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Section I – Kinesiology

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Changes in Injury Risk Mechanisms After Soccer-Specific Fatigue in Male Youth Soccer Players

by
Michal Lehnert[1], Mark De Ste Croix[2], Zuzana Xaverova[1], Michal Botek[1], Renata Varekova[1], Amr Zaatar[1], Ondrej Lastovicka[1], Petr Stastny[3]

The aim of this study was to examine the acute effects of soccer specific fatigue on muscular and neuromuscular function in male youth soccer players. Elite soccer players ($n = 20$; age 15.7 ± 0.5 y; body height 177.75 ± 6.61 cm; body mass 67.28 ± 8.29 kg) were measured before and after soccer specific exercise (SAFT^{90}). The reactive strength index (RSI) was determined by a drop jump test, leg stiffness (LS) by a 20 sub-maximal two-legged hopping test, and a functional hamstring to quadriceps strength ratio from isokinetic concentric and eccentric strength of the dominant and non-dominant leg (measured at angular velocities of 1.05 rad · s^{-1} and 3.14 rad · s^{-1}). Metabolic response to the SAFT^{90} was determined by blood lactate and perceived exertion was assessed by the Borg scale. After simulated match play, a significant decrease in absolute LS ($t = 4.411$; $p < 0.001$; $\omega^2 = 0.48$) and relative LS ($t = 4.326$; $p < 0.001$; $\omega^2 = 0.49$) was observed and the RSI increased significantly ($t = 3.806$; $p = 0.001$; $\omega^2 = 0.40$). A reduction in LS found after the SAFT^{90} indicates possible reduction in dynamic knee stabilization. However, if we consider the changes in other observed variables, the present study did not clearly confirm that fatigue induced by a soccer specific protocol increased the risk of ACL and hamstring injury. This may be attributed to the simulated rather than actual match play used in the present study.

Key words: *leg stiffness, reactive strength, neuromuscular function, isokinetic, ACL.*

Introduction

Currently in soccer, player's strength, speed, agility and endurance are considered important components in terms of being able to perform effectively in both offensive and defensive phases (Bravo et al., 2008; Maly et al., 2014). Moreover, strength of the lower limbs correlates to match activity of the players, specifically the players with greater muscle strength and power express lower performance decrements during the final stages of the game (Lipinska and Szwarc, 2016; Mikołajec et al., 2012; Silva et al., 2013). Strength of knee flexors and extensors and their ratio have also been identified as an important parameter in injury risk of the lower extremities (Hughes and Watkins, 2006; Proske et al., 2004). In soccer players aged 16-18 years, injuries of the lower extremities account for 70% of all leg injuries (Rumpf and Cronin, 2012). The most common lower extremity injuries in soccer include those of the knee joint and hamstrings (Pfirrmann et al., 2016; Woods et al., 2004). With regard to the knee joint, injuries frequently affect the anterior cruciate ligament (ACL) and the medial collateral ligament (Wetters et al., 2016) with the ACL being the most frequently injured knee joint ligament (Moses et al., 2012). The incidence of ACL and muscle injuries is higher in the final stages of soccer game, which coincides with the presence of

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[1] - *Palacky University Olomouc, Faculty of Physical Culture, Department of Sport, Olomouc, Czech Republic.*
[2] - *University of Gloucestershire, Exercise and Sport Research Centre, School of Sport and Exercise, Gloucester, United Kingdom.*
[3] - *Charles University, Faculty of physical education and Sport, department of Sport games, Czech Republic.*

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muscle fatigue (Ekstrand et al., 2010).

In previous studies (Dai et al., 2014; Hughes and Watkins, 2006), mechanisms related to ACL and hamstring injuries have been identified, and it is suggested that the deficit in muscle strength of the knee flexors and extensors and increased ipsilateral muscle strength imbalance due to neuromuscular fatigue are associated with etiological factors of ACL injuries (Hughes and Watkins, 2006) and hamstring strain injuries (Woods et al., 2004). Hamstring strains occur especially during eccentric actions during the latter part of the swing phase of sprinting (before foot contact with the surface) when the muscle tension is maximal to stabilize the knee; the risk of this injury also increases as a consequence of muscle deficit due to fatigue (Mair et al., 1996).

Knee joint stability and injury protection also rely on adequate feedback and feed-forward systems to improve muscular stiffness and consequently lower limb stiffness during functional tasks (Riemann and Lephart, 2002; Maszczyk, et al. 2018). Muscular stiffness is an important component of lower limb stiffness and includes the ability of muscles to resist movement within the tibiofemoral joint (tibiofemoral shear movements), which prevents passive structures of the knee, such as the ACL, to be under strain (Hughes and Watkins, 2006). Thus, lower limb stiffness as an injury protection mechanism is another significant indicator of ACL injuries especially when fatigue is present. Information about lower limb stiffness is particularly important in terms of risk of injuries resulting from impact after a jump or change of direction (Oliver and Smith, 2010). Fatigue may also lead to changes in reactive strength of leg muscles (Toumi et al., 2006), which may be assessed by means of the reactive strength index (RSI). The RSI represents an individual ability of transition from eccentric to concentric muscle contraction during the stretch-shortening cycle and is determined for monitoring stress exerted on the muscle-tendon complex during plyometric exercise.

The results of the above-mentioned studies suggest that screening in youth athletes has the potential for being effective in reducing injuries in team sports (Dallinga et al., 2012). Nevertheless, there are only a few studies dealing with changes in muscle strength, muscle imbalance and the RSI as a result of fatigue, especially focusing on adolescent male and female soccer players (De Ste Croix et al., 2015; Lehnert et al., 2016; Toumi et al., 2006). Therefore, this study aimed to examine the acute effects of soccer specific fatigue on muscular and neuromuscular functions in male youth players. We hypothesized that soccer-specific fatigue would have negative effects on the observed variables in elite youth soccer players.

Methods

Participants

The study involved a group of elite youth soccer players (n = 20; age 15.7 ± 0.5 years; body height 177.75 ± 6.61 cm; body mass 67.28 ± 8.29 kg). All tested players were fully informed about the aim of the study and the testing procedures that would be employed. The leg preferred for kicking was considered the dominant leg (DL) and the contralateral leg as the nondominant leg (NL). The study was approved by the institution's ethics committee and conformed to the Declaration of Helsinki regarding the use of human subjects. Written informed consent to the testing procedures and the use of the data for further research was obtained from the players' parents. Players completed a health questionnaire prior to participation in order to be included in the research. The day before testing, the players were not exposed to any training loads.

Procedures

During the first session, a week before testing, the players underwent anthropometric measurements, familiarisation with the fatigue protocol and isokinetic dynamometry. During the second session, before testing started, the players completed nonspecific warm-up exercises, which included cycling on a stationary bicycle ergometer for 5 min at 1.5 W/kg, dynamic stretching exercises for six minutes, which targeted the main muscle groups involved during testing, and finally fifteen squats. The warm-up routine was performed under the supervision of the researcher. The subsequent testing procedure consisted of measuring reactive strength, leg stiffness and isokinetic strength. Afterwards the players performed the soccer specific fatigue protocol (SAFT^{90}). Immediately after its completion the tests were repeated in the same order.

Reactive strength

The reactive strength index (RSI) was determined by means of a drop jump test with hands on the hips. Vertical jump performance was assessed using a portable optical timing system Optojump Next (Microgate, Bolzano, Italy) with manufacturer-declared accuracy of 0.001 s. The players jumped from a 30 cm box in order to perform a maximum jump for the shortest period of take-off (Dalleau et al., 2004). To familiarize the players with testing, two trials were performed followed by three measured attempts and there was a 30 s rest interval between the sets. The greatest value recorded from the three attempts was used for further analysis. The RSI was calculated as the ratio between jump height and contact time on the floor (Flanagan and Comyns, 2008).

Leg stiffness

To determine stiffness of the lower limbs, all players performed one trial set and two measured sets of 20 sub-maximal two-legged hopping tasks using an Optojump next system (Microgate, Bolzano, Italy) with hands on the hips and the torso in an upright position. The frequency of hopping was maintained at 2.5 Hz by using a mechanical metronome (Wittner GmbH & Co. KG, Isny, Germany). Of the two sets performed, the set in which the frequency of jumps corresponded most closely to the frequency determined by the metronome was selected. From this set for further analysis the ten consecutive jumps that were closest to the determined frequency of hopping were used (Lloyd et al., 2009). There was a 1 min rest interval between the sets. Both absolute leg stiffness (ALS; $kN \cdot m^{-1}$) and relative leg stiffness (RLS; $kN \cdot m^{-1}$), i.e. normalization of absolute muscle stiffness according to leg length and body mass, were calculated (Dalleau et al., 2004).

Isokinetic dynamometry

Strength of the dominant and non-dominant leg during concentric and eccentric action of the knee flexors and of the concentric action of the knee extensors was measured using an isokinetic dynamometer IsoMed 2000 (D. & R. Ferstl GmbH, Hemau, Germany). The reproducibility for the IsoMed 2000 dynamometer in measuring concentric and eccentric knee extension has been reported as being high (Dirnberger et al., 2012). Players were tested in a sitting position with a hip angle of 100°. For fixation of the pelvis and thigh of the tested leg, fixing straps were used; the shoulders were fixed by shoulder pads in the ventral-dorsal and cranial-caudal direction. The participants were instructed to hold the handgrips located at the side of the seat during all testing. The axis of rotation of the dynamometer was aligned with the axis of rotation of the knee (lateral femoral epicondyle). The arm of the dynamometer lever was fixed to the distal part of the shin and the lower edge of the shin pad was placed ≈2 cm over the medial apex malleolus.

A static gravitational correction was applied according to the manufacturer's instructions. The testing range of motion was 80° and was set from 10 to 90° of knee flexion (with 0° = full voluntary extension). The testing protocol was conducted at angular velocities of $1.05\ rad \cdot s^{-1}$ and $3.14\ rad \cdot s^{-1}$ in a concentric and eccentric single action of knee flexion (e.g. no reciprocal action) and angular velocities of $1.05\ rad \cdot s^{-1}$ and $3.14\ rad \cdot s^{-1}$ in a concentric single action of knee extension. Slow velocity preceded higher velocity and concentric action preceded eccentric action. The testing protocol consisted of two contraction sets (specific warm-up and testing) of each test with a rest period of 1 min between the tests. In the first warm-up set, the players performed 4-5 trials with a progressive increase in muscle action until a maximum action was performed. After a 30 s rest the players performed a set of 3 maximum repetitions. During the testing procedure the players were provided with concurrent visual feedback in the form of an isokinetic strength curve displayed on the dynamometer monitor and accompanied by verbal encouragement to push as hard and as fast as possible (concentric mode) or to resist as hard as possible (eccentric mode) to ensure maximum effort. The right leg was measured first; the rest period between measurements of the legs was 3 min. For the assessment of changes in isokinetic strength, absolute peak torque (PT; N·m) was monitored and further used to calculate the hamstring eccentric-to-quadriceps concentric functional ratio (H/Q_{FUNC}) using the PT value.

Blood Lactate sampling and analysis

Blood lactate was sampled at rest and two minutes after completion of the $SAFT^{90}$ protocol. Before collecting the sample, the finger was cleaned using an alcohol wipe in order to make the area clean and free of sweat. The skin was punctured with a lancet and the first blood drop was wiped away, while the second drop was analysed using a blood analyser Lactate Scout+ (EKF, Germany). The instrument's accuracy was checked before sampling according to the manufacturer's guidelines.

Psychometric analysis

Immediately after the end of the SAFT^{90}, each soccer player was asked to score the subjective feelings of fatigue using the rating of perceived exertion (RPE) scale developed by Borg (Borg, 1982). The scale ranged from 6 (no exertion at all) to 20 (maximum exertion).

Fatigue protocol

The fatigue protocols are common in team sport games, where those protocols contain the loading time and rest time according to the tested discipline (Hůlka et al., 2017). The SAFT^{90} was created according to data from English Championship matches (Prozone®) and was validated to replicate the fatigue response of a soccer match play (Small et al., 2010).

Table 1

Isokinetic strength, reactive strength and leg stiffness characteristics before and after the soccer specific fatigue protocol.

Variable	Pre-fatigue	Post-fatigue	
	Mean ± SD	Mean ± SD	% Change
Peak torque (N·m)			
Q Con 1.05 DL	211.87 ± 45.54	204.72 ± 49.11	-3.3
Q Con 3.14 DL	179.12 ± 30.12	177.73 ± 35.17	-0.3
Q Con 1.05 NL	197.04 ± 44.93	193.03 ± 41.82	-2.0
Q Con 3.14 NL	165.94 ± 34.12	168.24 ± 38.71	2.0
H Con 1.05 DL	144.14 ± 22.39	142.77 ± 23.60	-0.2
H Con 3.14 DL	170.20 ± 27.30	163.88 ± 26.15	-3.6
H Con 1.05 NL	138.53 ± 31.79	133.20 ± 29.80	-3.5
H Con 3.14 NL	160.64 ± 30.68	155.98 ± 24.60	-2.5
H Ecc 1.05 DL	157.37 ± 34.27	149.43 ± 30.00	-4.8
H Ecc 3.14 DL	187.66 ± 26.56	181.76 ± 24.22	-2.8
H Ecc 1.05 NL	149.22 ± 35.13	134.84 ± 28.26	-9.5
H Ecc 3.14 NL	181.22 ± 25.63	177.95 ± 25.21	-5.7
H/Q$_{FUNC}$			
1.05 DL	0.75 ± 0.11	0.75 ± 0.17	0
3.14 DL	1.05 ± 0.11	1.04 ± 0.12	-4
1.05 NL	0.75 ± 0.11	0.75 ± 0.11	0
3.14 NL	1.05 ± 0.18	1.10 ± 0.18	10
RSI	0.40 ± 0.07	0.43 ± 0.06**	7.5
ALS	27.17 ± 4.41	24.81 ± 4.12**	-8.1
RLS	34.89 ± 5.54	31.81 ± 4.63**	-6.4

SD – standard deviation; Q – quadriceps; H – hamstrings; Con – concentric action; Ecc – eccentric action; DL – dominant leg; NL – non-dominant leg; H/Q$_{FUNC}$ – isokinetic hamstrings eccentric-to-quadriceps concentric functional ratio; 1.05, 3.14 – angular velocities; RSI – reactive strength index; ALS – absolute leg stiffness; RLS – relative leg stiffness; $*p < 0.05$; $**p < 0.01$.

Duration of the fatigue protocol (2 x 40 min, 15 min half) matched the regular time of a competitive match of the corresponding age category according to the current rules of the Football Association of the Czech Republic. The movement intensity and activity during the test were maintained using verbal signals from an MP3 player, i.e. a modified 15 min sequence of commands constantly changing on both ends of the track.

Statistical analyses

Descriptive statistics (means, medians and standard deviations) were calculated for all variables. The distributions of the data sets were checked using the Kolgomorov-Smirnov test. One-sample t-tests were used to examine whether the soccer specific fatigue protocol led to significant changes in the variables observed. The effect size was determined by the ω^2 coefficient and evaluated as small (0.01 – 0.05), medium (0.06 – 0.13) and large (0.14 and greater) (Vincent, 2005; Maszczyk et al., 2014). The level of significance was set at $p < 0.05$. Statistical analysis was performed using the data analysis software system Statistica, version 12 (StatSoft, Inc., Tulsa, USA).

Results

The values for the variables measured before and after the fatigue protocol are reported in Table 1. No significant change was found in PT for concentric and eccentric muscle actions at any angular velocity. Similarly, a comparison of $H/Q_{FUNC\_1.05}$ and $H/Q_{FUNC\_3.14}$ before and after the fatigue protocol did not reveal any significant changes. The RSI increased significantly ($t = 3.806$; $p = 0.001$; $\omega^2 = 0.40$) after the SAFT^{90}. Conversely, muscle fatigue induced through the fatigue protocol was associated with a significant decrease in absolute leg stiffness ($t = 4.411$; $p < 0.001$; $\omega^2 = 0.48$) and relative leg stiffness ($t = 4.326$; $p < 0.001$; $\omega^2 = 0.49$).

Discussion

The main finding of the study was that the SAFT^{90}, which was designed as a soccer-specific match simulation protocol, did not induce significant changes in muscular control (isokinetic strength of the hamstrings and quadriceps and H/Q_{FUNC} ratio); however, it impaired absolute leg stiffness and relative leg stiffness.

Peak torque

The SAFT^{90} did not induce significant changes in strength of knee flexors (concentric and eccentric action) and knee extensors (concentric action). We only observed a trend towards reduction in $PT_{H\ Ecc180\ DL}$ by 3.1% ($p = 0.06$), $PT_{Q\ Con60\ DL}$ by 3.3% ($p = 0.08$), $PT_{H\ Con180\ DL}$ by 7% ($p = 0.09$), $PT_{H\ Ecc\ 60\ DL}$ by 5% ($p = 0.08$) and $PT_{H\ Con\ 180\ NL}$ by 2.9% ($p = 0.11$). This finding suggests that after the SAFT^{90} the players did not increase the risk of injury due to muscle strength loss and deterioration of the stabilization function of the knee muscles.

Unfortunately, it is not possible to compare our results with findings of similar fatigue studies as data are only available from male adult players. In one of these studies (Greig, 2008), the author observed no effect of a 90 min treadmill protocol replicating the activity profile of soccer match-play except eccentric hamstring PT, which was impaired at all of the measured velocities (1.05, 3.14, and 5.25 rad · s^{-1}) with significant reduction at the two highest velocities. Similarly, in a newer study (Small et al., 2010), only eccentric hamstrings peak torque decreased significantly (16.8%) at a velocity of 2.1 rad · s^{-1}.

On the contrary, there are studies where a significant reduction in both quadriceps and hamstrings PT was found either following a soccer specific protocol in male amateur players (Rahnama et al., 2003) or following soccer game modelling in university students (Robineau et al., 2012). This conflicting data and in particular the absence of studies focusing on the assessment of changes in muscle strength in youth athletes in a fatigue state suggest that more studies are needed in which important production mechanisms will be examined.

H/Q_{FUNC}

The average value of the $H/Q_{FUNC\_1.05}$ in our players in both measurements exceeded the value of 0.7, which from an injury perspective some authors consider a risk threshold (Yeung et al., 2009). However, others (Coombs and Garbutt, 2002) report that at an angular velocity of 1.05 rad · s^{-1} a ratio of 1.0 indicates adequate joint stability and that in such a case the risk of the ACL, hamstring and soft tissue injury is reduced. The SAFT^{90} did not induce significant changes in $H/Q_{FUNC\_1.05}$ and $H/Q_{FUNC\_3.14}$ in either the DL or NL. Considering that H/Q_{FUNC} expresses the ability of the knee flexors to slow down the movement conducted by the quadriceps and that the significance of flexor activity increases with increasing angular velocity of movement (Coombs and Garbutt, 2002), we suggest that after the SAFT^{90} the stability of the knee joint during the implementation of soccer-specific movements did not change.

Our finding does not support the suggestion that one of the reasons for hamstring injuries in a fatigue state is that the hamstrings have more rapid fast-twitch fibres than the quadriceps (Garrett et al., 1984) and therefore are more prone to fatigue during prolonged work. Some authors suggest that this difference leads to an imbalance that could also increase the risk of injury during eccentric contraction at maximum acceleration when the limit of muscle tissue is exceeded (Wright et al., 2009). Neither of the results supports the findings concerning a greater loss of hamstring strength in eccentric action compared with concentric (Greig, 2008; Rahnama et al., 2003).

Our result is in agreement with the results of a recent study (Lehnert et al., 2016) on elite male youth soccer players aged 14.4 ± 0.5 y, where the data showed no fatigue related change in the H/Q$_{\text{FUNC}}$ after completing the SAFT^{90}. Our result can be also compared with that of a study on female youth soccer players (De Ste Croix et al., 2015), where muscle control was compromised in U13, unchanged in U15 (similar age to the current study's sample) and improved in U17 categories following a soccer specific fatigue protocol. This result and also the one of our study could be justified by the improvements of neuromuscular mechanisms with maturation (Dotan et al., 2012) and possibly with training experience. Older children may have better motor unit synchronization, greater rate coding of higher threshold motor units (especially with regard to eccentric actions), and overall enhanced volitional muscle activation (Dotan et al., 2012). Thus, older children may have a greater capacity to call upon a combination of these mechanisms, when in a fatigued state, and this may result in more effective muscular control.

Beside the results of PT and H/Q$_{\text{FUNC}}$ also the mean post-test blood lactate concentration (1.72 ± 0.32 mmol · L^{-1}) did not significantly (p =0.687) differ from its pre-testing level (1.82 ±0.98 mmol · L^{-1}) and the mean of the RPE score was equal to only 11.6 ± 2.09 points. In a previous study (Lovell et al., 2008) blood lactate of 4.7 mmol · L^{-1} and of 4.0 mmol · L^{-1} was measured after the first half and the second half of the SAFT^{90} in semi-professional adult soccer players. Similarly, in a previous comprehensive review (Stølen et al., 2005) the authors reported that the mean blood lactate concentration after the second half of the soccer match ranged from 3 to 7 mmol · L^{-1} in professional players. One of the reasons of this discrepancy could be partly explained by the difference in anthropometric characteristics (elite youth players: body height 177.8 ± 6.6 cm; body mass 67.3 ± 8.3 kg, adult semi-professional players: body height 184.8 ± 6.6 cm; body mass 78.3 ± 5.4 kg), which could influence physical demands during specific movements, especially during changing of direction and acceleration/deceleration. Similar weight differences between youth and adult professional soccer players have been found recently (Botek et al., 2016). Therefore, based on our results, it seems that the SAFT^{90} applied in elite youth soccer players did not represent a high enough intensity of exercise to produce high lactate concentrations, RPE response and a decrease in muscular control. Thus, we suggest for highly trained youth soccer players with a relatively lower body mass, a more demanding fatigue protocol. The squad-specific simulation with a more demanding activity profile should be used to replicate in particular physiological demands of match play (Barrett et al., 2013).

Reactive strength

With regard to the RSI, the results showed that the stress exerted on the muscle-tendon complex during plyometric exercise did not increase after the SAFT^{90}. On the contrary, an increase of the RSI by 7.5% was observed. Our finding is somewhat surprising, in particular if we consider the changes in leg stiffness. However, one previous study (Lloyd et al., 2011) indicated that the RSI demonstrated a limited amount of common variance with leg stiffness. The authors also suggested that in maximum hopping (as used to determine the RSI), stiffness was closely connected with maximum power and therefore the ability to recruit motor units was more influential.

If we consider the high influence of knee extensor strength on jump height (Rodacki et al., 2002), and also the high correlation between maximum strength of the leg muscles and vertical jump performance (Wisløff et al., 2004), then this result could be to some extent explained by the finding that quadriceps PT did not significantly decrease after finishing the $SAFT^{90}$. Besides, studies dealing with the effect of age on the results of the RSI (Lloyd et al., 2011) point to gradually improving results during adolescence. However, findings of the current study differ from the recent study (Lehnert et al., 2016) where reactive strength and also leg stiffness were both compromised ($p < 0.001$) after the $SAFT^{90}$. One possible explanation of our findings is that the results could be influenced by insufficient familiarization with this test because the drop jump was not included in the familiarization session and only two trials as a familiarization preceded measured attempts.

Stiffness

The results of our study showed a significant decrease ($p < 0.05$) in absolute and relative leg stiffness after a fatigue protocol (Table 1). The effect size values ($\omega^2 = 0.48$ in both cases) point to a large effect of the fatigue protocol on both absolute and relative leg stiffness. These results suggest that the fatigue protocol compromised neuromuscular pre-activation and neuromuscular feed-forward control as an important indicator of dynamic stability of the knee (Hughes and Watkins, 2006). The reduction in stiffness by 14.3% and 8.6%, respectively, indicates longer ground contact times and a likely shift in the neural control to a lower contribution from pre-activation and short latency stretch reflexes. This in turn is likely to lead to more of a yielding action with an increase in the centre of mass displacement during ground contact and subsequently an increase in the excessive load of the knee passive structures such as the ACL, and consequently an increase in the relative risk of injury, especially during landing (De Ste Croix et al., 2015; Hughes and Watkins, 2006). These findings replicate results from a previous study where leg stiffness (both absolute and relative) was compromised ($p < 0.001$) after a soccer specific fatigue protocol (Lehnert et al., 2016). Our results can be also compared with those of another recent study (Oliver et al., 2014) in which muscle stiffness was determined in 15-year-old soccer players. The authors reported a non-significant decrease in terms of absolute muscle stiffness after a fatigue protocol, but this might be attributed to the fact that they used a soccer-specific intermittent exercise test performed on a non-motorised treadmill and the duration of the test only corresponded to one half of simulated match play. The finding of the current study is also in agreement with some studies on adults (Avela and Komi, 1998; Kuitunen et al., 2002), while the results of other studies on adult players (Hunter and Smith, 2007; Morin et al., 2006) showed non-significant changes in lower limb stiffness after completing a fatigue protocol. In one study on adult players (Hunter and Smith, 2007), the authors pointed out that changes in muscle stiffness were highly individual. The observed significant decrease only in leg stiffness following the $SAFT^{90}$ fatigue protocol and at the same time a low level of post-test blood lactate concentration suggest that leg stiffness is more sensitive to soccer-specific fatigue than other studied parameters i.e. PT, H/Q_{FUNC} and RSI.

One of the limitations of the study is that the indicators of neuromuscular fatigue were measured only after the fatigue protocol and not during the half time (Ekstrand et al., 2010). Another limitation of isokinetic testing is that the functional hamstring/quadriceps ratio (H/Q_{FUNC}) should be determined during the first 30° of knee flexion as this is the joint angle where injury is most likely to occur (Ayala et al., 2012). This study refers to H/Q_{FUNC}, but muscle co-activation in the knee area depends also on thigh muscle strength ratios to hip abductors (Stastny et al., 2015, 2016), which was not taken into account in the present analyses.

Conclusions

We may conclude that the $SAFT^{90}$ fatigue protocol, which simulates the work rate in soccer, induced a significant reduction in leg stiffness. However, PT of the knee flexors and extensors and their ratio did not decrease significantly, and surprisingly the RSI increased significantly. Therefore, our hypothesis was partly confirmed by a reduction in leg stiffness, and thus potentially compromised the stretch shortening cycle capability. However, as hamstring and quadriceps strength did not decline, and the RSI increased, we could conclude that our data do not support the hypothesis that soccer specific fatigue compromises muscular capability in youth soccer. A reduction in leg stiffness found in our group of players indicates an increased risk of lower limb injury due to a reduction in dynamic stabilization of the knee; however, the present study did not confirm unequivocally that fatigue induced by a soccer specific fatigue protocol increased the risk of ACL and hamstring injury in adolescent soccer players. Furthermore, the results of the blood lactate concentration and subjective feeling of fatigue assessed using the Borg scale indicate that in our group of soccer players, the SAFT^{90} did not represent a stimulus as demanding as competitive game loads and therefore we recommend the verification of this soccer-specific fatigue protocol in a group of youth players of similar age and physical fitness.

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Corresponding author:

Petr Stastny
Charles University, Faculty of physical education and Sport, Jose Martiho 31, Prague 6, 162 52,
Czech Republic;
Cell-phone number +420 777198764
E-mail: stastny@ftvs.cuni.cz