Ann Appl Sport Sci 10(2): e1033, 2022.
http://www.aassjournal.com; e-ISSN: 2322–4479; p-ISSN: 2476–4981. 10.52547/aassjournal.1033

ORIGINAL ARTICLE

The Effects of Short-Duration High-Intensity Soccer Fatigue Simulation on Dynamic Balance and Lower Limb Isokinetic Strength in Youth Soccer Players

[1]Saiful Adli Bukry, [2,3]Raja Mohammed Firhad Raja Azidin, [1]Maria Justine, [1,2]Haidzir Manaf*

[1]Center for Physiotherapy Studies, Faculty of Health Sciences, Universiti Teknologi MARA, Puncak Alam Campus, 42300 Puncak Alam, Selangor, Malaysia. [2]Clinical and Rehabilitation Exercise Research Group, Faculty of Health Sciences, Universiti Teknologi MARA, Puncak Alam Campus, 42300 Puncak Alam, Selangor, Malaysia. [3]Faculty of Sports Science and Recreation, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

Submitted 26 June 2021; Accepted in final form 22 August 2021.

ABSTRACT

Background. This study investigated the effects of short-duration high-intensity simulation of soccer fatigue on the dynamic balance and isokinetic strength of the lower limbs in youth soccer players. **Methods.** Thirty-nine youth soccer players completed a high-intensity fatigue simulation in 5-min. The participants performed tests on dynamic balance and isokinetic strength before the fatigue simulation (PRE), immediately after simulation (POST5), and 20 min (POST20) and 35 min (POST35) after simulation. Dynamic balance was measured using the Y-Balance test for both legs in the anterior, posteromedial (PM), and posterolateral (PL) directions. The muscle strength of the lower limb was measured using the maximal isokinetic contraction of the dominant leg only. **Results.** Dynamic balance was significantly reduced after stimulation in all directions for both legs ($P<0.005$). Significant reduction in the eccentric hamstring, concentric hamstring, and concentric quadriceps peak torques were also observed ($P<0.05$). However, no significant reductions were found in the functional hamstring/quadriceps ratio and conventional hamstring/quadriceps ratio ($P>0.05$). **Conclusion.** Fatigue influences dynamic balance, hamstrings, and quadriceps strength which may have implications for higher risk of knee injury in youth players.

KEYWORDS: ***Muscle Fatigue, Torque, Balance, Injury.***

INTRODUCTION

Knee injury is among youth soccer players (1). An epidemiology study has shown that the highest incidence of lower limb injuries is recorded at the end of the soccer match (2, 3). During fatigue, the quality and efficiency of the body's sensory input may deteriorate and impair the motor output (4). Studies have shown that decreased hamstring strength during fatigue may negatively impact knee stability and increase the risk of hamstring strain (5, 6). In addition to the muscle strength, a reduction in the functional integrity of the knee joint tends to impair the postural balance and, in turn, increases the risk of anterior cruciate ligament (ACL) injury (7).

Dynamic balance plays an essential role in most soccer technical skills that require one of the lower limbs to provide body support and balance while the other limb controls the ball (8, 9). This

*. Corresponding Author:
Haidzir Manaf, Ph.D.
E-mail: haidzir5894@uitm.edu.my

state is one of the biomechanical markers for lower limb injury risk (8). The reduced posterolateral direction during a Y-balance test (YBT) is associated with the risk of ACL injury (7). A few studies have explored the effect of soccer-related fatigue on the muscle strength in adult soccer players (10-12). The reduced muscle strength, especially that of the hamstring eccentric (Hecc) (10), and the muscle imbalance between the hamstring eccentric and quadriceps concentric (H/Q_{FUNC}) (10, 11) are associated with the risk of a hamstring and ACL injuries. The results from these studies may indicate that fatigue plays a crucial role in the muscular risk factors in the mechanism of a hamstring and ACL injuries. In addition, the predictor of ACL and hamstring injury may be more useful when measured during the fatigue state (13).

In soccer, various studies have used different types of soccer-specific fatigue simulations, such as the Loughborough intermittent shuttle test (11, 14, 15), soccer-simulation protocol (16), soccer match simulation (17), and soccer-specific aerobic field test ($SAFT^{90}$) (6, 18). Meanwhile, soccer-specific match simulation ($SAFT^5$) is a short-duration test with high-intensity multidirectional movements that have been demonstrated to induce physiological responses comparable to those in longer-term match-play conditions (10). The short duration of $SAFT^5$ helps resolve issues on the time-consuming nature of inducing fatigue and can be used to screen a large group of soccer players. However, most studies that used the $SAFT^5$ protocol have only focused on the adult population involving recreational and amateur soccer players (10, 19). Studies that focused on changes in the dynamic balance and muscle strength due to fatigue and mainly involved youth soccer players are lacking. Investigating this population is essential because the rate of injury among youth soccer players is twice that of adult injuries (19). The development of short-term protocols, such as $SAFT^5$, is important to induce fatigue, and these methods may indicate better injury predictors. However, $SAFT^5$ does not include ball-oriented activities, which are vital in soccer. Bishop et al. (20) suggested that fatigue simulation should be modified based on the nature of specificity of a sport. Therefore, this study aimed to investigate the effects of short-duration high-intensity fatigue simulation on the dynamic balance and isokinetic strength among male youth soccer players. The hypothesis was that fatigue would change these selected biomarkers of lower limb injury among youth soccer players.

MATERIALS AND METHODS

Thirty-nine high school youth soccer players (age: 15.9±0.9 years, height: 1.7±0.1 m, and weight: 54.4±8.7 kg) participated in this cross-sectional, repeated measures design study. Power analysis with sample-size estimation (10) showed that 39 participants would provide 80% power with a risk of type 1 error of 0.05. The participants were recruited from a government-funded secondary school by using purposive sampling. Participants were included if they regularly played soccer 3 to 5 times per week and for 40–60 min per session. Participants were excluded if they had an injury of the lower limb within six months before testing. All participants and guardians were fully informed about the study procedure and signed the consent forms before participating. The Research Ethical Committee granted ethical approval (600-IRMI [5/1/16]), while the Ministry approved permission to conduct the study of Education.

Fatigue Simulation. The fatigue simulation was a 5-min high-intensity exercise protocol modified from the previous study (10). The study involved over-ground (incorporating four positioned poles/markers) high-intensity multidirectional and utility movements, with frequent high accelerations and decelerations (Figure 1). The distance was modified to 12-m to make the protocol feasible for youth soccer players. This soccer fatigue simulation included several soccer-specific movements, such as kicking, jumping, heading, and sprints with a ball. The modification in the fatigue simulation activities is shown in Table 1. A pilot study was conducted to identify the reliability of the simulation. The relative reliability showed that the ICCs for Rating of 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 (21).

Physiological Assessment. Heart rate (HR) was monitored continuously throughout the protocol to ensure that all players performed the protocol within the desired range (Polar heart rate system, Electro, Finland). In case where HR was not within the high-intensity range, encouragement was given to increase the participant's motivation. The RPE (20-point Borg scale) and CMJ were assessed to monitor the level of fatigue and recorded during pretest (PRE), immediately following fatigue simulation (POST5), after 15 min of passive rest (POST20), and after 30 min of passive rest (POST35). The CMJ (free arm) height was measured with the My Jump 2 application (version 6.0.3) and was valid and reliable with satisfactory relative reliability (ICC≥0.88) and absolute reliability (CV<10%) (22).

Table 1. Activity Profiles of Recent Fatigue Simulation Compared with the Activity Profiles of SAFT[5]

No	Activity Fatigue Simulation	Activity SAFT[5]	Speed (m/s)	Time (s)
0	5x Ball Passing	10 x scissors	-	-
1	Stand	Stand	0	4
2	Jog	Jog	2.86	10
3	5x Ball double-leg jump heading	CMJ	1.39	17
4	Stride	Stride	4.17	7
5	Agility ladder drill + 1 x Ball shooting	Agility ladder drill	1.39	17
6	CMJ + jog	Jog	2.86	10
7	Sprint with a ball	Sprint	5.58	6
8	Stand	Stand	0	4
9	Jog	Jog	2.86	10
10	5x Ball Passing	10 x scissors	1.39	17
11	CMJ + jog	Jog	2.86	10
12	5x Ball double-leg jump heading	CMJ	1.39	17
13	Stride	Stride	4.17	7
14	Agility ladder drill + 1 x Ball shooting	Agility ladder drill	1.39	17
15	Stand	Stand	0	4
16	Jog	Jog	2.86	10
17	5x Ball Passing	10 x scissors	1.39	17
18	CMJ + jog	Jog	2.86	10
19	Jog	Jog	2.86	10
20	Jog	Jog	2.86	10
21	5x Ball double-leg jump heading	CMJ	1.39	17
22	CMJ + jog	Jog	2.86	10
23	Agility ladder drill + 1 x Ball shooting	Agility ladder drill	1.39	17
24	Stride	Stride	4.17	7
25	Stand	Stand	0	4
26	5x Ball Passing	10 x scissors	1.39	17
27	Jog	Jog	2.86	10
28	Sprint with a ball	Sprint	1.39	6
29	CMJ			

CMJ: counter-movement jump

Dynamic Balance. The participant's dynamic balance was measured using the YBT for both legs (7). This test was conducted according to the guideline provided, in which the participants stood on one leg at the center of the Y and were instructed to try to reach as far as they could by using the other leg (23). Participants were required to place their hands on their hips and maintain their balance while reaching and returning to a bilateral stance. The YBT was completed in this order: dominant anterior, non-dominant anterior, dominant posterolateral (PL), non-dominant PL, dominant posteromedial (PM), and non-dominant PM. A trial was considered to fail if the participants lost their balance through the movement, raising both arms to balance their body, touching the ground while reaching, and lifting the standing leg heel during execution. For each direction, nine trials were performed, and the measurement was taken during the 7th, 8th, and 9th execution. The length of each leg was measured before the test. The average (absolute reach distance) of three trials of the YBT was calculated and normalized to the limb length (relative reach distance) by using the following formula:

Relative Reach Distance:

$$\frac{Absolute\ reach\ distance\ (cm)}{Leg\ Length\ (cm)} \times 100$$

Isokinetic Strength of the Lower Limb. Several studies have determined the reliability and validity of the isokinetic test by using Biodex System 3 (24, 25). The dominant leg was tested by using an isokinetic dynamometer (IKD, Biodex System 3, Shirley, NY) to determine the maximum voluntary contractions (MVC) of the eccentric hamstring strength (Hecc), concentric quadriceps strength (Qcon), and concentric hamstring strength (Hcon). The dominant leg was determined based on the most favored leg during kicking. The IKD was calibrated before the study was started by following the manufacturer's instructions. The lateral epicondyle of the dominant knee was aligned with the rotational axis of the dynamometer, and the distal calf cuff was positioned two fingers above the lateral malleolus. The seat of the IKD 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 isolate the hamstrings and quadriceps of the dominant leg. The participants were required to perform repeated maximum isokinetic contractions within 90° ROM at 120°/s for concentric MVC five times. Then, the participants had to resist the passive external knee extension over 90° ROM and at 120°/s during eccentric MVCs. The velocity was chosen because it was widely used to measure muscle strength in soccer players (26).

Testing Procedure. All tests were conducted in the laboratory because of its ample space, optimal room temperature (28-31.1 °C), and lack of external interference. Demographic data, which included the age, height, body weight, body mass index (BMI), and dominant leg of the participants, were collected and recorded before the testing. The Physical Activity Readiness Questionnaire was used to detect the risk factors of cardiovascular diseases, general health, and well-being when the exercise level was increased (27). Then, the familiarization session was conducted one week before the actual testing procedure. During the familiarization sessions, participants were instructed to be familiarized with a dynamic warm-up, CMJ, fatigue simulation, YBT, and IKD. The dynamic balance and muscle strength tests were conducted on two days, with a rest between a week. On the actual testing day, the participants first warmed up. Then, the HR, RPE, and CMJ heights were recorded. Afterward, the YBT was performed, followed by a fatigue simulation. After completing the fatigue simulation, the participants immediately performed the test at POST5, followed by POST20 and POST35 with 15 min of passive rest. The participants performed the same procedures on the second day of the test, but the IKD test measured them.

Statistical Analysis. Data were analyzed using SPSS (Version 23; SPSS Inc., USA). Descriptive statistics of outcome measures included means and standard deviations. The Shapiro-Wilk test confirmed the normality of the data. A one-way repeated measure ANOVA was used to investigate the influence of fatigue simulation on each dependent variable. A Bonferroni procedure was used for the post-hoc analysis, and the alpha level was set to 0.05. Cohen's classification was used to rank the size (0.01=small effect, 0.06=medium effect, and 0.14=large effect) to determine the effect size's magnitude. Changes in percentages and recovery scores were also reported.

RESULTS

Participants' Characteristics. The participants' characteristics are presented in Table 2.

Physiological Changes. Significant increase in the HR ($F_{3.0,\ 108}$=498.379, P=0.001, effect size=0.93) and RPE ($F_{2.28,\ 82.167}$=304.786, P=0.001, effect size=0.894) but a significant reduction in CMJ height ($F_{2.33,\ 83.95}$=165.901, P=0.001, effect size=0.822) were observed after the complete fatigue simulation.

Dynamic Balance. Means and standard deviations of the anterior, PM, and PL are shown in Table 3. Significant reductions were found in the dominant limb anterior, PM, and PL at POST5, POST20, and POST35 [($F_{1.814,\ 68.928}$=21.461, P=0.001), ($F_{1.867,\ 70.959}$=17.724, P=0.001), and ($F_{1.490,\ 56.612}$= 14.790, P=0.001), respectively] after the fatigue simulation was performed. The corresponding effect sizes were 0.859, 0.318, and 0.280. Significant reduction was found in the nondominant limb anterior, PM, and PL at POST5, POST20, and POST35 ($F_{1.740,\ 66.128}$= 48.423, P=0.001), ($F_{1.453,\ 55.197}$=16.207, P=0.001), and ($F_{1.681,\ 63.894}$=29.446, P=0.001), respectively. The corresponding effect sizes calculated from the partial eta square were 0.560, 0.299, and 0.437.

Muscle Strength of the Lower Limb. The means and standard deviation of the Hcon, Hecc, Qcon, H/Q_{CONV}, and H/Q_{FUNC} are shown in Table 4. Significant reductions were found in the Hcon ($F_{2.733,\ 117.59}$ =6.661, P=0.001), Hecc ($F_{3,\ 264.565}$=5.366, P=0.002), and Qcon ($F_{2.182,\ 429.604}$=9.695, P<0.001) peak torques, and the corresponding effect sizes were 0.418, 0.376, and

0.504. Finally, no significant differences were found in the H/Q_{CONV} ($F_{3, 114}$=0.234, P=0.929) and H/Q_{FUNC} ($F_{2.541, 0}$=0.116, P=0.873) ratios with corresponding effect sizes of 0.003 and 0.006.

Table 2. Mean and standard deviation of demographic

	Mean	Standard Deviation (SD)
Age (Year)	15.9	0.7
Height (m)	1.7	0.1
Weight (kg)	54.4	8.7
BMI (kg/m2)	19.5	2.6
Limb Length (cm)	88.8	3.6

Table 3. Mean, standard deviation, and effect of condition for dynamic balance

	Mean ± SD							Effect of Condition	
	PRE	POST 5	% Change	POST 20	% Recovery	POST 35	% Recovery	F-statistic (df1,df2)	p-value
Dominant									
Anterior	85.30±10.44	80.27±10.79	5.90	81.06±10.64	4.97	83.51±10.49	2.10	21.461(1.814, 68.928)	0.001
Posteromedial	110.79±9.23	104.50± 9.57	5.68	107.65±10.04	2.83	109.06±9.13	1.56	17.724(1.867, 70.959)	0.001
Posterolateral	107.67±10.65	101.66±10.64	5.58	105.14± 10.25	2.35	105.91±10.60	1.63	14.790(1.490, 56.612)	0.001
Non-dominant									
Anterior	87.23± 9.23	80.34± 10.64	7.90	82.02± 9.61	5.97	83.38± 9.06	4.41	48.423(1.740, 66.128)	0.001
Posteromedial	112.33± 8.67	106.12± 10.55	5.53	108.45± 8.65	3.45	110.46± 8.58	1.66	16.207(1.453, 55.197)	0.001
Posterolateral	108.27± 9.07	100.07± 11.30	7.57	104.31± 10.90	3.66	106.27± 9.04	1.85	29.446(1.681, 63.894)	0.001

Table 4. Mean, Standard Deviation and Effect of Condition for Muscle Peak Torque

	Mean ± SD							Effect of Condition	
	PRE	POST 5	% Change	POST 20	% Recovery	POST 35	% Recovery	F-Statistic (df1,df2)	P-Value
Hcon	65.55± 10.44	61.69± 10.16	5.89	62.76± 10.71	4.26	62.69± 10.57	4.36	6.661(2.733, 117.59)	0.001
Hecc	108.77± 19.66	102.53± 20.12	5.74	104.81± 22.85	3.64	106.11± 20.23	2.45	5.366(3, 264.565)	0.002
Qcon	116.60± 15.55	109.86± 15.30	5.78	111.86± 16.14	4.07	112.65± 16.65	3.39	9.695(2.182, 429.604)	0.001
Hcon/Qcon	0.56± 0.067	0.56± 0.078	0	0.56± 0.068	0	0.56± 0.081	0	0.234(3, 114)	0.929
Hecc/Qcon	0.93± 0.15	0.93± 0.18	0	0.94± 0.18	0	0.94± 0.16	0	0.116 (2.541, 0)	0.873

DISCUSSION

The results demonstrated that dynamic balance was affected in all directions by fatigue. Muscle strength also significantly reduced the dominant limb Hecc, Hcon, and Qcon peak torques. However, no significant differences were found in the H/Q_{FUNC} and H/Q_{CONV}.

In this study, fatigue simulation was used because it applies ball-oriented soccer-specific drills, such as passing, heading, shooting, and sprinting, to mimic the common movements during a soccer match. The results showed that fatigue significantly reduced all directions of the YBT score for both legs. This phenomenon was in agreement with that obtained by Aymen et al. (2017) (28), who investigated balance among the youth (10–13 years old) recruited from youth taekwondo and induced fatigue using the isometric and isokinetic protocol. Pau et al. (2016) (29) obtained a similar result for elite youth soccer players under 15. The reduction in the balance after fatigue could be due to decreased force production and muscle activation (30), decreased nerve conduction activity, and deterioration of the sensory input (4).

Meanwhile, Pau et al. (2016) (29) discussed that alterations in proprioception, sequence of activation, timing, and amplitude of contraction of the muscles after fatigue might negatively impact the dynamic balance. A similar study did not show significant differences in the dynamic balance after the induction of a generally localized fatigue simulation (31). This phenomenon could be due to the fact that the fatigue effect was diminished, because they did not measure the dynamic balance immediately after completion of the fatiguing protocol but rather after 2 min.

According to which direction was the most affected, the relative reach distance of the dominant and non-dominant leg scores in the current study showed that the PL reach was affected the most after fatigue, followed by the PM and anterior directions. A recent study could not be compared with other studies because of the limited sources on the effect of fatigue on the dynamic balance among the youth population. The only study that investigated the effect of fatigue used the YBT among the youth but did not state which direction was affected the most (28). Other studies involved an adult population, and a recent study was inconsistent with the results obtained by Johnston et al. (32), in which the anterior reach was affected the most, followed by PL and PM. Another study found the highest decline in the anterior reach, followed by PM and PL (33). However, a study shows that the anterior was the least affected (34). The different directions may have been caused by the distinct fatigue protocols applied. Johnston et al. (32) applied the cycling fatigue protocol that used the anterior and posterior thigh muscles more than the medial and lateral ones. Meanwhile, Hosseini and Hejazi (33) used soccer fatigue protocol for players with ankle instability, which may cause other compensations by the muscle used during the test.

Another component in this study is the recovery time after fatigue. The repeated measure of the YBT was performed to observe the time frame needed to recover following an episode of exertion in a game. In this study, the degradation of the dynamic balance returned close to the PRE baseline after 20 min for the dominant PM, dominant PL, and non-dominant PL. Meanwhile, according to the means of all directions, the non-dominant PL showed the highest decrease in the reach after fatigue (PRE to POST5). This result showed that the non-dominant PL was the most affected by fatigue. However, the non-dominant PL showed a significant increase between POST5 and POST20, which indicated a fast recovery despite being affected the most.

In a recent study, the anterior reach for both leg recovery processes was the slowest among the three directions. Compared with those by Johnston et al. (32), these results showed that the anterior score recovered the fastest within 10 min. Meanwhile, PM recovered progressively in 20 minutes, but PL took more than 20 minutes to start recovering. However, these results could not be strictly compared with those obtained by Johnston et al. (32) because they only measured the dominant leg and used a different population. The factor that might be suitable for this finding was that most participants had a dominant right leg. This characteristic indicates that the participants were used to balancing on the left leg while kicking, and this practice may have helped develop better postural control from the muscles of the left leg muscle. This result was in agreement with those by Barone (35), who investigated the balance ability between the dominant and non-dominant legs. They found that soccer players showed better standing balance on the non-dominant leg due to the soccer activity. The slow recovery in the anterior direction in both legs is supported by Khan et al. (36), who investigated the recovery in the balance after a sport-specific sprint protocol. They found that the anterior reach is the slowest to recover compared with PM and PL in SEBT. This phenomenon could be due to the more usage of the anterior muscle during the simulation, which stressed more the quadriceps and hamstring for movement, such as jumping, sprinting, and high knee running (37). In addition, the anterior muscles were more active and sustained more damage during the anterior movement (37).

Significant reductions were noted in the Hecc, Hcon, and Qcon peak torques after fatigue simulation, contrary to the results of Lehnert et al. (12). In their study, fatigue was induced in elite youth soccer players by using SAFT^{90}. The results showed no significant reduction in the three peak torques after fatigue simulation. The findings in the current study were difficult to compare with those from previous studies due to the limited reports that involved youth soccer players. Among the studies that involved adult soccer players, mostly the Hecc peak torques showed a significant reduction (2, 6, 10, 14, 38, 39). Only two studies showed significantly reduced Hcon, Hecc, and Qcon (2, 10). The significant reduction in the Hecc may be because the hamstring have more type-2 muscle fibers compared with the quadriceps (40). Therefore, this characteristic was perceived to increase the risk of injury because Greig (5) mentioned that the reduction in the Hecc might cause the varus malalignment on the knee, which can lead to a hamstring strain. In addition, anatomically, the Hecc strength is essential to stabilize the knee joint to assist the ACL from excessive anterior tibial translation caused by extreme load forces, especially generated during knee extension (10, 18). The reduction in the Hecc could increase the risk of ACL injury.

Despite the significant reductions in the three peak torques over time, the H/Q_{CONV} ratio did not significantly change. This result is inconsistent with that in a previous study, in which the laboratory-based soccer-specific exercise (41) and a field test representative of soccer-specific movements (11) verified a significant reduction in H/Q_{CONV} after completion of the fatigue simulation. Olyaei et al. (42) and Small et al. (6) obtained results that supported the current findings. Therefore, fatigue produced by fatigue simulation did not cause an imbalance between the hamstring and quadriceps concentrically. A recent study showed nonsignificant findings in the H/Q_{FUNC} ratio, which is consistent with Lehnert et al. (12). It could be because the Hecc and Qcon peak torques were reduced spontaneously, and muscle imbalance between them did not occur. Hence, instead of muscle imbalance, both muscles globally became weak, resulting in reduced performance and increased risk of injury.

CONCLUSION

Fatigue simulation negatively affected a soccer player's dynamic balance, Hecc, Hcon, and Qcon. The soccer player is at risk of lower limb injury in a fatigued state because fatigue alters the dynamic balance and reduces the muscle strength ability of youth soccer players. Since fatigue has been proved as one of the causes that contribute to injury, many prevention strategies need to be applied. Therefore, physical therapy should be added to the criteria when assessing the return-to-play condition. This activity may reduce the risk of another injury and improve the player's performance.

Several limitations were revealed in the current study. The participants were recruited among recreational youth soccer players and did not represent the whole population of youth soccer players. Second, the literature on the effect of fatigue among youth soccer players is limited, resulting in the inappropriateness of comparison with the adult population. Lastly, the fatigue simulation only exerted the participants for 5-min, which is only a short duration. This fatigue simulation could reproduce the same physiological changes as during the long-duration fatigue simulation, and the former can be more practically used in hospitalization. However, the effect produced might not be the same as during a real soccer game, which lasts for 90 min.

APPLICABLE REMARKS

- Fatigue simulation for 5-min is practically used in the clinical setting according to the time consumption.

ACKNOWLEDGMENTS

The authors thank Geran Kolaberasi Entiti Penyelidikan UiTM (KEPU) 2021(600-RMC/ KEPU 5/3 (001/2021).

CONFLICT OF INTEREST

The authors reported no potential conflict of interest.

REFERENCES

1. Faude O, Rossler R, Junge A. Football injuries in children and adolescent players: are there clues for prevention? *Sports Med*. 2013;**43**(9):819-837. **doi:** 10.1007/s40279-013-0061-x **pmid:** 23723046
2. Delextrat A, Gregory J, Cohen D. The use of the functional H:Q ratio to assess fatigue in soccer. *Int J Sports Med*. 2010;**31**(3):192-197. **doi:** 10.1055/s-0029-1243642 **pmid:** 20157872
3. Woods C, Hawkins R, Hulse M, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of preseason injuries. *Br J Sports Med*. 2002;**36**(6):436-441; discussion 441. **doi:** 10.1136/bjsm.36.6.436 **pmid:** 12453838
4. Paillard T. Effects of general and local fatigue on postural control: a review. *Neurosci Biobehav Rev*. 2012;**36**(1):162-176. **doi:** 10.1016/j.neubiorev.2011.05.009 **pmid:** 21645543
5. Greig M. Concurrent changes in eccentric hamstring strength and knee joint kinematics induced by soccer-specific fatigue. *Phys Ther Sport*. 2019;**37**:21-26. **doi:** 10.1016/j.ptsp.2019.02.003 **pmid:** 30802762
6. Small K, McNaughton L, Greig M, Lovell R. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. *J Sci Med Sport*. 2010;**13**(1):120-125. **doi:** 10.1016/j.jsams.2008.08.005 **pmid:** 18976956

7. Lee M, Sim S, Jiemin Y. Y-Balance Test But Not Functional Movement Screen Scores Are Associated With Peak Knee Valgus Moments During Unplanned Sidestepping: Implications For Assessing Anterior Cruciate Ligament Injury Risk. *Int Societ Biomechanic Sport*. 2017;**35**(1):77-80.
8. Gkrilias P, Zavvos A, Fousekis K, Billis E, Matzaroglou C, Tsepis E. Dynamic balance asymmetries in pre-season injury-prevention screening in healthy young soccer players using the Modified Star Excursion Balance Test-a pilot study. *J Phys Ther Sci*. 2018;**30**(9):1141-1144. **doi:** 10.1589/jpts.30.1141 **pmid:** 30214113
9. Teixeira LA, de Oliveira DL, Romano RG, Correa SC. Leg preference and interlateral asymmetry of balance stability in soccer players. *Res Q Exerc Sport*. 2011;**82**(1):21-27. **doi:** 10.1080/02701367.2011.10599718 **pmid:** 21462682
10. Bossuyt FM, Garcia-Pinillos F, Raja Azidin RM, Vanrenterghem J, Robinson MA. The Utility of a High-intensity Exercise Protocol to Prospectively Assess ACL Injury Risk. *Int J Sports Med*. 2016;**37**(2):125-133. **doi:** 10.1055/s-0035-1555930 **pmid:** 26509378
11. Delextrat A, Baker J, Cohen DD, Clarke ND. Effect of a simulated soccer match on the functional hamstrings-to-quadriceps ratio in amateur female players. *Scand J Med Sci Sports*. 2013;**23**(4):478-486. **doi:** 10.1111/j.1600-0838.2011.01415.x **pmid:** 22107131
12. Lehnert M, Croix MS, Xaverova Z, Botek M, Varekova R, Zaatar A, et al. Changes in Injury Risk Mechanisms after Soccer-Specific Fatigue in Male Youth Soccer Players. *J Hum Kinet*. 2018;**62**:33-42. **doi:** 10.1515/hukin-2017-0157 **pmid:** 29922375
13. Pinto MD, Blazevich AJ, Andersen LL, Mil-Homens P, Pinto RS. Hamstring-to-quadriceps fatigue ratio offers new and different muscle function information than the conventional non-fatigued ratio. *Scand J Med Sci Sports*. 2018;**28**(1):282-293. **doi:** 10.1111/sms.12891 **pmid:** 28378509
14. Cohen DD, Zhao B, Okwera B, Matthews MJ, Delextrat A. Angle-specific eccentric hamstring fatigue after simulated soccer. *Int J Sports Physiol Perform*. 2015;**10**(3):325-331. **doi:** 10.1123/ijspp.2014-0088 **pmid:** 25203540
15. Nicholas CW, Nuttall FE, Williams C. The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. *J Sports Sci*. 2000;**18**(2):97-104. **doi:** 10.1080/026404100365162 **pmid:** 10718565
16. Stone KJ, Oliver JL, Hughes MG, Stembridge MR, Newcombe DJ, Meyers RW. Development of a soccer simulation protocol to include repeated sprints and agility. *Int J Sports Physiol Perform*. 2011;**6**(3):427-431. **doi:** 10.1123/ijspp.6.3.427 **pmid:** 21911867
17. Russell M, Benton D, Kingsley M. Influence of carbohydrate supplementation on skill performance during a soccer match simulation. *J Sci Med Sport*. 2012;**15**(4):348-354. **doi:** 10.1016/j.jsams.2011.12.006 **pmid:** 22230353
18. De Ste Croix MB, Priestley AM, Lloyd RS, Oliver JL. ACL injury risk in elite female youth soccer: Changes in neuromuscular control of the knee following soccer-specific fatigue. *Scand J Med Sci Sports*. 2015;**25**(5):e531-538. **doi:** 10.1111/sms.12355 **pmid:** 25556396
19. Smith MR, Coutts AJ, Merlini M, Deprez D, Lenoir M, Marcora SM. Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Med Sci Sports Exerc*. 2016;**48**(2):267-276. **doi:** 10.1249/MSS.0000000000000762 **pmid:** 26312616
20. Bishop D, Spencer M, Duffield R, Lawrence S. The validity of a repeated sprint ability test. *J Sci Med Sport Med Australia*. 2001;**4**(1):19-29. **doi:** 10.1016/S1440-2440(01)80004-9
21. Fleiss J. Reliability of measurement. The design and analysis of clinical experiments. New York: Wiley; 1986. p. 1–32.
22. Balsalobre-Fernandez C, Glaister M, Lockey RA. The validity and reliability of an iPhone app for measuring vertical jump performance. *J Sports Sci*. 2015;**33**(15):1574-1579. **doi:** 10.1080/02640414.2014.996184 **pmid:** 25555023
23. Gribble PA, Hertel J. Effect of lower-extremity muscle fatigue on postural control. *Arch Phys Med Rehabil*. 2004;**85**(4):589-592. **doi:** 10.1016/j.apmr.2003.06.031 **pmid:** 15083434
24. Drouin JM, Valovich-mcLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol*. 2004;**91**(1):22-29. **doi:** 10.1007/s00421-003-0933-0 **pmid:** 14508689

25. Zawadzki J, Bober T, Siemieński A. Validity analysis of the Biodex System 3 dynamometer under static and isokinetic conditions. *Acta Bioengineer Biomech*. 2010;**12**(4):25-32.
26. Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of injury preventive warm-up programs on knee strength ratio in young male professional soccer players. *PLoS One*. 2012;**7**(12):e50979. **doi:** 10.1371/journal.pone.0050979 **pmid:** 23226553
27. Adams R. Revised Physical Activity Readiness Questionnaire. *Canada Famil Physic Med Famil Canada*. 1999;**45**:992-1005.
28. Ben Othman A, Chaouachi A, Hammami R, Chaouachi MM, Kasmi S, Behm DG. Evidence of nonlocal muscle fatigue in male youth. *Appl Physiol Nutr Metab*. 2017;**42**(3):229-237. **doi:** 10.1139/apnm-2016-0400 **pmid:** 28177751
29. Pau M, Mereu F, Melis M, Leban B, Corona F, Ibba G. Dynamic balance is impaired after a match in young elite soccer players. *Phys Ther Sport*. 2016;**22**:11-15. **doi:** 10.1016/j.ptsp.2016.05.008 **pmid:** 27579802
30. Taylor JL, Gandevia SC. A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. *J Appl Physiol (1985)*. 2008;**104**(2):542-550. **doi:** 10.1152/japplphysiol.01053.2007 **pmid:** 18032577
31. Zech A, Steib S, Hentschke C, Eckhardt H, Pfeifer K. Effects of localized and general fatigue on static and dynamic postural control in male team handball athletes. *J Strength Cond Res*. 2012;**26**(4):1162-1168. **doi:** 10.1519/JSC.0b013e31822dfbbb **pmid:** 22446681
32. Johnston W, Dolan K, Reid N, Coughlan GF, Caulfield B. Investigating the effects of maximal anaerobic fatigue on dynamic postural control using the Y-Balance Test. *J Sci Med Sport*. 2018;**21**(1):103-108. **doi:** 10.1016/j.jsams.2017.06.007 **pmid:** 28625539
33. Attarzadeh Hosseini S, Hejazi K. The Effect of Fatigue Protocol on Dynamic Balance in Soccer Players with Functional Ankle Instability. *Australia J Basic Appl Sci*. 2013;**2013**(7):2.
34. Whyte E, Burke A, White E, Moran K. A high-intensity, intermittent exercise protocol and dynamic postural control in men and women. *J Athl Train*. 2015;**50**(4):392-399. **doi:** 10.4085/1062-6050-49.6.08 **pmid:** 25689420
35. Barone R, Macaluso F, Traina M, Leonardi V, Farina F, Di Felice V. Soccer players have a better standing balance in non-dominant one-legged stance. *Open Access J Sports Med*. 2010;**2**:1-6. **doi:** 10.2147/OAJSM.S12593 **pmid:** 24198563
36. Khan MA, Moiz JA, Raza S, Verma S, Shareef MY, Anwer S, et al. Physical and balance performance following exercise induced muscle damage in male soccer players. *J Phys Ther Sci*. 2016;**28**(10):2942-2949. **doi:** 10.1589/jpts.28.2942 **pmid:** 27821967
37. Hesari AF, Maoud G, Ortakand SM, Nodehi MA, Nikolaïdis P. The Relationship Between Star Excursion Balance Test and Lower Extremity Strength, Range of Motion and Anthropometric Characteristics. *Med Sportiva*. 2013;**17**(1):24-28.
38. Coratella G, Bellin G, Beato M, Schena F. Fatigue affects peak joint torque angle in hamstrings but not in quadriceps. *J Sports Sci*. 2015;**33**(12):1276-1282. **doi:** 10.1080/02640414.2014.986185 **pmid:** 25517892
39. Greig M. The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors. *Am J Sports Med*. 2008;**36**(7):1403-1409. **doi:** 10.1177/0363546508314413 **pmid:** 18326034
40. Garrett WE, Jr., Califf JC, Bassett FH, 3rd. Histochemical correlates of hamstring injuries. *Am J Sports Med*. 1984;**12**(2):98-103. **doi:** 10.1177/036354658401200202 **pmid:** 6234816
41. Rahnama N, Reilly T, Lees A, Graham-Smith P. Muscle fatigue induced by exercise simulating the work rate of competitive soccer. *J Sports Sci*. 2003;**21**(11):933-942. **doi:** 10.1080/0264041031000140428 **pmid:** 14626373
42. Olyaei GR, Hadian MR, Talebian S, Bagheri H, Malmir K, Olyaei M. The effect of muscle fatigue on knee flexor to extensor torque ratios and knee dynamic stability. *Arabian J Sci Engineer*. 2006;**31**(2):121-127.