might have sought information about the potential effects of the FIFA+ Kids program on physical performance reported in previous studies. However, neither trainers nor any member of the research staff reported any suspicion about this issue and hence, we consider that this potential source of bias was negligible.

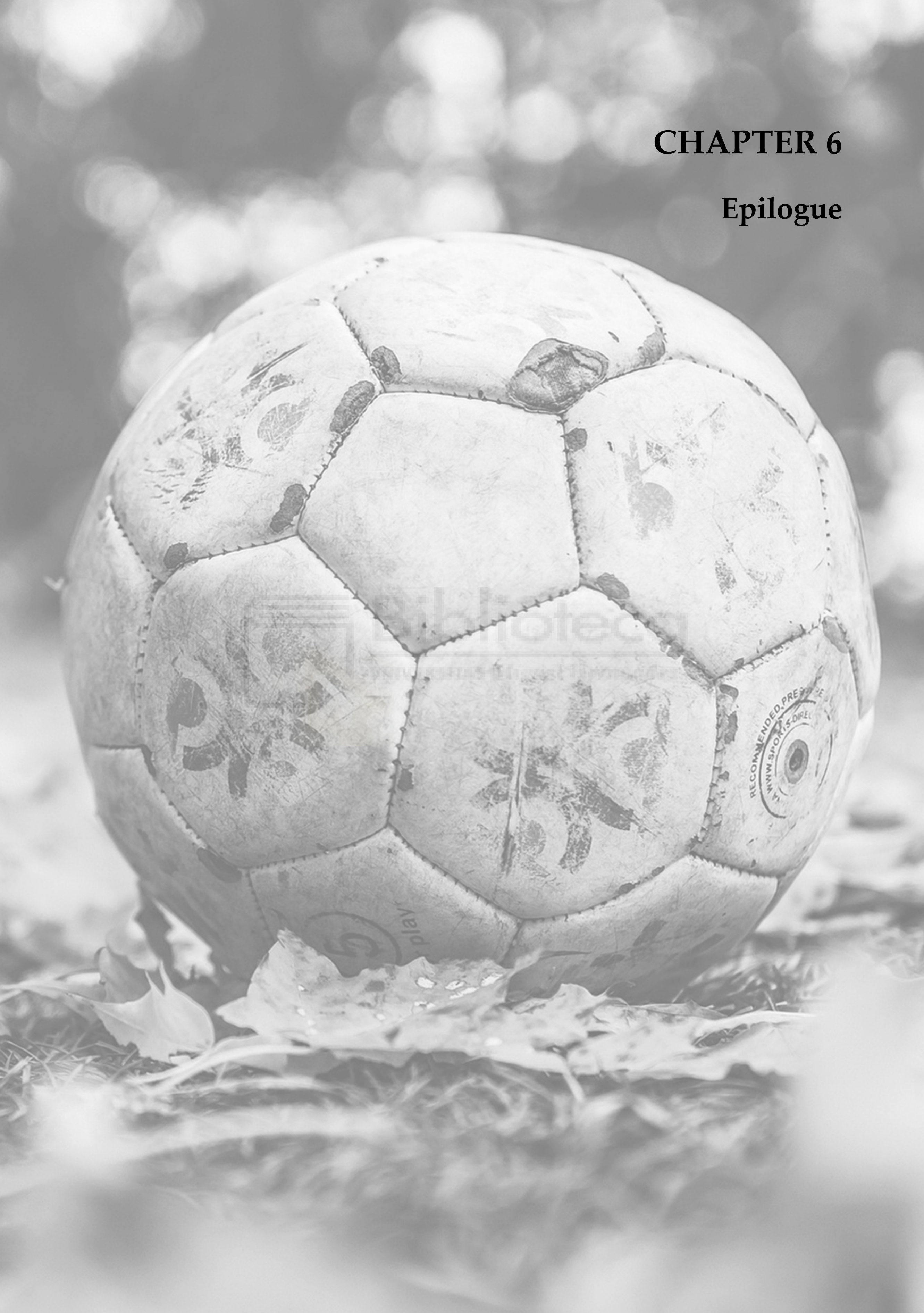
Future studies that investigate the effects of longer interventions than that conducted in the current study (>4 weeks) on several physical performance variables using randomized control trial designs are needed to understand better potential mechanisms behind the reported reduction in injury incidence reported by the FIFA 11+ Kids.

5.7 CONCLUSION

Given the improvements in jump performance, balance, and agility, our study would advocate the introduction of these essential movement competency skills in prepubertal children. It would appear that a structured warm-up routine, such as the FIFA 11+ Kids, focusing on balance, jumping/landing, coordination, and stability should be advocated at an early age. These movements should be focused and delivered early in any long-term athlete development model to enhance movement literacy in young athletes [164].

CHAPTER 6

Epilogue



6

EPILOGUE

6.1 GENERAL CONCLUSIONS

The studies included in the present doctoral thesis:

a) Describe the acute (post-exercise) and training (long lasting) effects of the FIFA 11+, Harmoknee and dynamic warm-up routines on major physical performance and neuromuscular control measures in male young (adolescents) soccer players.
b) Analyze the training effects elicited by the FIFA 11+ Kids on measures of physical performance in male children soccer players.
c) Provide robust arguments in favor of the implementation of the FIFA 11+ Kids and FIFA 11+ warm-up strategies, as alternatives to traditional practices, in everyday training sessions and competitions in children and adolescent soccer players, respectively.

Overall, the main findings of the current doctoral thesis may help clinicians, coaches and sports science specialists in the decision-making process of injury prevention and sport performance optimization.

The following summarizes the major contributions of this thesis:

Study 1. *Acute effects of three neuromuscular warm-up strategies on several physical performance measures in football players.*

1. Both the FIFA 11+ and the Harmoknee programs provoke similar acute effects on several physical performance and neuromuscular control measures to the warm-up routines currently performed by most young soccer players prior to training sessions and matches.

2. The FIFA 11+ and Harmoknee may be considered "good" or "appropriate" warm-up programs to be performed prior to formal training and competition in youth soccer as they have demonstrated eliciting physiological acute changes (post-exercise effects) to positively affect the major physical performance

measures (i.e., sprinting and jumping) and neuromuscular injury risk factors (i.e., dynamic postural control, H/Q strength ratios).

Study 2. *Training effects of the FIFA 11+ and Harmoknee on several neuromuscular parameters of physical performance measures.*

3. The training stimuli provided by the implementation of the FIFA 11+, three times per week for four weeks (12 sessions), appears to be sufficient to cause substantial improvements in several physical performance (sprint time and jumping height) and neuromuscular (dynamic postural control, single legged hop limb symmetry [triple hop]) measures in young amateur soccer players.
4. Enhancements in physical competency and neuromuscular control are possible key mechanisms for explaining the well-documented injury prevention effect of FIFA 11+.
5. The Harmoknee program, when it is regularly performed (three times per week for four weeks) in training sessions as substitute to traditional warm-ups, may produce significant improvements in sprint and jump performance in young amateur soccer players.
6. The FIFA 11+ seems to be more effective in reducing injury risk factors (poor physical performance in postural control and neuromuscular control) than the Harmoknee and traditional warm-up routines in adolescent male amateur soccer players.

Study 3. *Training effects of the FIFA 11+ Kids on physical performance in youth football players: a randomized control trial.*

7. The training stimuli provided by the implementation of the FIFA 11+ kids, two times per week for four weeks (eight sessions), substituting normal warm-up routines in children soccer appears to be sufficient to elicit small to moderate improvements in some (dynamic postural control, agility run, and jumping [standing long jump, CMJ, and DJ]) physical performance parameters.
8. The reported improvements in jump performance (tendon stiffness), postural control and agility may partially explain the mechanism behind the recently shown injury prevention effect of FIFA 11+ kids in children soccer players.

6.2 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This doctoral thesis is not without limitations. Most of them have been discussed in each of the different studies previously presented (chapters 3 to 5). In addition, this section highlights some general limitations that can be used as a starting point for future research:

1. *To investigate the training effects of longer interventions using larger sample sizes*. Future studies should analyze the long-lasting effects of longer interventions using a large number of participants than that conducted in the current study (>4 weeks and 50 participants per group) on several physical performance and neuromuscular control variables using randomized control trial with placebo control group designs to understand better potential mechanisms behind the reported reduction in injury incidence by the FIFA 11+, Harmoknee and FIFA 11+ Kids programs.
2. *To examine the efficacy of structured prevention exercises programs for individuals at high and low risk of injury*. In order to achieve a better understanding of the training effects elicited by structured prevention exercises programs (e.g., FIFA 11+, Harmoknee and FIFA11+ Kids) on injury risk, future studies should explore whether these programs are more beneficial (or not) for high-risk versus low-risk individuals within at-risk groups, for a range of injury risk factors (e.g., knee abduction moment on landing and kinematics, leg stiffness and unilateral dynamic balance).
3. *To explore grass-root soccer coaches´ reasons for not implementing standardized injury prevention programs in their daily training sessions and matches*. Available data consistently indicate that standardized injury prevention programs (including FIFA 11+ and FIFA 11+ Kids) are effective only when high compliance rates are maintained. Coaches play a major role in encouraging and ensuring that participants of their teams adopt appropriate safe practices. Therefore, future studies should identify the main factors and barriers that influence grass-root coaches´ decision-making processes for implementing or not injury prevention programs in their soccer teams and explore strategies to better support players and coaches in this issue.

4. *To analyze and compare the effects of standardized and individualized injury prevention programs on neuromuscular risk factors and sport performance parameters in young soccer players*. It has been suggested that the design and implementation of tailored exercise programs to each player needs (in terms of physical and neuromuscular performance, maturity status and sex) may be a better injury risk mitigation strategy than the use of the standardized injury prevention programs currently available in the literature. Therefore, an interesting future research line may be the study of the efficacy of short-duration exercise programs purposely designed to address each player individual needs in terms of injury risk and sport performance outcomes.

CAPÍTULO 7

Epílogo

7

EPÍLOGO

7.1 CONCLUSIONES GENERALES

Los estudios incluidos en la presente tesis doctoral:

a) Describen los efectos agudos (post-ejercicio) y crónicos (de larga duración) de las rutinas FIFA 11+, Harmoknee y dynamic warm-up sobre las principales medidas de rendimiento físico y control neuromuscular en jugadores de fútbol jóvenes (adolescentes).
b) Analizan los efectos crónicos provocados por el FIFA 11+ Kids sobre medidas de rendimiento físico en jugadores de fútbol niños varones.
c) Proporcionan argumentos sólidos a favor de la implementación de las estrategias de calentamiento FIFA 11+ Kids y FIFA 11+ como alternativas a las prácticas tradicionales, en las sesiones de entrenamiento diarias y competiciones en jugadores de fútbol niños y adolescentes, respectivamente.

En general, los principales hallazgos de la actual tesis doctoral pueden ayudar a los médicos, entrenadores y especialistas en ciencias del deporte en el proceso de toma de decisiones para la prevención de lesiones y a la optimización del rendimiento deportivo.

A continuación, se resumen las principales contribuciones de esta tesis:

Estudio 1. *Efectos agudos de tres estrategias de calentamiento neuromuscular sobre algunas medidas de rendimiento físico en jugadores de fútbol.*

1. Tanto el programa FIFA 11+ como el Harmoknee provocan efectos agudos similares en varias medidas de rendimiento físico y control neuromuscular a las rutinas de calentamiento que actualmente realizan la mayoría de los jugadores de fútbol jóvenes antes de las sesiones de entrenamiento y partidos.

2. El FIFA 11+ y Harmoknee pueden considerarse programas de calentamiento "buenos" o "apropiados" que se deben realizar antes del entrenamiento formal y la competición en el fútbol juvenil, ya que han demostrado que provocan cambios fisiológicos agudos (efectos posteriores al ejercicio) al afectar de

manera positiva a las principales medidas de rendimiento físico (es decir, carreras de velocidad y saltos) y a los factores de riesgo de lesión neuromuscular (es decir, control postural dinámico y ratios de fuerza H/Q).

Estudio 2. *Efectos del entrenamiento del FIFA 11+ y Harmoknee sobre varios parámetros neuromusculares de medidas de rendimiento físico.*

3. Los estímulos del entrenamiento proporcionados por la implementación del FIFA 11+, tres veces por semana durante cuatro semanas (12 sesiones), parecen ser suficientes para provocar mejoras sustanciales en varias medidas de rendimiento físico (tiempo de sprint y altura de salto) y neuromusculares (control postural dinámico, simetría de las extremidades en el salto unipodal [triple salto]) en jugadores de fútbol jóvenes amateurs.
4. Las mejoras en la competencia física y control neuromuscular son posibles mecanismos clave para explicar el documentado efecto de prevención de lesiones del FIFA 11+.
5. El programa Harmoknee, cuando se realiza con regularidad (tres veces por semana durante cuatro semanas) en sesiones de entrenamiento como sustituto de los calentamientos tradicionales, puede producir mejoras significativas en el rendimiento del sprint y del salto en jugadores de fútbol jóvenes amateurs.
6. El FIFA 11+ parece ser más efectivo para reducir los factores de riesgo de lesión (bajo rendimiento físico en el control postural y control neuromuscular) que el Harmoknee y las rutinas de calentamiento tradicionales en jugadores de fútbol jóvenes amateurs.

Estudio 3. *Efectos del entrenamiento del FIFA 11+ Kids sobre el rendimiento físico en jugadores de fútbol jóvenes: un ensayo de control aleatorizado.*

7. Los estímulos del entrenamiento proporcionados por la implementación del FIFA 11+ Kids, dos veces por semana durante cuatro semanas (ocho sesiones), sustituyendo a las rutinas de calentamiento tradicionales en niños parecen ser suficientes para provocar mejoras de pequeñas a moderadas en algunos parámetros de rendimiento físico (control postural dinámico, carrera de agilidad y saltos [salto de longitud de pie, CMJ y DJ]).

8. Las mejoras reportadas en el rendimiento del salto (rigidez de los tendones), el control postural y la agilidad, pueden explicar parcialmente el mecanismo detrás del efecto preventivo de lesiones recientemente demostrado del FIFA 11+ Kids en jugadores de fútbol infantiles.

7.2 LIMITACIONES Y RECOMENDACIONES PARA FUTURAS INVESTIGACIONES

Esta tesis doctoral no está exenta de limitaciones. La mayoría de ellas han sido discutidas en cada uno de los diferentes estudios presentados anteriormente (capítulos 3 a 5). Además de esto, esta sección destaca algunas de las limitaciones generales que se pueden utilizar como punto de partida para futuras investigaciones:

1. *Investigar los efectos del entrenamiento de intervenciones más longevas utilizando tamaños de muestra más grandes.* Los estudios futuros deben analizar los efectos a largo plazo de intervenciones más prolongadas con un número mayor de participantes que el realizado en el estudio actual (>4 semanas y 50 participantes por grupo) sobre varias variables de rendimiento físico y control neuromuscular mediante un ensayo de control aleatorizado con grupo control placebo diseñado para comprender mejor los posibles mecanismos detrás de la reducción informada de la incidencia de lesión por los programas FIFA 11+, Harmoknee y FIFA 11+ Kids.
2. *Examinar la eficacia de los programas de ejercicios preventivos estructurados para personas con alto y bajo riesgo de lesión.* Para lograr una mejor comprensión de los efectos del entrenamiento provocados por los programas de ejercicios de prevención estructurados (por ejemplo, el FIFA 11+, Harmoknee y FIFA 11+ Kids) sobre el riesgo de lesión, los estudios futuros deberían explorar si estos programas son más beneficiosos (o no) para los individuos de alto vs bajo riesgo de lesión dentro de los grupos de riesgo para una variedad de factores de riesgo de lesión (por ejemplo, el momento de abducción de la rodilla y su cinemática al aterrizar, la rigidez de la pierna y el equilibrio dinámico unilateral).
3. *Explorar las razones de los entrenadores de fútbol base para no implementar programas estandarizados de prevención de lesiones en sus sesiones de entrenamientos diarias y partidos.* Los datos disponibles indican consistentemente que los programas estandarizados de prevención de lesiones (incluidos el FIFA 11+ y FIFA 11+

Kids) son efectivos solo cuando se mantienen altas tasas de cumplimiento. Los entrenadores desempeñan un papel importante a la hora de alentar y garantizar que los participantes de sus equipos adopten prácticas seguras adecuadas. Por lo tanto, los estudios futuros deben identificar los principales factores y barreras que influyen en los procesos de toma de decisiones de los entrenadores de fútbol base para implementar o no programas de prevención de lesiones en sus equipos de fútbol y explorar estrategias para apoyar mejor a sus jugadores y entrenadores en este tema.

4. *Analizar y comparar los efectos de los programas de prevención de lesiones estandarizados e individualizados sobre los factores de riesgo neuromuscular y los parámetros de rendimiento deportivo en futbolistas jóvenes.* Se ha sugerido que el diseño y la implementación de programas de ejercicio personalizados para las necesidades de cada jugador (en términos de rendimiento físico y neuromuscular, maduración y sexo) puede ser una mejor estrategia de mitigación del riesgo de lesiones que el uso de programas estandarizados de prevención de lesiones actualmente disponibles en la literatura. Por lo tanto, una línea de investigación futura interesante puede ser el estudio de la eficacia de los programas de ejercicios de corta duración diseñados expresamente para abordar las necesidades individuales de cada jugador en términos de riesgo de lesión y resultados de rendimiento deportivo.

CHAPTER 8

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8

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