THE EFFECT OF SOCCER MATCH INDUCED FATIGUE ON NEUROMUSCULAR PERFORMANCE

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Original scientific paper
UDC 796.332:159.944:613.8-055.1

Abstract:

The study evaluates the effect of soccer match induced fatigue on the neuromuscular performance. Prior to, during the break period between the 1st and 2nd part of the game and after the game, parameters of agility, explosive power of lower limbs, static and dynamic balance, speed of step initiation and the soccer kick were evaluated in a group of 10 soccer players. Reaction time in the agility test was measured using the FiTRO Agility Check. The task of the subject was to touch, as fast as possible, with either the left or right lower limb one of the four mattresses located in the four corners inside of a square (80 cm and 1.5 m, respectively) in accordance with the location of stimulus in one of the corners of the screen. Heights of squat jump (SJ) and countermovement jump (CMJ) were calculated from the flight time registered by the FiTRO Jumper. The same method was applied to measure contact time during a drop jump from a height of 45 cm. Postural stability was evaluated under both the static and dynamic conditions (wobble board) with the eyes open (EO) and eyes closed (EC). Velocity of the centre of pressure (COP) was registered at 100 Hz by means of the posturography system FiTRO Sway check based on a dynamometric platform. Speed of step initiation and the soccer kick were measured using the FiTRO Dyne. Results showed that after the first 45 minutes of a soccer match only dynamic balance with EC was impaired and the drop jump ground contact time increased. Its further increase was observed after the second part of the match. Along with it also the dynamic balance with EO and the agility performance in the test on a shorter (80 cm) distance between mats was affected. On the other hand, there were no pre-post match differences in the agility performance in the test on a longer (1.5 m) distance between mats, height of SJ and CMJ, speed of step initiation and soccer kick, and static balance with EO and EC. It may be concluded that soccer match induced fatigue increases the drop jump ground contact time, concomitant with the impairment of dynamic balance and agility performance when moving over a short distance. In contrast, there were no changes in the agility performance over a longer movement distance, explosive power of lower limbs, speed of step initiation, speed of the soccer kick, and static balance.

Key words: *agility, explosive power of lower limbs, reaction time, speed of the soccer kick, speed of step initiation, static and dynamic balance*

Introduction

In our previous studies (e.g., Zemková & Hamar, 2003; Zemková & Hamar, 2004; Zemková, 2005; Zemková & Hamar, 2005; Zemková, Hamar, Dzurenková, & Schickhofer, 2005; Zemková, Dzurenková, Kukurová, & Marček, 2008) functional exercise protocols were used to evaluate the effect of fatigue induced by different forms of exercise on the postural control system. However, these classical laboratory studies, with the subjects exercising continuously for more than 5 minutes on a treadmill or cycle ergometer, in many ways represent artificial situations. Nevertheless, these procedures provide standardized conditions and permit comparisons to be made of repeated measurements. They can also simulate the demands placed on the body in many sport events.

Despite many advantages of laboratory diagnostics, such exercise sessions do not reflect any specific changes in the neuromuscular system induced by a particular sport activity. Thus, from both a practical and a theoretical point of view, it is equally important to study the effect of intermittent exercise, which better reflects the type of muscular activities encountered in most types of ordinary exercise or recreational activity. Furthermore, intermittent exercise at a high intensity level is an activity pattern of many sports, such as basketball, soccer, ice hockey, and tennis, where periods of intense exertion are interspersed with periods of active or passive recovery. Therefore, in order to be closer to sport-specific exercise, simulated fatigue induced protocols have been studied.

For instance, Ribeiro, Santos, and Oliveira (2007) found that a volleyball match induced fatigue significantly changes the knee joint position sensitivity. Also, maximal voluntary contraction (MVC) and rapid muscle force characteristics (rate of force development - RFD, impulse) were acutely affected concurrently with marked reductions in muscle electromyographic (EMG) activity following a handball match (Thorlund, Michalsik, Madsen, & Aagaard, 2008).

However, more information is needed on the changes in functional performance after a game. It may be assumed that using portable computerized diagnostic systems and easily administered tests would provide actual information on an athlete´s response to such an intervention.

Therefore the aim of the study was to evaluate the effect of soccer match induced fatigue on the parameters of static and dynamic balance, agility, speed of step initiation and the soccer kick, and explosive power of the lower limbs.

Methods

Subjects

A group of 10 elite soccer players (age 21.8±1.3 years, height 178.8±2.6 cm, and weight 78.2±4.6 kg) volunteered to participate in the study. All of them were informed of the procedures and of the main purpose of the study. The procedures presented were in accordance with the ethical standards on human experimentation.

Study setting

The subject were measured 3 times, that is, prior to, during the break period between the 1st and 2nd part of the soccer match and after the game, the parameters of static and dynamic balance, agility, speed of step initiation and the soccer kick, as well as explosive power of the lower limbs were measured (Figure 1). The tests were randomly carried out by five assistants.

Test protocols and diagnostic equipments

Postural stability was evaluated under both the static and dynamic conditions (tilting platform) with both the eyes open (EO) and closed (EC). The mean velocity of the centre of pressure (COP) was registered at 100 Hz by means of the posturography system FiTRO Sway Check based on a force platform (www.fitronic.sk). The subjects stood barefoot with their feet 10 cm apart. They were instructed to minimize the postural sway by standing as still as possible. The test consisted of 2 thirty-second trials. The better result was taken for the evaluation.

Reaction time in the agility test was measured using the FiTRO Agility Check (www.fitronic.sk). The task of the subject was to touch, as fast as possible, with either the left or right lower limb one of the four mattresses located in the four corners inside of a square. Two distances between mats were used: 80 cm and 1.5 m, respectively. The mattresses had to be touched in accordance with the location of the stimulus in one of the corners of the screen. The protocol in both tests consisted of 20 stimuli while the mean of 16 best reaction times was taken for the evaluation. More information on the agility test can be found in the book of Zemková and Hamar (2009).

The speed of step initiation was measured using FiTRO Dyne Premium (www.fitronic.sk), the system based on the precise analogue velocity sensor with a sampling rate of 100 Hz. The device was anchored to the wall and its nylon tether attached to the ankle of the subject. His task was to run (1-2 steps), as fast as possible, while pulling the nylon tether of the device. The same procedure was carried out to measure the speed of the soccer kick. The task was to perform a kick as fast as possible. In both cases, the test result was the highest velocity of three trials performed with the dominant leg.

In order to assess the explosive power of the lower limbs the FiTRO Jumper (www.fitronic.sk) consisting of a special contact switch mattress connected by means of an interface to computer was used. The system measures contact and flight times (with an accuracy of 1 ms) during jumps and calculates the basic biomechanical parameters (e.g. height of the jump and power in the concentric phase of a take-off). The subjects performed a squat jump (SJ) from the full extension stance to a knee angle of 90°, a countermovement jump (CMJ) with the knees flexed at an angle of 90°, and a drop jump (DJ) from a height of 45 cm. The subjects performed all the jumps with their hands kept on the hips. Each test consisted of 3 trials. The best result was taken for the evaluation.

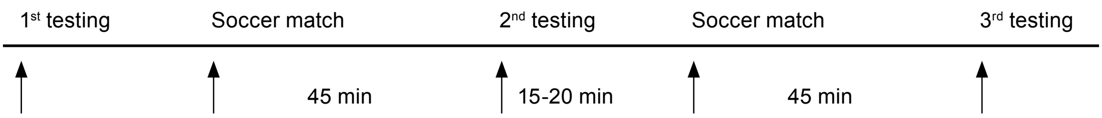

Figure 1. Schematic representation of the experimental protocol

Height of the jump was calculated as follows:

$$h = \frac{g \cdot Tf^2}{8}$$

Power in the concentric phase of a take-off was calculated as follows:

$$P_{con} = \frac{g^2 \cdot Tf \cdot (Tc + Tf)}{4Tc}$$

where Tf is flight time, Tc is contact time, and g is 9.81 ms^{-2}.

During the game the heart rate was continuously monitored by means of a SportTester (only in four subjects). A subjective level of exertion was estimated at the end of each period of the game using Borg's 6 to 20 Rating of Perceived Exertion Scale (Borg, 1970).

Statistical analysis

Basic descriptive parameters including mean and standard deviation were calculated. The Wilcoxon test was employed to determine the statistical significance of differences between the pre- and post-match values of the examined abilities, and $p \leq .05$ was considered significant.

Results

Results showed (Table 1) no differences in the sway velocity registered in the static conditions with the eyes open (EO) (from 13.2±2.2 mm/s to 13.3±2.7 mm/s and to 13.6±3.2 mm/s) and with the eyes closed (EC) (from 14.5±3.1 mm/s to 14.8±3.5 mm/s and to 15.5±3.8 mm/s). On the other hand, a significant ($p \leq .05$) increase was found in the dynamic conditions with the eyes closed (EC) after the first 45 minutes of the match (from 114.0±16.5 mm/s to 131.8±18.9 mm/s), whereas no further changes after the second 45 minutes were observed (to 128.0±20.2 mm/s). In the eyes-open condition the dynamic balance did not change after the first 45 minutes of the match (from 87.8±12.1 mm/s to 90.2±12.6 mm/s), but a significant ($p \leq .05$) increase in COP velocity after the second 45 minutes was found (to 111.4±16.2 mm/s).

Also, the reaction time in the agility test performed over a distance of 80 cm between the mats increased significantly ($p \leq .05$) only after the second half-time of the game (from 801.4±54.0 ms to 869.9±59.8 ms and to 1072.0±68.6 ms). In contrast, no changes were found in the test performed over a longer distance of 1.5 m (from 1494.0±118.2 ms to 1523.9±118.0 ms and to 1539.3±124.8 ms).

A slight decrease in the speed of step initiation (from 355.0±32.4 cm/s to 348.1±33.4 cm/s and to 341.9±34.7 cm/s) and in the speed of the soccer kick (from 498.6±35.0 cm/s to 485.9±30.2 cm/s and to 480.2±31.8 cm/s) after the match was observed.

However, the ground contact time significantly ($p \leq .05$) increased after the first half-time of the match (from .270±.045 ms to .291±.048 ms). An even greater increase ($p \leq .01$) was observed after the second 45 minutes (to .328±.068 ms).

On the other hand, Δ height of the countermovement and squat jump did not change after the soccer match (from 3.8 cm to 3.8 cm and to 3.5 cm).

According to Borg´s scale (1970) the subjects perceived the match as: somewhat hard – 13 (n=2), hard – 15 (n=5) to very hard – 17 (n=3).

Discussion and conclusions

It has been found that after the first 45 minutes of a soccer match only the sway velocity registered in the dynamic conditions with EC and the drop jump ground contact time increased. Its further increase was observed following the second 45

Table 1. Summary of the results

Test	Parameter	Results of 2nd testing	Results of 3rd testing
Bipedal stance on the stable platform (EO)	COP velocity (mm/s)	–	–
Bipedal stance on the stable platform (EC)	COP velocity (mm/s)	–	–
Bipedal stance on the wobble board (EO)	COP velocity (mm/s)	–	↑*
Bipedal stance on the wobble board (EC)	COP velocity (mm/s)	↑*	–
Agility test (distance of 80 cm among mats)	Reaction time (ms)	–	↑*
Agility test (distance of 1.5 m among mats)	Reaction time (ms)	–	–
Step initiation	Max and mean velocity (cm/s)	–	–
Soccer kick	Max and mean velocity (cm/s)	–	–
Drop jump (from the height of 45 cm)	Contact time (ms)	↑*	↑**
Countermovement and squat jumps	Δ Jump height (cm)	–	–

Legend: EO – eyes open, EC – eyes closed, COP – centre of pressure
* $p \leq .05$, ** $p \leq .01$

minutes of the game. Along with it also the dynamic balance under visual control (EO) and the agility performance when moving over a short distance of 80 cm were affected.

Contrary to this, the agility performance over a longer movement distance of 1.5 m was not affected. The soccer match has also shown not to impair static balance either with the eyes open and the eyes closed. In addition, there were no changes either in the explosive power of the lower limbs or in the speed of step initiation and the soccer kick.

With regard to our hypothesis, fatigue is responsible for the impairment of neuromuscular performance after the game. The greatest changes in the drop jump ground contact time are in agreement with the results of Gollhofer, Komi, Miyashita, and Aura (1987) and Gollhofer, Komi, Fujitsuka, and Miyashita (1987) who reported a fatigue-induced increase in the contact time with more pronounced influence on the concentric phase of stretch-shortening cycle (SSC). This effect may be ascribed to the altered sensory feedback of the periphery to the central nervous system (CNS) that could contribute to less precise stiffness regulation of the relevant muscles. Since muscle stiffness is also important in a dynamic stabilization task, these changes might affect the postural sway adjustments in altered surface conditions.

In particular, fatigue-induced proprioceptive deficits may account for the increased postural sway. Reduced sensitivity of proprioceptors rather than a loss of cutaneous mechanoreceptors sensation has been associated with deficits in the dynamic postural responses (Van Deursen & Simoneau, 1999). This effect may be attributed to their function. While cues from plantar cutaneous receptors are involved in exteroceptive functions like the evaluation of the support structure or of relative foot-to-surface motion, cues from deep receptors subserve proprioceptive functions like the control of the centre of pressure shifts within the limits of the foot support base (Maurer, Mergner, Bolha, & Hlavacka, 2001).

Indeed, clinical investigations have demonstrated (Skinner, Wyatt, Hodgdon, Conard, & Barrack, 1986) that fatigue negatively affects joint proprioception through deficiencies in the activation of the muscular mechanoreceptors. Stimulation of the Meissner and Pacinian endings has been found (Hollins & Roy, 1996) to influence activation of the muscle spindles. Experiments in animals showed (Nelson & Huton, 1985; Pedersen, Ljubislavlevic, Bergenheim, & Johansson, 1998) impairment of their sensitivity by prolonged exercise, possibly under the influence of several metabolites and inflammatory substances (Pedersen, et al., 1998), or via the modulation of reflex pathways originating from small-diameter muscles afferents (namely, group III and IV afferents) (Bigland-Ritchie, Dawson, Awson, Johansson, & Lippold, 1986).

The decrease in proprioceptive input is known to decrease postural reflexes, resulting in altered balance. More specifically, Latash (1998) states that monosynaptic reflexes are affected by neuromuscular fatigue, whereas polysynaptic reflex mechanisms are not. Both reciprocal inhibition, as well as the time course of the reformation of intrafusal cross-bridge links may explain the depression of the monosynaptic stretch reflex (Gollhofer & Rapp, 1993). A delay in reflex responses might contribute to the increase in sway velocity during stance on an unstable platform with the body drift over larger displacements before corrective feedback mechanisms are applied.

However, an increase in postural sway under EC conditions after the soccer match indicates not only a change in the sensory inflow but also in the central processing of proprioceptive input. It has been shown (Hagbarth & Macefield, 1995) that muscle fatigue induces a depression in the spindle afferent fibre discharge, possibly due to a decrease in the γ-motoneurone activation. The gamma spindle system is known to facilitate the alpha motoneurons that control slow-twitch fibres. These fibres are involved in the maintenance of balance (Johnson, Polgar, Weightman, & Appleton, 1973), which may be corroborated by a correlation between the centre of pressure displacement and the activity of soleus muscle (Nardone, Tarantola, Galante, & Schieppati, 1998).

More specifically, the calf muscles play an important part as prime postural muscles in the anterior shift of the COP (Panzer, Bandinelli, & Hallett, 1995), whereas the increase in mediolateral displacement results from the increase in muscle latency of the peroneals (Douris, 1993). In this cohort, Konradsen and Bohsen Ravn (1991) found a high degree of correlation (r=.92) between delays in peroneal muscle reaction time (onset of EMG following sudden ankle inversion) and increases in postural sway amplitude. This delay in peroneal reaction time is associated with a delay of the muscular force generation, which is similar to the electromechanical delays in force generation seen with muscular fatigue (Häkkinen & Komi, 1983; Hortobagyi, Lambert, & Kroll, 1991). Delays in muscle force generation may be the mechanism described by Tropp, Ekstrand, and Gillquist (1984) that leads to greater postural sway and results in ankle joint injury during the game. In other words, if the forces required for the correction of an unstable placement of the foot are delayed due to fatigue, then the ankle joint would be at risk of injury.

It is therefore possible that a reduction in muscle force was not the mechanism that produced greater postural sway in the present study, which may be corroborated with only a slight decrease in the height of SJ and CMJ after the game. Though this finding is in agreement with several authors (e.g. Kernell & Monster, 1982), others (e.g. Tropp, 1986; Lentell, Katzman, & Walters, 1990; Lundin, Feuerbach, & Grabiner, 1993) have reported that a decrease in the force/power output influences postural sway. The reason for this may be that the effect depends on the level of fatigue and the type of preceding exercise.

This may also explain why soccer match induced fatigue did not affect the static balance. In such a case, small perturbations are attenuated by the ankle strategy by the stretch reflex (Yaggie & McGregor, 2002). According to Schieppati and Nardone (1999) group II spindle afferent fibres are responsible for the late part of stretch reflex in the lower limb postural muscles. The length signals coming from the less adaptable spindle secondaries provide an appropriate input to the CNS for detecting low-frequency displacements occurring mainly around the ankle (Gurfinkel, Ivanenko, Levik, & Babakova, 1995) and for triggering foot and calf muscle reflex responses (Schieppati, Nardone, Siliotto, & Grasso, 1995). Any increase in postural sway may indicate that compensatory mechanisms, e.g. increased reflex activity in muscle spindles or increased muscle stiffness due to fatigue were used for the postural control (Adlerton & Moritz, 1996). Another reason may be the testing duration of about 15-20 minutes after the cessation of the game. As recovery progressed, the response from type III and IV muscle afferents may have increased, yielding an increase in somatosensation. The increase in proprioceptive input may have increased reflexive postural responses resulting in a better maintenance of balance. It is therefore likely that as the muscle spindles recovered from fatigue, they were able to compensate for the altered postural sway after the soccer match. Milner-Brown, Mellenthin, and Miller (1986) found a shorter recovery time for the ankle (1.5 min) than for the knee musculature (5.9 min).

The recovery time may also partly explain lack of any pre-post match differences in the speed of the soccer kick and the step initiation. However, our results are in the disagreement with those of Kellis, Katis, and Vrabas (2006) who found that the velocity of the ball and the ball/foot speed ratio significantly decreased after a 90 min intermittent exercise protocol that simulates soccer game conditions. According to the authors this could be attributed to alterations of the function of the neuromuscular system and force generation capacity, possibly altering the mechanics of the soccer kick. Moreover, Apriantono, Nunome, Ikegami, and Sano (2006) documented that not only the ability to generate force and speed during kicking but also inter-segmental coordination is affected by leg muscle fatigue. However, as mentioned previously, we did not find any changes in the height of the SJ and CMJ, indicating no reduction in strength after the match.

Lack of changes in the speed of step initiation after the game may in part explain the fact that there was no impairment of agility performance with a longer movement distance. Based on this assumption, the post-match increase in reaction time in the agility test performed over a shorter movement distance may be very probably due to impairment of perception (stimulus detection) and perhaps the decision stage (response selection) of the agility task. This indicates that besides proprioceptive function also central processing might be affected by soccer match induced fatigue.

As a consequence of longer ground contact time, loss of dynamic balance and agility may increase the risk of injuries. Ankle sprains and rupture of the anterior cruciate ligament (ACL) are examples of the most serious injuries in players. These injuries occur mostly at the end of the match, which raises the possibility that muscular fatigue at the ankle and knee joints would place them at a greater risk of injury.

Soccer match induced fatigue increases drop jump ground contact time, concomitant with the impairment of dynamic balance and agility performance when moving over a short distance. On the other hand, there are no changes in agility performance over a longer movement distance, explosive power of the lower limbs, speed of step initiation and the soccer kick, and static balance.

These findings indicate that the usage of portable computerized diagnostic systems and easily administered tests may provide actual information on the changes in functional performance after the game, namely in dynamic balance, agility and explosive power of the lower limbs. However, more sensitive and specific tests are needed to evaluate the speed of step initiation and the soccer kick in well-trained soccer players.

Acknowledgements

This project was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (No. 1/0611/08).

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Submitted: December 12, 2008
Accepted: November 26, 2009

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UTJECAJ UMORA NA ŽIVČANO-MIŠIĆNU UČINKOVITOST NAKON IGRANJA NOGOMETNE UTAKMICE

Istraživanje procjenjuje utjecaj umora, uzrokovanog igranjem nogometne utakmice na živčano-mišićnu učinkovitost. Parametri agilnosti, eksplozivna snaga donjih ekstremiteta, statična i dinamična ravnoteža, brzina prvoga koraka i brzina udarca po nogometnoj lopti izmjereni su na skupini od 10 nogometaša prije utakmice, u poluvremenu utakmice i nakon nogometne utakmice. Brzina reakcije u *Agility testu* mjerena je pomoću FiTRO *Agility* instrumentarija. Ispitanici su trebali, bilo kojom nogom, što brže dotaknuti jednu od četiri strunjače postavljene u kutovima kvadrata 80 x 80 cm, odnosno 1,5 x 1,5 m u skladu s reakcijom na vizualni podražaj sa semafora. Visina skoka u testovima skok iz čučnja i skok iz čučnja s pripremom izvedena je iz vremena leta, registriranoga pomoću uređaja FiTRO *Jumper*. Isti se sustav koristio za mjerenje vremena kontakta s podlogom tijekom izvedbe dubinskog skoka s povišenja od 45 cm. Ravnoteža je mjerena u statičnim i dinamičnim uvjetima na balans dasci pod vizualnom kontrolom i bez nje (ispitanikove oči otvorene i zatvorene). Brzina osciliranja težišta u testovima ravnoteže mjerena je posturografskim sustavom FiTRO *Sway check*, postavljenim na dinamometrijsku platformu. Brzina prvoga koraka i brzina simuliranog nogometnog udarca po lopti mjerene su pomoću aparature FiTRO *Dyne*. Rezultati su pokazali da je prvih 45 minuta nogometne utakmice dovelo samo do smanjenje uspješnosti u održavanju dinamične ravnoteže zatvorenim očima i do povećanja vremena kontakta s podlogom u dubinskom skoku. Vrijeme kontakta s podlogom također se pruduljilo i nakon drugog dijela nogometne utakmice. Nakon drugog poluvremena utakmice zabilježeni su slabiji rezultati u održavanju dinamične ravnoteže s otvorenim očima i u testu agilnosti kretanjem na kraćoj udaljenosti (80 x 80 cm). S druge strane, u testovima agilnosti na većoj udaljenosti (1,5 x 1,5 m), visini skoka iz čučnja i visini skoka iz čučnja s pripremom, brzini prvoga koraka i brzini nogometnog udarca te održavanju statične ravnoteže otvorenim i zatvorenim očima nije bilo statistički značajne razlike prije i nakon nogometne utakmice. Zaključeno je da umor nakon odigrane nogometne utakmice povećava vrijeme kontakta s podlogom u dubinskim skokovima popraćeno smanjenjem uspješnosti u održavanju dinamične ravnoteže i agilnosti pri kretnjama na malim udaljenostima. Naprotiv, nisu dobivene statistički značajne razlike u agilnosti kretanja na većim udaljenostima, eksplozivnoj snazi nogu, brzini prvoga koraka i brzini nogometnog udarca te održavanju statične ravnoteže.

Ključne riječi: *agilnost, eksplozivna snaga donjih ekstremiteta, umor, nogometna utakmica, brzina simuliranog nogometnog udarca, statična ravnoteža, dinamična ravnoteža, vizualna kontrola*