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

Abstract

The main purpose of this study was to analyse the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance measures in youth amateur football players. Forty-one adolescent players were randomised within each team into two 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. Thirteen 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 favour 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 programmes 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

Introduction

Football (soccer) is one of the most popular sports in the world. Despite the numerous health benefits, participation in a physically demanding sport such as football can lead to greater exposure to causal factors of injury [32,48]. The increased risk of injury (mainly in the lower extremities) produced by playing football is especially relevant in cases in which growth and maturation are not yet completely developed, such as in childhood and adolescence [5]. Specifically, injury incidence in adolescent populations has recently been aligned to peak height velocity, when rapid growth is evident [39,47]. Furthermore, recent epidemiology studies have reported that the frequency and severity of injuries among youth football players is striking in comparison to other sports [17,21,40]. Particularly, injury rates in youth football vary from 5.6 injuries per 1000 hours of exposure [26] to 37.6 injuries per 1000 match hours [7]. Consequently, football-related injuries can counter the beneficial effects of sports participation at a young age if a child or adolescent is unable to continue to participate because of the effects of injury [31].

Therefore, there is a clear necessity to develop and implement measures aimed at preventing and reducing the number and severity of football-related injuries in youth players. The FIFA 11+ [6] and Harmoknee [28] are two training programmes designed to prevent injuries in youth football players. Both programmes 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 [38]) and based on scientific evidence and best practise [6,28]. Recent cluster randomised controlled trials have demonstrated that the FIFA 11+ is effective in reducing lower extremity injury rates in male [37,43] and female [44,45,46] 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 [28].

Although the main purpose of both FIFA 11+ and Harmoknee is injury prevention, the knowledge of training effects elicited by these training programmes on physical performance can help in identifying the potential mechanisms behind the reported reduction in injury incidence [24]. Although some studies have explored the training effects of both programmes (mainly FIFA 11+) on some measures of neuromuscular performance (lower extremity balance [14,45] and core stability [24], knee proprioception [14], knee strength [8,13,24]), and sprinting and jumping ability [12,24,29] (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 programmes.

Therefore, the main purpose of this study was to analyse the training effects of the FIFA 11+ and Harmoknee on several parameters of physical performance in youth amateur football players. We hypothesised that these two programmes would show beneficial and superior effects on physical performance (particularly in balance, sprint and jumping measures) in comparison to the traditional practises 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, submaximal speed lineal running]).

Materials and methods

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 degrees (standard deviation of 0.95 degrees) 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.

Participants

A total of 60 male youth amateur football players were contacted to take part in the study. Participants were recruited from 3 different football teams that were engaged in the Official Amateur Championships of the Spanish Football 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 month 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 hours 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 [20],.

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 football players (age: 16.8 ± 0.7 y; body mass: 70.2 ± 3.5 kg; stature: 173.9 ± 6.7 cm; years playing football: 6.1 ± 2.2 y) from 2 different football teams completed this study.

Research design

A parallel, two-group, pre-post, randomised controlled trial with double baseline (two 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 two different 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 (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 programmes (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 pre-test sessions were completed, participants were randomised 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 programme. One of the researchers without any contact or knowledge of the players completed the allocation and randomisation. Therefore, no allocation concealment mechanisms were necessary.

For the following 4 weeks (intervention phase), the participants completed only one of the 3 intervention programmes 3 days a week as part of their weekly training sessions. As the FIFA 11+ and Harmoknee were initially proposed as training programmes 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 two 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 [3], dynamic postural control [33], sprinting and jumping [22] after performing a specific training programme.

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 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 (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.

Testing procedure

During each testing session, participants began by completing a standardised 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 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 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 were carried out 3-5 min after the standardised warm-up. The order of the tests was consistent through the experimental sessions and is displayed in figure 1.

Dynamic postural control

Dynamic postural control was evaluated using the Y-Balance test and following the guidelines proposed by Shaffer et al. [42]. Players were allowed a maximum of 5 trials to obtain 3 successful trials for each reach direction (anterior [appendix 1a], posteromedial [appendix 1b] and posterolateral [appendix 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 [42]. 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) [18]. Leg length was defined as the length measured in centimetres 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 [16]. The dominant lower extremity was defined as the participant´s kicking leg (self-reported).

Hip, knee and ankle range of motions

The passive hip flexion (passive straight leg raise test [appendix 2a]), knee flexion (Modified Thomas test [appendix 2b]) and ankle dorsiflexion (weight-bearing lunge with knee extended test [appendix 2c]) range of motions of the dominant and non-dominant extremities were assessed following the methodology previously described [9]. Participants were barefoot and instructed to perform, in a randomised 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 two 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 (appendix 3a). The triple hop for distance was performed with the participant standing on 1 leg and performing 3 consecutive hops as far as possible (appendix 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 centimetre 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%. [41].

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 football players [34]. 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. [36]. 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 three jumps was used for statistical analysis.

Agility

The Illinois agility test is commonly used in measuring agility in football [1,27,29]. The length of the zone is 10m, while the width (distance between the start and finish points) is 5m. Four cones were placed in the centre of the testing area at a distance of 3.3 m from one another (appendix 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). Three trials were performed by each player with the best time used for analysis [1,29].

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 six 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 to 25 minutes (Kiani et al., 2010). Similar to the FIFA 11+, Harmoknee was also performed 3 times per week for 4 weeks substituting their normal warm-up routine.

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 versus 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 versus 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 two baseline measures).

Magnitude-based inference analysis of the interventions (FIFA 11+, Harmoknee and control) were estimated using a spreadsheet designed by Hopkins [22] 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 two 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 [9], 3% for measures of dynamic postural control [35], 1.0% for 10 and 20 m sprint times [15], 1.2% for Illinois agility [19] and 6% for DJ height [3]. For those variables (single and triple hop measures) where no studies have analysed the inter-session reliability, 0.20 standardised units (that is a fraction of the between-participants standard deviation at baseline) was chosen as the substantial change [10]. The default of 0.20 gives chances that the true effect is at least small [23].

The qualitative descriptors proposed by Hopkins [23] 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 lie 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) [23]. 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 standardised values that permit the determination of the magnitude of differences between groups or experimental conditions [10], were also calculated for each of the variables using the method previously described by Cohen [10]. Cohen [10] 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]).

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 1 (FIFA 11+ and control) and table 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 figure 2 and 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 versus FIFA 11+ (in favour 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 2). However, no main effects were observed ($p > 0.05$; trivial effect with a probability of 55-98%; $d < 0.2$) between control versus 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 3).

Discussion

The findings of the current study indicate that the training stimuli provided by the implementation of the FIFA 11+ three 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 analysed.

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 football players and hence, direct comparisons are not possible. However, previous studies using different football player cohorts [12,24,29] have reported conflicting training effects of the FIFA 11+ on dynamic postural control, sprint, jump and agility measures. Thus, whereas Daneshjoo et al. [12], and Kilding et al. [29] 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) football players respectively; Impellizzeri et al. [24] 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 football 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 [12,24,29] 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, emphasising 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 [2,49].

The current study also found that the Harmoknee injury prevention programme 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 programme were higher than those previously reported by Daneshjoo et al. [12]. Daneshjoo et al. [12] reported an improvement of -0.5% and 1.9% for the sprint time and jumping height respectively after implementing the Harmoknee programme 3 times per week for 8 weeks in a group of male professional under 21y-old football 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. 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. [14], 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 programme might be higher. Thus, while Daneshjoo et al. [14] 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 programme 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+ programme 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 football players [37,43,44,45,46] 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 [28] 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 foot 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 [30]. In addition, the training frequency should be at least 2-3 non-consecutive days per week [30]. 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 analysed. In fact, we only used paired control groups as in previous similar studies [12-14,24,29] 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 (two 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 [12-14,29] and allowed main effects were identified. Another possible limitation of the current study is the sample used. The age distribution of participants (16.8 ± 0.7 y) 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 programmes. In addition, further research is needed to identify the exercises really necessary for preventing injuries in order to develop more time-efficient prevention programmes 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 programme can have positive effects on performance variables. Thus, the results of this study showed that performing the FIFA 11+ three 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 programme in adolescent male amateur soccer players. We would therefore advocate exchanging traditional warm-up programmes for the FIFA 11+ in male youth soccer players.

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Figure legend

Figure 1: Schematic representation of the study design.

Figure 2: Net effects (expressed as percentage) of the intervention on neuromuscular parameters of physical performance for the "FIFA 11+" and control group.

Figure 3: Net effects (expressed as percentage) of the intervention on neuromuscular parameters of physical performance for the Harmoknee and control group.

Appendix legend

Appendix 1: dynamic postural control assessment (anterior [a], posteromedial [b] and posterolateral [c] directions).

Appendix 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.

Appendix 3: Single legged hop limb symmetry assessment (single hop for distance [a]; and triple hop for distance [b]).

Appendix 4: Illinois agility run dimensions and completion route. m = meters.

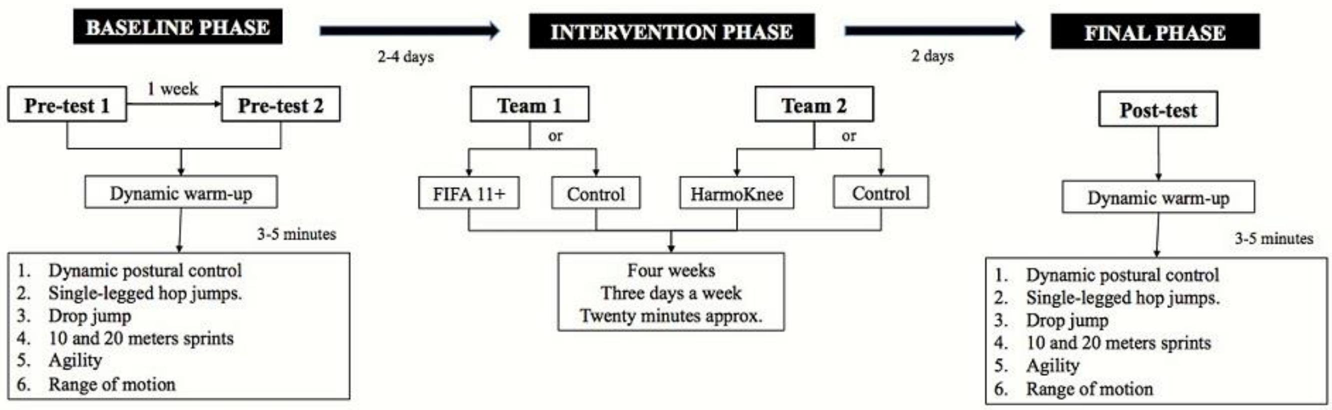


Figure 1

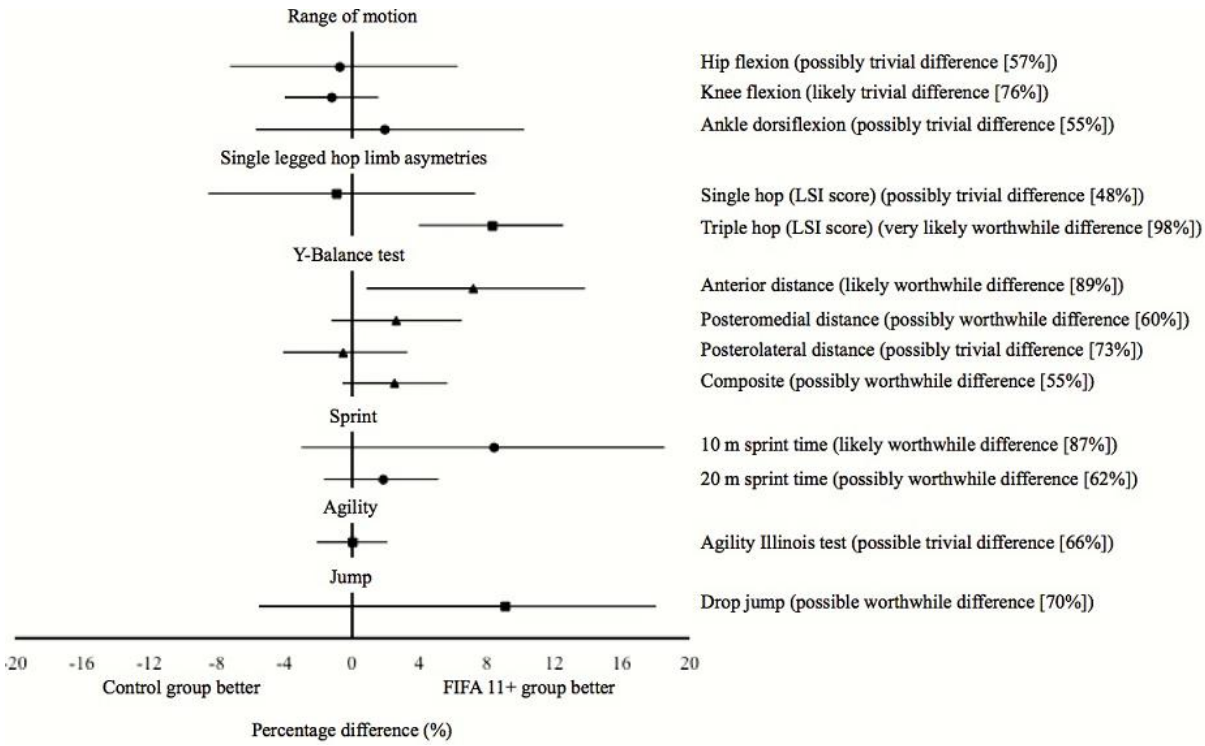


Figure 2

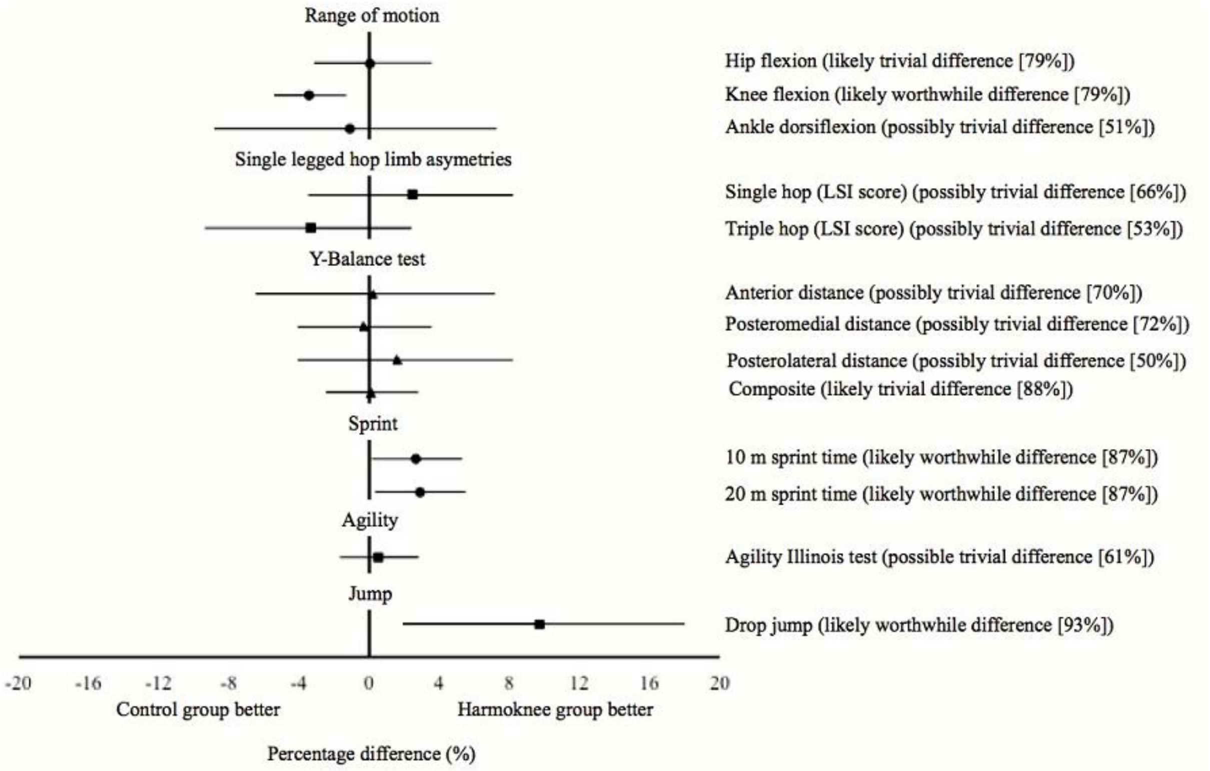
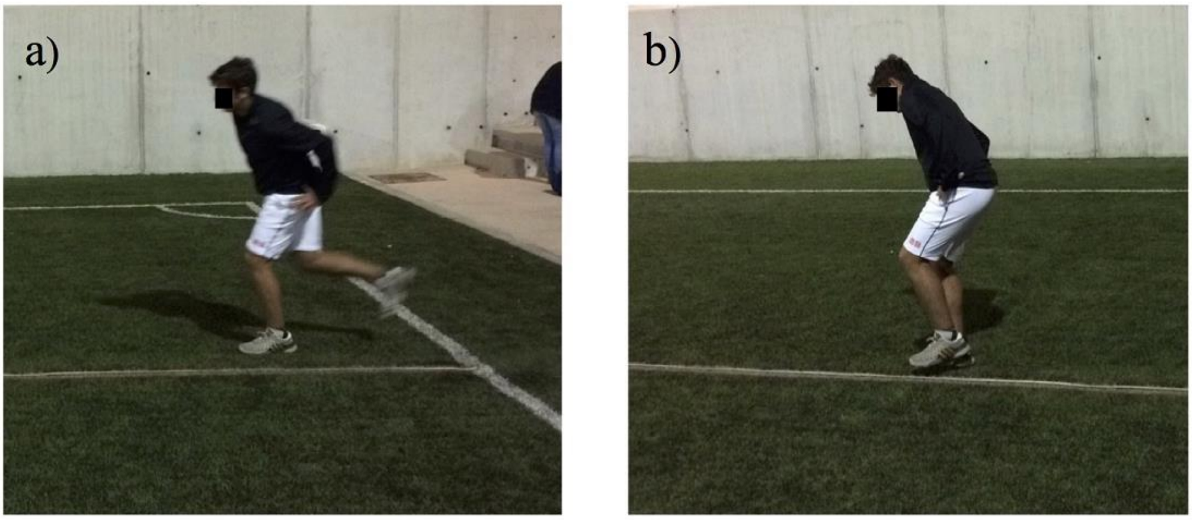

Range of motion
Hip flexion (likely trivial difference [79%])
Knee flexion (likely worthwhile difference [79%])
Ankle dorsiflexion (possibly trivial difference [51%])
Single legged hop limb asymetries
Single hop (LSI score) (possibly trivial difference [66%])
Triple hop (LSI score) (possibly trivial difference [53%])
Y-Balance test
Anterior distance (possibly trivial difference [70%])
Posteromedial distance (possibly trivial difference [72%])
Posterolateral distance (possibly trivial difference [50%])
Composite (likely trivial difference [88%])
Sprint
10 m sprint time (likely worthwhile difference [87%])
20 m sprint time (likely worthwhile difference [87%])
Agility
Agility Illinois test (possible trivial difference [61%])
Jump
Drop jump (likely worthwhile difference [93%])
-20 -16 -12 -8 -4 0 4 8 12 16 20
Control group better
Harmoknee group better
Percentage difference (%)

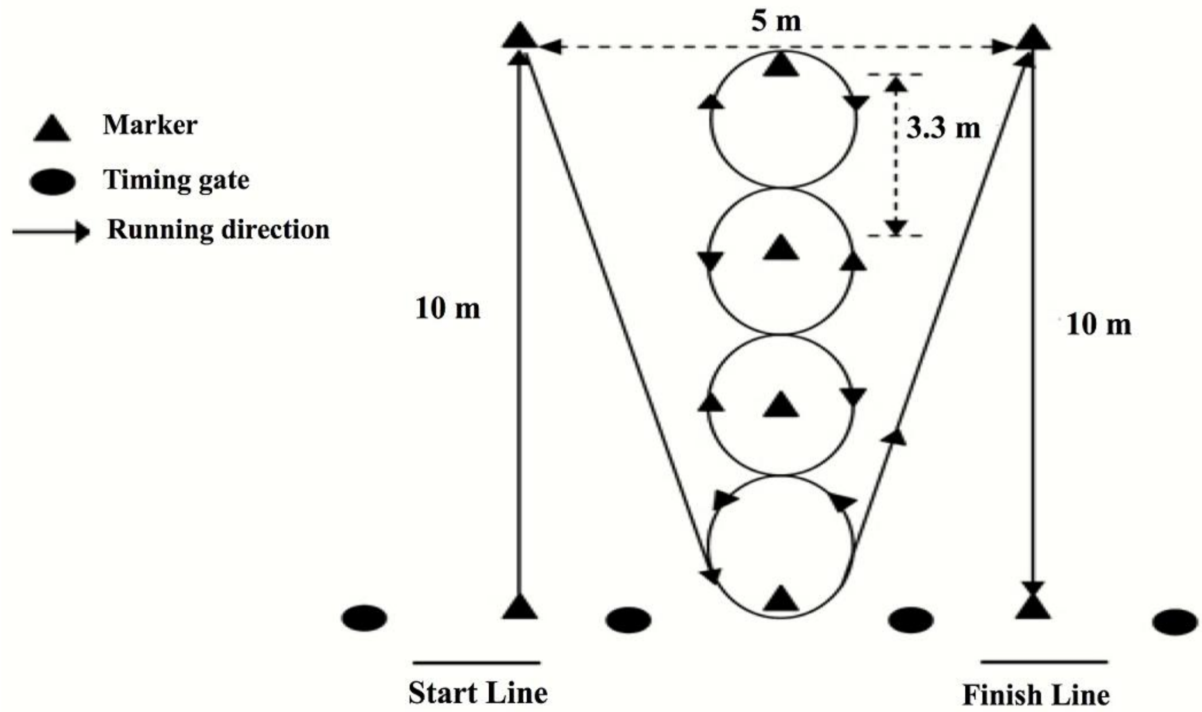
Figure 3

Appendix 1

Appendix 2



Appendix 3


5 m
Marker
Timing gate
Running direction
3.3 m
10 m
10 m
Start Line
Finish Line

Appendix 4

Table 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	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	36.5	±2.5	-0.5	±2.1
Single legged hop limb asymmetries												
▪ 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	±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	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	5.2	±7.8	1.82	±0.28	2.09	±0.33	14.8	21.1
▪ 20 m	3.3	±0.18	3.24	±0.15	-1.8	±6.2	3.28	±0.15	3.31	±0.23	0.9	±5.5
Agility (s)	16.66	±1.16	16.26	±0.83	-2.4	±5.6	16.57	±0.98	16.4	±1.37	-1.0	±3
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 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	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	±3.5	41.3	±1.8	41.9	±4	1.5	±7.8
Single legged hop limb ~~a~~symmetries												
▪ Single hop	100.9	±6.6	98	±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	±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	±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	±4.1	93	±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	81.07	±5	81.3	±4.4	0.3	±2.1
Sprint time (s)												
▪ 10 m	1.81	±0.05	1.81	±0.07	0.0	±2.4	1.86	±0.04	1.91	±0.07	2.7	±3.8
▪ 20 m	3.25	±0.09	3.17	±0.05	-2.5	±2.1	3.34	±0.05	3.36	±0.13	0.6	±3.1
Agility (s)	16.6	±0.31	16.41	±0.33	-1.1	±1.4	17.24	±0.43	17.14	±0.47	-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	0.4	±6.7

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