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Effects of the FIFA 11+ injury prevention programme on muscle strength and landing biomechanical markers of ACL injury during fatigue among youth soccer players

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Abstract

Study aim: This study aimed to investigate the effect of the FIFA 11+ injury prevention programme on strength and on muscle strength and landing biomechanical markers of anterior cruciate ligament (ACL) injury during fatigue among youth recreational soccer players.

Material and methods: Thirty volunteer participants were assigned to the intervention group (n = 15) and control group (n = 15). The intervention group performed the FIFA 11+ programme as a warm-up activities, while the control group performed unstructured warm-up twice per week for 8 weeks. The data measurements were taken before fatigue simulation (PRE), immediately after simulation (POST5), after 20 min (POST20), and 35 min (POST35) after simulation before and after the completion of the intervention. Five-minute fatigue simulation was used for fatigue induction. Muscle strength was measured using an isokinetic machine during concentric and eccentric contractions of the hamstrings and quadriceps. Meanwhile, landing biomechanics was measured by the Landing Error Scoring System.

Results: No significant differences were observed in individual muscle strength, H/Q CONV, and H/Q_{FUNC} ratio. The biomechanical landing markers showed a significantly higher score in PRE (P = 0.004; effect size = 0.32) and POST5 (P = 0.007; effect size = 0.29) in the FIFA 11+ group compared to the control group.

Conclusion: Twice a week for eight weeks of FIFA 11+ is adequate to detect positive changes in biomechanical markers of ACL injury during fatigue.

Keywords: Simulation – Landing – Isokinetic – Football – Knee

Introduction

Soccer is a physically demanding sport that involves frequent high-intensity activity and contact, including sprinting, jumping, and tackling. This dynamic nature of the game leads to a relatively high rate of injuries compared to other sports [35]. Studies have shown that soccer players experience 4 to 7.6 injuries per 1000 hours of play [16]. In the USA, youth under 15 experience around 36,000 injuries [24]. A study involving children aged 7 to 12 years participating in soccer revealed that over two seasons, a total of 6038 players accrued 395,295 hours of soccer exposure, resulting in 417 reported injuries [36]. Additionally, injuries tend to occur more frequently during matches (15–20 per 1000 hours) than during training (1–5 per 1000 hours) [15]. This suggests that the intense competition and pressure of a game can increase the risk of injury.

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments in the knee. The ACL is responsible for providing stability to the knee joint and preventing excessive forward movement of the tibia in relation to the femur. Injuries to the ACL can occur due

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to various mechanisms, including direct trauma, twisting, or cutting movements. However, fatigue has been identified as a significant risk factor for ACL injury in soccer players. Fatigue can affect the knee joint in several ways, leading to an increased risk of ACL injury. The casualties among soccer players usually occur toward the end of the first and second half of match play, associated with increased fatigue severity [3]. Previous findings have shown that fatigue can increase the risk of ACL rupture [8, 19]. One of the main mechanisms of fatigue-related ACL injury is a decrease in muscle strength and power [14], ratio imbalance between the quadriceps concentric and hamstring eccentric contraction [37], muscle weakness [33], and alteration of the postural mechanics at the later stage of gameplay [20]. This can make the knee more susceptible to injury, especially when performing high-impact activities or movements that stress the ACL. In addition, previous studies have shown that fatigued knee joints have a decreased ability to absorb energy, making them more susceptible to injury when performing activities such as jumping or landing, which place stress on the ACL. Understanding how fatigue contributes to ACL injury can help us better prevent and treat this injury.

FIFA 11+ is a warm-up programme designed for soccer players to prevent injuries and improve performance. Developed by FIFA (Fédération Internationale de Football Association) in collaboration with leading sports medicine experts, the programme is designed to improve general fitness, and increase muscle strength, making it an ideal exercise regimen for soccer players of all ages. This warm-up programme reduces the injury rate among youth and adult soccer players [28, 37]. In addition, it significantly improves performance, balance, strength, and proprioception [6, 13]. This is especially beneficial for soccer players involved in high-intensity activities such as sprinting, jumping, and changing direction.

Overall, FIFA 11+ is an effective programme for reducing the injury rate and increasing the performance of soccer players [28, 37]. There is a lack of research on the effects of the FIFA 11+ injury prevention programme on landing biomechanics and muscle strength in youth soccer players. Thus, this study aimed to explore the impact of FIFA11+ on muscle strength and the biomechanical markers associated with ACL injury risk among youth soccer players under conditions of fatigue. We hypothesised that FIFA 11+ significantly increased muscle strength and reduced biomechanical markers of ACL injury risk in youth soccer players during a state of fatigue. Understanding the effects of the FIFA 11+ programme on these factors would provide valuable information for coaches and trainers in developing training programmes for youth soccer players.

Material and methods

Study design and participants

Thirty high school male youth soccer players (means, age = 16.00 ± 0.9 years old, height = 1.69 ± 0.06 m, mass = 53.95 ± 6.06 kg) participated in this quasi-experimental pre-test and post-test study. The participants were divided into two non-randomized groups (N = 15 control and 15 = FIFA 15+ group). A power analysis using a sample-size estimation based on Arsenis et al. [4] showed that approximately 30 participants, allowing for a 20% dropout rate, would provide 80% power with a risk of type 1 error of 0.05. Participants were recruited from a government-funded secondary school using purposive sampling. The inclusion criteria for participation included: 1) regularly playing soccer 3 to 5 times per week, 2) playing for 40 to 60 minutes per session. Participants with a history of injury or illness that would prevent them from participating in a warm-up routine were excluded from the study. All participants and guardians were fully informed about the study procedure and signed the consent form before participation. The study was conducted according to the Declaration of Helsinki and was reviewed and approved by the institutional review board (IRB) before initiation. Any adverse events were reported to the IRB.

Youth Soccer Fatigue Simulation ($YoSFS^5$)

Fatigue was induced using $YoSFS^5$, a 5-min high-intensity exercise protocol modified from a previous study [8]. The simulation involves over-ground (incorporating four positioned poles/markers) high-intensity multidirectional and utility movements, with frequent high accelerations and decelerations (Figure 1). Moreover, this soccer fatigue simulation added specific movements such as kicking, jumping, heading, and sprinting with a ball. The relative reliability of $YoSFS^5$ showed that the ICCs for rating perceived exertion (RPE) (0.92) (95% CI 0.79–0.97) and counter-movement jump (CMJ) (0.85) (95% CI: 0.79–0.97) were excellent according to Fleiss [17].

Physiological assessment during $YoSFS^5$

Heart rate was monitored using a Polar watch (S410, Polar heart rate system, Electro, Finland) continuously throughout the protocol to ensure all players performed the protocol within the desired range. The RPE was recorded using the 20-point Borg scale at pre-test (PRE), immediately following the YoSFS5 (POST5), after 15 minutes of passive rest (POST20), and after 30 minutes of passive rest (POST35). Additionally, the level of fatigue was monitored through the counter-movement jump (CMJ) and recorded at the same time as the RPE. The CMJ (free arm) height was measured with the My Jump 2 application

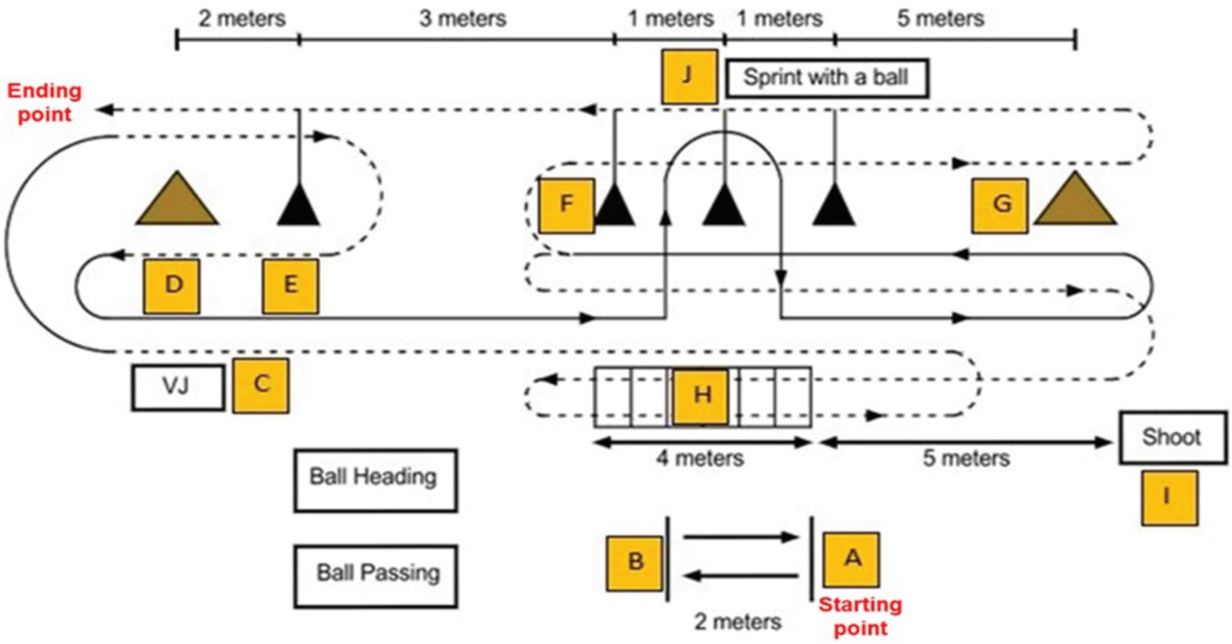

Figure 1. Diagrammatic representation of the fatigue simulation activity profile

(version 6.0.3, Carlos Balsalobre-Fernández, Spain) using iPhone IV [5].

Lower limb isokinetic strength

The dominant leg was tested using an isokinetic dynamometer machine (IKD, Biodex System 3, Shirley, NY) to determine the maximum voluntary contractions (MVC) of eccentric hamstring strength (Hecc), concentric quadriceps strength (Qcon) and concentric hamstring strength (Hcon). The dominant leg was determined based on the leg most favoured during kicking. The isokinetic dynamometer was calibrated before the study began, following the manufacturer's instructions. The isokinetic values were normalised to the body weight. The lateral epicondyle of the dominant knee was aligned with the dynamometer's rotational axis, and the cuff for the distal calf was positioned two fingers above the lateral malleolus. The seat of the isokinetic dynamometer was adjusted according to the participants' comfort. A seat belt with upper body cross straps and a strap on the distal thigh were installed to adequately test the hamstrings and quadriceps of the dominant leg. Participants were required to perform repeated maximum isokinetic contraction within 90° ROM at 120°/s for concentric MVC for five repetitions. No trial was performed because the participants needed to perform it while fatigued. Then, participants had to resist the passive external knee extension over 90° ROM and at 120°/s during eccentric MVCs [32,38]. Several studies have validated the reliability and validity of isokinetic testing using Biodex System 3 [26, 33]. The peak torque values of eccentric Hamstring (Hecc), concentric Hamstring (Hcon), and concentric Quadriceps (Qcon) were recorded. Using these values, the ratio of concentric hamstring to concentric quadriceps (H/Q_{CONV}) and the ratio of eccentric hamstring to concentric quadriceps (H/Q_{FUNC}) were calculated [34].

Landing biomechanics

The Landing Error Scoring System (LESS) is a tool marker to detect possibly high-risk movement patterns during a jump landing manoeuvre and is used as a prediction tool to detect potential ACL injury [29]. Participants performed three standardized jump landing tasks during each test session. The participant stood on a 30-cm-high box at a distance of half the body height away from a landing area. A line on the ground marked the landing area. The participants were instructed to jump forward so that both limbs left the box simultaneously, landed just past the line, and jumped to the maximum height immediately after landing. Participants were asked to perform a few trials until they were comfortable with the task and performed it correctly. The trial was disqualified and repeated if participants jumped vertically from the box or did not reach the maximum height after landing [30]. Two high-speed digital video cameras were placed 3 m in front of and to the right of the participants to capture frontal and sagittal images of all jump landing trials. The testing was carried out by recording several trials of jump landing tasks performed by participants using standard video cameras. The scoring was made by reviewing the video recordings. The LESS consisted of 17 items and was evaluated from the sagittal, frontal, and general view of the jump landing task participant. The sagittal and frontal views were analysed using the camera placed in front and on the right side. Meanwhile, the general view pertained to the overall impression of the participants' landing, specifically whether they exhibited a soft landing with no frontal-plane or transverse-plane motion. Landings were scored for 'errors' according to the LESS's checklist. A total score of 5 or more indicates that the individual is at a greater risk of sustaining noncontact or indirect contact ACL injury than those with LESS scores below 5 [18].

Interventions

Control group

Participants were instructed to perform their usual warm-up routines for a duration similar to the FIFA 11+ (15–20 minutes). Warm-up routines vary slightly among teams, including running, stretching, ball-handling exercises, and games. The researcher observed the participants during the warm-up routines and took notes on the exercises and activities performed.

FIFA 11+ group

The FIFA 11+ programme has three parts. The initial part consists of running exercises at a slow speed, active stretching, and controlled contact with a partner. The running course includes six to ten pairs of cones (depending on the number of players) about five to six metres apart (length and width). The running exercise includes running straight ahead and quickly forward and backwards. The second part consists of six different sets of exercises: strength, balance, and jumping, each with three levels of increasing difficulty. The final part combines speed running with football-specific, bounding, and plant-cut movements [28].

Testing procedure

All tests were carried out in the university's high-performance laboratory. This laboratory was selected due to its ample space, lack of external interference and optimal room temperature (28–31.1°C). The temperature of the room could not be controlled because it did not have an air conditioner. Demographic data, including age, height, body weight, body mass index (BMI), and dominant leg, were collected and recorded before the testing procedures. The Physical Activity Readiness Questionnaire (PAR-Q) was used to detect risk factors of cardiovascular diseases, general health, and well-being when increasing the exercise level [2]. Then, the familiarization session was conducted one week before the testing procedure. During the familiarization sessions, participants were instructed to familiarize themselves with a dynamic warm-up, CMJ, $YoSFS^5$, and isokinetic dynamometer. Participants received demonstrations, followed by a few practice trials until they could do it correctly.

Initially, participants were assigned to the control and intervention groups (see Figure 2). After that, the baseline data on muscle strength and LESS were tested by two sessions separated by at least three days [8]. Both sessions included a dynamic warm-up, followed by a pre-test (PRE), the $YoSFS^5$, then a test immediately following $YoSFS^5$ (POST5), after 15 min of passive rest (POST20), and after 30 min of passive rest (POST35). Then, the same procedure was conducted after eight weeks of intervention (see Figure 3).

$YoSFS^5$ uses high-intensity exercises. The distance for $YoSFS^5$ is 12 metres, and the time spent is 5 minutes. Functional high-intensity movements and ball-orientated activities were included in this simulation to make it more similar to an actual soccer match. Participants need to repeat the cycle of activities for 5 minutes. Instructions on activity sequences were provided using verbal cues on an audio recording. Before, during, and after the simulation, the participants were assessed regarding their HR, RPE, and CMJ height. The HR was monitored to ensure that the participants were in a high-intensity mode phase. Meanwhile, RPE and CMJ were indicators of fatigue level. Verbal encouragement was applied if the participant was not in the high-intensity mode.

Statistical analysis

The data were analysed using SPSS (Version 23; SPSS Inc., USA). Descriptive statistics of the outcome measures included means, percentages, and standard deviations. The Shapiro-Wilk test confirmed the normality of the data. Then, means, standard deviations and range characteristics at baseline between groups were assessed by the independent t-test. A 2 × 2 mixed analysis of variance was conducted to determine the impact of two different interventions (unstructured programme vs FIFA 11+) on participants at PRE, POST5, POST20 and POST35 across two time periods (pre-intervention and post-intervention). The main hypothesis of interest was the group×time interaction. Cohen's magnitude of the effect size classification for partial eta squared was used to rank the size (0.01= small effect, 0.06 = medium effect, 0.14 = large effect).

Results

Characteristics of participants

The demographic characteristics of participants at baseline are presented in Table 1. There were no significant differences between the control and the FIFA 11+ group in all dependent variables at baseline.

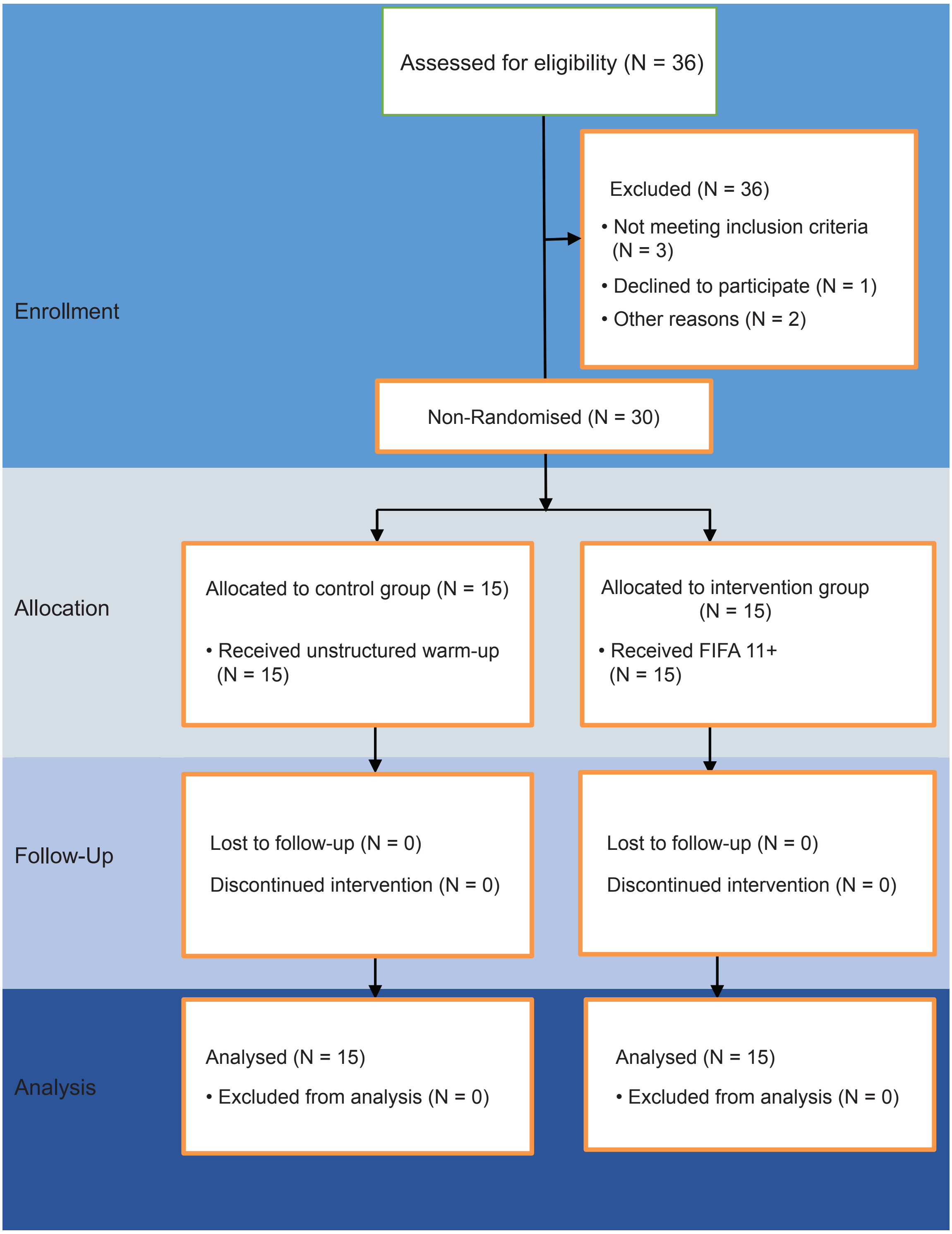

Figure 2. Study flowchart

Muscle strength

A mixed between-within-subjects analysis of variance was conducted to assess the impact of two different interventions and showed no significance within or between the groups for Hecc, Hcon, Qcon, H/Q_{CONV} and H/Q_{FUNC}, as shown in Table 2.

Effect of FIFA 11+ injury prevention programme on landing biomechanics

A mixed between-within-subjects analysis of variance was conducted to assess the impact of two different interventions (unstructured programme, FIFA 11+) on

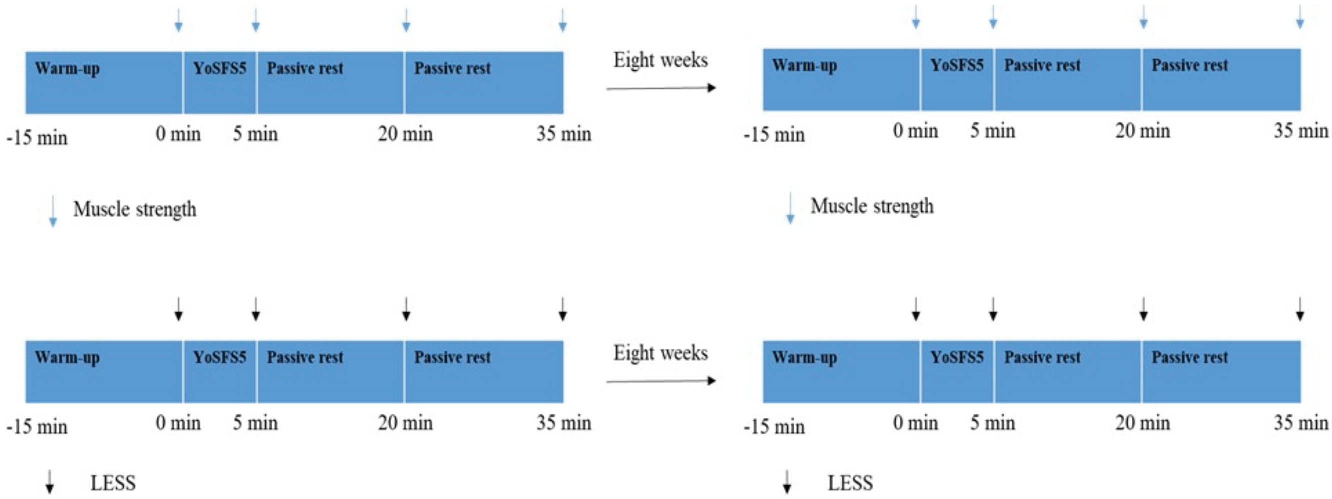

Figure 3. Illustration of time data recording before and after intervention in the control and intervention group

Table 1. Demographic baseline data of participants

Characteristics	Control (N:15)		Intervention (N:15)		CI	p-value
	Mean ± SD	Range	Mean ± SD	Range		
Age [years]	16.00 ± 0.85	15–17	16.17 ± 0.84	15–17	–0.88÷0.55	0.633
Height [m]	1.69 ± 0.06	1.57–1.81	1.66 ± 0.04	1.60–1.70	–0.01÷0.08	0.135
Weight [kg]	53.95 ± 6.06	43–62	53.44 ± 8.45	43.9–67.9	–5.71÷6.73	0.867
BMI [kg/m^2]	18.89 ± 1.51	16.56–21.45	19.48 ± 2.99	15.94–25.25	–2.64÷1.46	0.549
Limb length [cm]	89.21 ± 2.90	84–93	86.62 ± 3.56	80–81	–0.41÷5.08	0.092
Heart rate [bpm]	89.92 ± 13.98	62–102	83.08 ± 14.61	61–101	–5.23÷18.89	0.253
Rating of perceived exertion	6.33 ± 0.49	6.0–7.0	6.25 ± 0.45	6.0–7.0	–0.32÷0.48	0.670
Counter-movement jump [cm]	41.19 ± 5.13	34.93–50.49	43.35 ± 5.91	35.48–57.33	–6.84÷2.53	0.350
Muscle strength						
Hecc [N · m]	109.03 ± 14.27	87.00–132.90	105.69 ± 19.95	72.20–139.90	–11.34÷18.03	0.642
Hcon [N · m]	67.18 ± 8.90	55.60–85.90	62.63 ± 9.62	48.30–76.80	–3.29÷12.41	0.241
Qcon [N · m]	119.78 ± 18.62	96.40–155.70	115.51 ± 13.87	90.20–134.60	–9.64÷18.17	0.531
H/Q_{CONV} [-]	0.58 ± 0.07	0.49–0.76	0.54 ± 0.08	0.41–0.67	–0.03÷0.01	0.234
H/Q_{FUNC} [-]	0.94 ± 0.13	0.76–1.12	0.91 ± 0.16	0.59–1.21	–0.10÷0.15	0.654
LESS [bpm]	4.72 1.55	3.00–7.30	4.35 0.80	2.70–5.30	–0.680÷1.41	0.475

*significant at p < .05, Hecc: hamstring eccentric, Hcon: hamstring concentric, Qcon: quadriceps concentric, H/Q_{CONV} : conventional hamstring-quadriceps ratio, $H/Q_{FUNC:}$ functional hamstring-quadriceps ratio, LESS: Landing Error Scoring System, bpm: beats per minute

participants' LESS scores at PRE, POST5, POST20, and POST35 across two time periods (pre-intervention and post-intervention). The effect of the eight weeks of FIFA 11+ injury prevention programmes on LESS for the FIFA 11+ and the control group among youth soccer players is shown in Table 3.

There was no significant main effect for the time in PRE on LESS score after the intervention (p = 0.43, partial eta squared = 0.03). The main effect comparing the two types of intervention was significant, suggesting a difference in the 11+ group, and shows the effectiveness at PRE (p < 0.05, partial eta squared = 0.45) (see Figure 4). There

Table 2. Effect of 8-week FIFA 11+ injury prevention programme on muscle strength during fatigue among youth soccer players

Performance		Control			Intervention			Mixed ANOVA outcome (p-value)		
		Baseline	Week 8	% change	Baseline	Week 8	% change			
		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Time	Group	Group × Time
Hcon	PRE	67.18 ± 8.90	70.28 ± 9.95	4.6	62.63 ± 9.62	64.23 ± 7.65	2.6	0.035*	0.150	0.481
	POST5	62.94 ± 10.99	62.58 ± 10.47	–0.6	60.64 ± 8.98	61.43 ± 9.31	1.3	0.909	0.640	0.759
	POST20	64.58 ± 11.30	66.11 ± 9.56	2.4	61.63 ± 8.51	59.28 ± 7.83	–3.8	0.708	0.198	0.085
	POST35	65.51 ± 8.22	64.28 ± 9.77	–1.9	58.89 ± 8.58	60.78 ± 9.68	3.2	0.821	0.154	0.288
Hecc	PRE	109.03 ± 14.27	117.78 ± 12.51	8.0	107.44 ± 21.77	115.61 ± 18.44	7.6	0.004*	0.775	0.914
	POST5	103.77 ± 12.34	111.88 ± 16.34	7.8	100.03 ± 24.00	107.65 ± 21.35	7.6	0.004*	0.595	0.921
	POST20	103.05 ± 13.04	111.65 ± 10.31	8.3	99.47 ± 23.07	103.05 ± 21.24	3.6	0.022*	0.381	0.321
	POST35	108.44 ± 8.68	112.33 ± 12.01	3.6	97.81 ± 19.90	100.08 ± 21.81	2.3	0.163	0.088	0.710
Qcon	PRE	120.61 ± 17.78	126.00 ± 20.38	4.5	115.51 ± 13.87	121.00 ± 20.34	4.8	0.184	0.686	0.712
	POST5	115.33 ± 17.17	117.51 ± 19.65	1.9	109.61 ± 14.34	114.91 ± 16.75	4.8	0.260	0.621	0.396
	POST20	116.76 ± 17.89	118.13 ± 22.20	1.2	112.74 ± 16.23	115.67 ± 15.95	2.6	0.411	0.648	0.764
	POST35	117.59 ± 20.44	120.03 ± 23.54	2.1	113.64 ± 15.68	115.26 ± 14.65	1.4	0.325	0.565	0.840
H/Q_{CONV}	PRE	0.57 ± 0.12	0.57 ± 0.12	0.3	0.55 ± 0.11	0.55 ± 0.12	–0.5	0.978	0.678	0.891
	POST5	0.56 ± 0.16	0.55 ± 0.14	–2.8	0.56 ± 0.12	0.55 ± 0.14	–2.4	0.472	0.957	0.951
	POST20	0.56 ± 0.11	0.58 ± 0.15	3.7	0.56 ± 0.13	0.53 ± 0.12	–6.1	0.685	0.566	0.104
	POST35	0.57 ± 0.12	0.56 ± 0.15	–2.8	0.53 ± 0.10	0.54 ± 0.12	2.1	0.876	0.507	0.409
H/Q_{FUNC}	PRE	0.93 ± 0.24	0.96 ± 0.20	2.7	0.94 ± 0.21	0.98 ± 0.22	4.3	0.271	0.856	0.833
	POST5	0.93 ± 0.25	0.98 ± 0.27	5.6	0.93 ± 0.24	0.95 ± 0.22	2.7	0.122	0.863	0.574
	POST20	0.91 ± 0.24	0.99 ± 0.26	8.0	0.90 ± 0.24	0.91 ± 0.24	1.0	0.118	0.634	0.220
	POST35	0.95 ± 0.20	0.97 ± 0.23	2.3	0.87 ± 0.20	0.88 ± 0.21	0.7	0.591	0.316	0.757

*significant at $p < .05$, Hecc: hamstring eccentric, Hcon: hamstring concentric, Qcon: quadriceps concentric, H/Q_{CONV}: conventional hamstring-quadriceps ratio, H/Q_{FUNC}: functional hamstring-quadriceps ratio

Table 3. Effect of 8-week FIFA 11+ injury prevention programme on LESS during fatigue among youth soccer players

Performance		Control			Intervention			Mix-ANOVA outcome (p-value)		
		Baseline	Week 8	% change	Baseline	Week 8	% change			
		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD		Time	Group	Group × Time
LESS	PRE	4.72 ± 1.55	5.80 ± 0.67	–22.9	4.35 ± 0.80	3.70 ± 0.52	14.9	0.433	0.001*	0.004*
	POST5	7.78 ± 2.1	8.25 ± 0.88	–6.0	7.04 ± 0.85	5.75 ± 0.57	18.3	0.180	0.001*	0.007*
	POST20	6.43 ± 1.76	6.78 ± 0.96	–5.4	5.69 ± 1.15	5.25 ± 1.32	7.7	0.900	0.011*	0.283
	POST35	6.01 ± 2.08	6.28 ± 1.16	–4.5	5.33 ± 0.96	5.17 ± 1.04	3.0	0.887	0.044*	0.577

*significant at $p < 0.05$; LESS: Landing Error Scoring System.

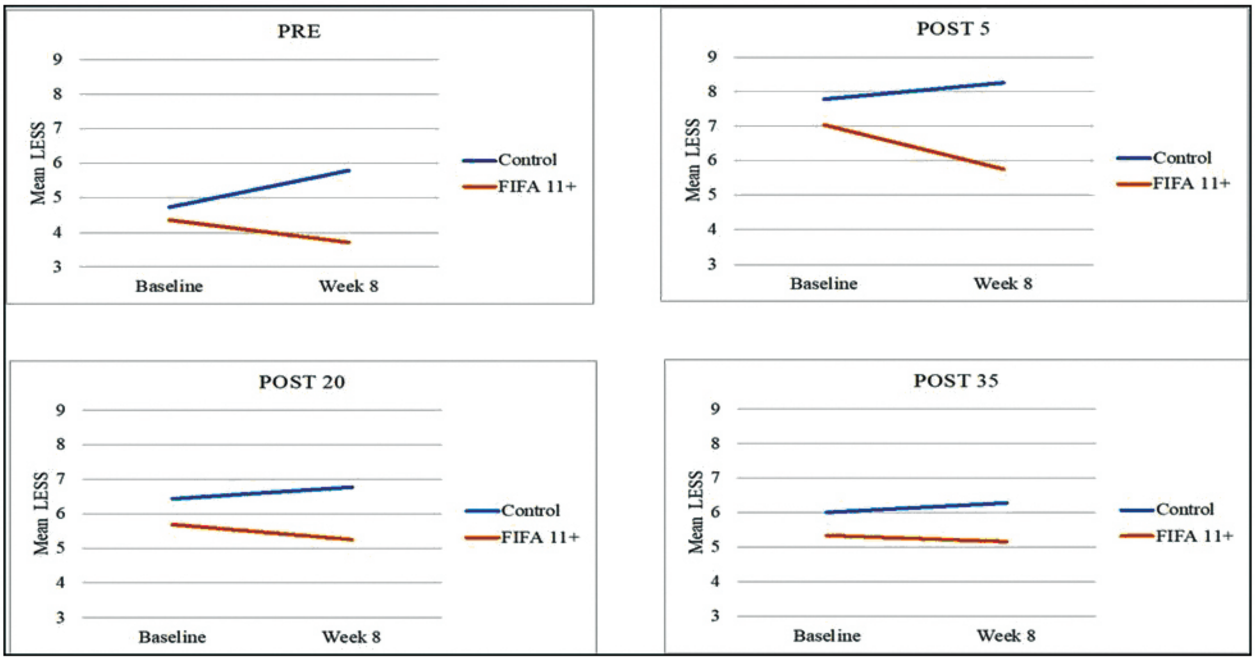

Figure 4. Effect of 8-week FIFA 11+ injury prevention programme on LESS during induced fatigue among youth soccer players at PRE, POST5, POST20, and POST35

was a significant interaction at PRE between intervention type and time ($p < 0.05$, partial eta squared = 0.32). Meanwhile, POST5 shows no significant main effect for the time at POST5 on LESS score after the intervention ($p = 0.18$, partial eta squared = 0.08). The main effect comparing the two types of intervention was significant, suggesting a difference in the FIFA 11+ group, and shows the effectiveness at POST5 after fatigue was induced ($p < 0.05$, partial eta squared = 0.41). There was a significant interaction at POST5 between the type of intervention and time ($p < 0.05$, partial eta squared = 0.29). The data show no significant interaction between programme type and time for POST20 and POST30.

Discussion

This study aimed to investigate the effect of FIFA11+ on muscle strength and landing biomechanical markers of ACL injury risk in youth soccer players during the fatigue state. We obtained some important findings. The FIFA 11+ and the unstructured warm-up programme did not show significant differences in muscle strength and the H/Q_{CONV} and H/Q_{FUNC} ratios. Meanwhile, the biomechanical markers for landing presented a significantly higher score at PRE and POST5 in the FIFA 11+ than in the control group.

This study found no significant difference in muscle strength on concentric and eccentric contraction between the groups after YoSFS[5]. However, the authors found an improvement in the percentage of Hecc contraction at PRE and POST5 immediately after YoSFS[5] in the FIFA 11+ group. This indicated that FIFA 11+ affected Hecc strength before and during fatigue, which could be due to eccentric hamstring exercise (Nordic exercise) in the FIFA 11+ programme itself, which helps improve the strength of Hecc contraction. Therefore, it may help to assist the ACL during knee extension activity and thus may reduce ACL injury. This statement is consistent with a recent study that found Nordic exercise can reduce the severity of muscle injury among high school soccer players [22]. Furthermore, eccentric hamstring training showed a positive change in the risk of ACL injury and hamstring strain [25]. This means that the programme was able to increase the strength of the players' hamstrings, which in turn may reduce the risk of injury.

Although individual muscle contraction is vital for evaluation, the H/Q_{CONV} ratio is widely used to determine the relationship between the strength of concentric contraction in the agonist and antagonist in the knee joint. The ratio would help estimate the functional capacities of the knee joints and the risk of knee injuries [21]. The normative value for H/Q_{CONV} should be greater than 0.60 [21]. This study shows that both groups did not achieve more than 0.6 before and after the intervention. Thus, no significant differences were found between the groups at any of the time points. The finding is similar to that of Daneshjoo and colleagues [12], who found no significant effect on the dominant leg. However, they found significant differences for the non-dominant leg at 60°/s but not at 180°/s and 300°/s. They argued that 60°/s is slow enough for muscles to recruit more motor units and increase peak torque. The velocity mode may affect the results of this study, as this study used isokinetic Biodex with mode 120/s; however, this higher velocity value is commonly used for games, competitions, daily practice, and technique drills [10]. In addition, the mode of 120/s is suitable for soccer, as the nature of the game is more indicative of power and explosiveness and less of slow-speed strength [12]. Meanwhile, a study by Oliano and colleagues [27] found a significant difference in the H/Q_{CONV} ratio in the dominant leg. However, this study could not be directly compared to their study because the participants were handball players, and the FIFA 11+ programme was modified toward the nature of handball activities.

The H/Q_{CONV} calculation for the risk of injury has some restrictions. The H/Q_{CONV} ratio is calculated based on the concentric work of the agonist and antagonist muscle groups. It is not a physiological activity that takes place in a sport-related activity. For these reasons, Aagaard and colleagues [1] came up with a new concept of the H/Q_{FUNC} ratio. This ratio calculated the value of the contraction of the agonist and antagonist during knee extension, representing the sport-related activities. The relationship between the strength of concentric contraction in the agonist and the eccentric contraction in the antagonist in the knee joint was introduced. The normative value of the ratio differed between the type of isokinetic machine, and a value of 1.05 is for the Biodex Isokinetic machine [9].

The H/Q_{FUNC} ratio in this study did not reveal significant differences within or between the groups. This is in line with the previous study by Daneshjoo and colleagues[12]. Interestingly, they found a significant decrease in the ratio value in the FIFA 11+ group in both limbs, indicating that FIFA 11+ has a negative effect instead of a positive impact. Although Hecc showed an increase at PRE and POST5 in the FIFA 11+ group, it was still unable to achieve statistical significance for the H/Q_{FUNC} ratio. To improve the H/Q_{FUNC} ratio, hamstring eccentric strength must exceed quadriceps concentric strength, as the former is divided by the latter in the calculation. However, the limited enhancement observed in this study's H/Q_{FUNC} ratio suggests that the FIFA 11+ injury prevention programme falls short in effectively boosting hamstring eccentric strength compared to quadriceps concentric contraction among youth soccer players. The study by Arsenis et al. [4] found a significant improvement in eccentric hamstring contractions and no significant improvement in quadriceps concentric contraction after eight weeks of the FIFA 11+ programme. However, the hamstring eccentric contraction did not statistically significantly improve the H/Q_{FUNC} ratio, suggesting that inadequate coordination between the hamstring and quadriceps muscles might lead to compromised knee stabilization during activities such as landing, potentially increasing the risk of ACL injury.

Regarding the effect of FIFA 11+ on landing biomechanics at PRE, the FIFA 11+ group showed a reduction of approximately 14% after eight weeks of the programme. This reduction could be due to the FIFA 11+ programme awareness of the correct postural position during activities [40]. In FIFA 11+ programme Part 2, participants must do a lateral jump exercise. During the exercise, they were told to make a proper landing. Participants were told to bend the knee and hip during landing because it is crucial to reduce the knee load on the ligament in the knee [31].

Furthermore, knee and hip flexion during initial contact is among the marking criteria in LESS. Therefore, this study suggests that participants in the FIFA 11+ group understood and coped with the training of the FIFA11+ programme. They can manage a good landing technique and score well for LESS, consistent with the FIFA 11+ programme's goal of avoiding high-risk movement patterns, such as development of knee valgus, and reducing landing forces [39].

The LESS score was reduced after fatigue simulation, which may be associated with an increased risk of ACL injury. The same pattern was observed in both groups after eight weeks of FIFA 11+ training and unstructured warm-up training. However, the FIFA 11+ group scored significantly better than the control group during fatigue (POST5) and recovery (POST 20 and POST35), which is good for reducing the risk of injury. However, the participants' score was still in the range of the higher risk of ACL injury at all times data were taken. This could be because the participants were fatigued and did not fully recover. Only the FIFA 11+ group scored < 5.0 at PRE, indicating that this group was at low risk of ACL injury before fatigue. In conjunction with previous studies, the FIFA11+ programme showed significant improvement during the non-fatigue state in performance, balance, strength, and proprioception [6, 7, 11].

Although the FIFA 11+ group members scored significantly better than the control group during fatigue (POST5) and recovery (POST 20 and POST35), they are still at high risk due to the effect of fatigue. This study revealed that fatigue is essential in some injury risk evaluations because most injuries occur in a fatigued state. Regarding the FIFA 11+ programme, it significantly improved LESS at recovery time, even though the LESS score is >5.0. However, the score tended to become lower after 30 minutes. Previous studies have shown the effectiveness of FIFA 11+ after eight weeks as the researchers measured their participants during a non-fatigued state [4, 12, 13, 23]. Therefore, this study suggests that implementing the FIFA 11+ protocol could be advantageous, indicating that increasing its frequency to more than twice a week over an eight-week period may decrease the risk of ACL injury, particularly under conditions of fatigue.

There were several limitations of the current study. First, the participants were recruited among recreational youth soccer players. Thus, they may not represent the entire population of young soccer players. Secondly, there is limited literature on fatigue among youth soccer players. Hence, it may not be appropriate to make comparisons with the adult population. Lastly, the participants were subjected to fatigue simulation for only 5 minutes, which is considered short. This YoSFS[5] can reproduce the same physiological changes as the long-duration fatigue simulation. However, the effect produced may not be the same as a real soccer game that lasts 90 minutes.

Practice applications

In conclusion, after eight weeks, the FIFA 11+ injury prevention programme demonstrates a reduction in the LESS score even when participants are fatigued. While it may enhance landing biomechanics, it does not significantly improve muscle strength. Therefore, further investigation is warranted to identify the effect of FIFA 11+ in reducing the risk of ACL injury.

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