J. Phys. Ther. Sci. 28: 2942–2949, 2016

The Journal of Physical Therapy Science

Original Article

Physical and balance performance following exercise induced muscle damage in male soccer players

Muzaffar Ahmad Khan[1)], Jamal Ali Moiz[1)*], Shahid Raza[1)], Shalini Verma[1)],
M.Y. Shareef[2)], Shahnawaz Anwer[3), 4)], Ahmad Alghadir[3)]

[1)] *Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia: New Delhi 110025, India*
[2)] *Faculty of Dentistry, Jamia Millia Islamia, India*
[3)] *Rehabilitation Research Chair, Department of Rehabilitation Sciences, College of Applied Medical Sciences, King Saud University, Saudi Arabia*
[4)] *Dr. D. Y. Patil College of Physiotherapy, Dr. D. Y. Patil Vidyapeeth, Pune, India*

Abstract. [Purpose] The present study aimed to determine the changes in physical and balance performance following exercise-induced muscle damage using a sport-specific protocol. [Subjects and Methods] Fifteen collegiate soccer players were asked to perform a sport-specific sprint protocol to induce muscle damage. The markers of muscle damage (soreness, range of motion, limb girth, muscle strength, creatine kinase and lactate dehydrogenase), physical performance (speed, agility and power) and balance (static and dynamic balance) were assessed at baseline and 24, 48 and 72 hours following the sprint protocol. [Results] All variables, including the markers of muscle damage, physical performance and balance showed a significant difference when assessed at the 4 time points. [Conclusion] The study demonstrated that both the physical and balance performance were affected following repeated sprint protocol in soccer players. It is recommended the balance performance of an athlete be continually assessed following exercise-induced muscle damage so as to determine the appropriate return to sport decision thereby, minimizing the risk of further injury.

Key words: Exercise-induced muscle damage, Static balance, Dynamic balance

(This article was submitted May 19, 2016, and was accepted Jul. 7, 2016)

INTRODUCTION

Soccer is the most popular sport consisting of exercise periods of high intensity interspersed between exercise periods of low intensity and involves activities that require numerous eccentric actions[1–3)]. Participation in the unaccustomed or increased intensity and duration of eccentrically biased exercise often results in ultra-structural damage to skeletal muscle in both novel and elite athletes[4–6)]. This temporary cellular damage occurring in the skeletal muscle after unaccustomed exercises is called exercise induced muscle damage (EIMD)[7)] which is characterized by the disruption of contractile and non-contractile proteins with the decomposition of sarcolemma[8)], increased concentration of muscle protein in bloodstream[9)], delayed-onset muscle soreness (DOMS)[10)], decreased range of motion[11)], swelling[12)], impaired proprioceptive function and neuromuscular control[13)], and prolonged loss of muscle function[14)]. Moreover, this skeletal muscle damage can affect performance through a reduction in the joint range of motion, pain, and peak torque[15)].

Researchers have utilized many modes of damaging exercise for inducing EIMD, more specifically downhill running and plyometric exercises, however, these protocols still lack sports specificity and direct application to field sports[16–21)] and are

---

*Corresponding author. Jamal Ali Moiz (E-mail: jmoiz@jmi.ac.in) mostly used for isolated muscle damage. Thompson et al.[22] found that an intermittent sprinting protocol resulted in muscle soreness by imposing a large mechanical stress on quadriceps and hamstrings as they work to decelerate the body's mass. Other researchers have also provided a useful model utilizing sports-specific repeated sprint sessions with a rapid deceleration to induce EIMD in the hamstrings, quadriceps, and the calf muscles[23, 24]. The current study, therefore, utilizes this sports specific task to elicit EIMD in soccer players.

Soccer is characterized by a large number of sprints, accelerations and decelerations[25] and direction changes. Therefore, the players require good speed, power, agility, and balance for the optimal performance. Balance in soccer is necessary to maintain single leg stance while shooting accurately, dribbling and passing the ball[26, 27]. Balance or postural control is a dynamic process by which the body is maintained in equilibrium[28]. Balance can be categorized into static, dynamic, and functional[29, 30]. Static balance is the ability to maintain a position with the minimal movement. Dynamic and functional balances involve the maintenance of the center of gravity (COG) over a moving base of support which is more critical for athletic movement than static balance.

Several factors such as proprioceptive deficits, muscle weakness, muscle injury (strain), and sports participation can affect balance[29, 31]. DOMS is often categorized as a type I muscle strain[32] and clinically, acute strains and DOMS are very similar[33]. Previous studies reported that muscle damage following eccentric exercises can change the kinesthetic sense[34, 35]. Therefore, DOMS is hypothesized to alter the balance. Balance ability has an important effect on the sports performance[36]. Poor balance has been associated with an increased risk of injuries in a number of sports[37]. However, there is a dearth of information as to how EIMD influences balance, as well as speed, agility and power, which are essential components of not only training and competition but also prevention and rehabilitation of sports injuries. Therefore, the purpose of the present study was to examine the changes in physical performance (speed, power and agility) and balance performance (static and dynamic balance) resulting from EIMD following sport-specific repeated sprints in male collegiate soccer players.

SUBJECTS AND METHODS

Fifteen male college soccer players (mean age, 21.3 ± 2 years, height 172.2 ± 6.6 cm, weight 66.1 ± 11 kg and BMI 22.3 ± 3.2) from Jamia Millia Islamia, New Delhi, India, participated in the study. Ethical approval was granted by the institutional ethics committee and the subjects were given a written informed consent. All the subjects regularly participated in the collegiate soccer and did sport-specific training at least 4 times/week. Those involved in resistance training for at least 12 months prior to this study, martial arts or dancing, which may influence balance abilities or prior balance training were excluded. In addition, individuals having any history of lower limb injury, cerebral concussion and vestibular disorders for 3 months before testing were also excluded. Participants were asked to refrain from competitive events, resistance exercise, and avoid use of alcohol, nutritional supplements, and non-steroidal anti-inflammatory drugs during the study duration. The sample size was calculated using the Pass 11 software which showed that a sample of 15 subjects would achieve a 95% power to detect a difference of 1 in a design with 4 repeated measurements having a compound symmetrical co-variance structure when the standard deviation is 1, the correlation between observation on the same subject is 0.5 and the α level is 0.05.

Subjects were tested on five separate days. Prior to each test, the subjects were given a demonstration of the tests. On the first day of testing, subject's height, weight, knee range of motion (ROM), thigh circumference and muscle strength for quadriceps and hamstrings (MVIC) were measured in the human performance lab, Centre of Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia. Two milliliter blood samples were drawn from the antecubital vein to determine baseline Creatine Kinase (CK) and Lactate Dehydrogenase (LDH) levels. Immediately thereafter, subjects were tested for physical performance parameters using the vertical jump, 20 meter (m) sprint and the Illinois agility test, and static and dynamic balance. On the second day of testing, the subjects performed the repeated sprints protocol[24] wherein, following a warm-up, the participants performed 15 × 30 meter sprints with a period of 1 minute rest between repetitions. Subjects were instructed to maximally sprint between the cones and stop within the 10 meter deceleration zone, laid out immediately after the 30 meter sprint zone. After the completion of a repetition (i.e., the subject had come to a halt), the rest period was initiated. The criterion measures were recorded at 24, 48 and 72 hours after the sprint protocol. The same therapist administered each individual test.

Muscle soreness, range of motion, thigh circumference, maximum voluntary contraction, CK, and LDH were assessed as markers of the muscle damage. The soreness in lower limb was assessed while squatting at a knee angle of approximately 90 degrees, using a 200 mm visual analogue scale with "no soreness" at one end and "unbearably painful" at the other[18]. Range of motion was measured for knee flexion using a plastic goniometer and universal landmarks (lateral epicondyle of the femur, lateral malleolus and greater trochanter) to ensure alignment[38]. Thigh circumference was measured at 5, 10 and 15 cm above the patella by a gulick tape measure while the participant was in the long-sitting position with a relaxed quadriceps muscle. The mean of 2 measurements was taken from each marked site, and the average value of the 3 measurement sites was used for statistical analysis[39]. Maximum voluntary contraction of the knee flexors and extensors was measured using the Lafayette MMT system (Model no. 01165; accuracy ± 1% over full scale or ± 0.2% lbs). The dynamometer test consists of an isometric "make contractions" in which the patient used each tested muscle group to push maximally against the plate and the piston of the hand-held dynamometer for 4–5 seconds[40]. Venous blood was used to measure CK and LDH. The blood was then centrifuged at 3,000 rpm for 10 min[41]. The serum was aspirated and stored at −20°C until being analysed for CK and LDH

Table 1. Change in markers of muscle damage following exercise induced muscle damage

Variables	Pre	24 h	48 h	72 h
	Mean ± SE	Mean± SE	Mean ± SE	Mean ± SE
VASQ†	0.0 ± 0.0	86 ± 5.61*	115 ± 6.94*	73 ± 4.80*
VASH†	0.0 ± 0.0	58.3 ± 6.80*	81.3 ± 7.80*	47.6 ± 4.70*
MVCQ†	258.2 ± 15.56	209.6 ± 11.83*	215.4 ± 12.65*	238.7 ± 12.73
MVCH†	176.2 ± 6.83	147.8 ± 5.84*	149.2 ± 8.83*	161.5 ± 8.10
ROM†	131.9 ± 0.50	124.1 ± 0.68*	127.5 ± 0.83*	131.9 ± 0.58
LG†	50.8 ± 1.07	52.2 ± 1.15*	52.1 ± 1.17*	50.9 ± 1.07
CK†	190.6 ± 16.78	620.7 ± 61.0*	502.4 ± 51.7*	341.5 ± 38.7*
LDH†	286.6 ± 21.05	563.8 ± 52.7*	467.7 ± 42.5*	392.6 ± 18.3

h: Hours; VASQ: visual analogue scale quadriceps; VASH: visual analogue scale hamstrings; MVCQ: maximal voluntary contraction quadriceps; MVCH: maximal voluntary contraction hamstrings; ROM: range of motion knee; LG: leg girth; CK: creatine kinase; LDH: lactate dehydrogenase; †Significant effect of time (pre, 24h, 48h, 72h) using repeated measure ANOVA ($p<0.05$); *Significant difference in comparison to baseline values, assessed using post hoc analysis ($p<0.05$)

activity[39, 42]. The serum CK and LDH activity was assessed by a spectrophotometer at 340 nm set wavelength using a CK kit (NAC act. Crest Biosystems, CORAL) and LDH kit (LDH, P-L, Crest biosystems CORAL) respectively.

Vertical Jump performance, 20 m single sprint, and the Agility (Illinois Agility Test) were used to assess the physical performance. Vertical Jump performance is commonly used as an index for the power of the lower limb or explosive leg power[43–46]. For squat jumps, the subjects were instructed to initiate from 90° knee flexion, and execute a maximum vertical jump while swinging their arms actively. To assess the counter movement jump, participants stood fully erect, and following a verbal command, initiated a countermovement followed by a maximal vertical jump in one continuous motion, keeping their legs straight whilst airborne, but using their arms during the jump[47]. 20 m single sprint is a standard test for assessing the running speed in soccer players[48]. The participants performed two 20 m trials separated by a 3 min recovery period. The best attempt was used for the analysis. Agility (Illinois Agility Test) is commonly used to measure agility in soccer. The best score (time) of three trials performed by each subject was used for the analysis[49–51].

Stork stand balance test was used to assess static balance. The test measures the ability of the participant to balance on the ball of the foot with hands placed on the hips while positioning the non-supporting foot against the inside knee of the supporting leg. The time (in seconds) for which the participant is able to maintain this position is indicative of his balance performance. The players performed three attempts and the best time was recorded for analysis[52]. The same procedure was carried out for both lower limbs. Dynamic balance was assessed using the modified star excursion balance test (SEBT), where 3 reach directions (Anterior, Posteromedial, Posterolateral) were measured[53]. Participants performed two practice and three test trials with each leg. The order of testing was random. The farthest reach distance was recorded (cm) with a mark on the tape in each direction. Reach distances were normalized to leg length (% leg length). If the evaluator felt the participant used the reaching leg for support, removed his foot from the centre of the grid, or was unable to maintain balance on the support leg, the test was discarded and repeated[54].

Data were assessed by a Shapiro-Wilk test for the normality of the distribution scores. SEBT scores that demonstrated non-normal distribution were log- transformed for further analysis. Fifteen participants were assessed during the experiment. To test for the difference across 4 assessments, a repeated measure ANOVA time (pre, 24, 48 and 72 hours) was employed. When the main effect of time was significant, a Bonferroni test was employed as post hoc analysis to locate the time points having significant difference. The significance level was set at $p<0.05$. For SEBT, the average of three distances (cm) scores was taken for all the three directions over the three trials and was normalized to leg length. [Reach distance/ leg length × 100 = percentage of leg length]. The normalized composite reach distances between the right and left leg were analyzed and compared using a paired t-test to examine the differences.

RESULTS

The markers of muscle damage showed a significant effect for time (Table 1), as did the physical performance and balance variables (Table 2). Moreover, the post hoc analyses revealed maximum differences between baseline and at 24 hours following EIMD and non-significant differences between baseline values and those recorded at 72 hours (Table 2). The paired t-test used to compare the scores for composite reach distances, indicated no significant difference between the right (M=85.7, SD=6.99) and left leg (M=86.3, SD=6.32), p=0.336.

Table 2. Changes in balance and physical performance variables following exercise induced muscle damage

Variables	Pre	24 h	48 h	72 h
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Balance performance variables				
SBTL†	47.7 ± 1.65	25.2 ± 1.67*	34 ± 1.77	47.3 ± 1.77
SBTR	34.2 ± 1.55	21.7 ± 1.58*	26.7 ± 1.66	33 ± 1.67
ANTL†	79.8 ± 2.70	74.2 ± 2.80*	74.5 ± 2.88*	79 ± 2.96
ANTR†	80.4 ± 2.90	73.2 ± 2.71*	75.8 ± 2.95*	78.8 ± 3.01
PLATL†	102 ± 1.44	95.2 ± 1.09*	96.6 ± 1.13*	101.8 ± 1.46
PLATR†	99.6 ± 1.49	92.1 ± 1.15*	94.8 ± 1.53*	99.1 ± 1.82
PMEDL†	99.2 ± 1.32	89.1 ± 0.85*	91.2 ± 1.07*	98.4 ± 1.18
PMEDR†	98.9 ± 1.27	89.6 ± 0.63*	91.6 ± 0.61*	97.8 ± 0.82
Physical performance variables				
Sprint†	3.4 ± 0.07	3.7 ± 0.07*	3.6 ± 0.07*	3.5 ± 0.07
IAT†	17.4 ± 0.25	18.1 ± 0.27*	17.8 ± 0.24*	17.4 ± 0.25
SJ†	42.8 ± 1.39	39.3 ± 1.89*	39.7 ± 1.91*	42.3 ± 1.57
CMJ†	47.3 ± 1.47	41.8 ± 2.18*	42 ± 1.94*	45.5 ± 1.53

h: Hours; SBTL: static balance test left leg; SBTR: static balance test right leg; ANTL: star excursion balance test in anterior direction left leg; ANTR: star excursion balance test in anterior direction right leg; PLATL: star excursion balance test in postero-lateral direction left leg; PLATR: star excursion balance test in postero-lateral direction right leg; PMEDL: star excursion balance test in postero-medial direction left leg; PMEDR: star excursion balance test in postero-medial direction right leg; IAT: Ilionois Agility Test; SJ: Squat Jump; CMJ: Counter-Movement Jump. †Significant effect of time (pre, 24h, 48h, 72h) using repeated measure ANOVA ($p<0.05$); *Significant difference in comparison to baseline values, assessed using post hoc analysis ($p<0.05$)

DISCUSSION

Objective of the present study was to examine whether EIMD following sport-specific repeated sprints would affect the physical and balance performance in the male collegiate soccer players. More pronounced increase in the muscle soreness, limb circumference, plasmatic CK and LDH activity and a decrease in ROM and maximal voluntary contraction provide indirect evidence to suggest that EIMD was present following the sport-specific repeated sprints. Our findings suggest that the EIMD was induced in both dominant and the non-dominant limbs. Indeed, all the variables chosen to examine the changes in physical and balance performance showed significant change after the protocol. Although, a previous study has investigated the EIMD using the markers of muscle damage and physical performance in athletes55). However, to the best of our knowledge, till date, no study has investigated the effects of EIMD on dynamic balance performance. This is the first study that comprehensively examined the pain sensation, biochemical, physical and balance performance in both dominant and non-dominant legs in athletes using a sport-specific protocol.

Muscle soreness, increased 24 hours after exercise, peaked at 48 hours and finally decreased at 72 hours in both quadriceps and hamstring, showing a similar trend as that observed by Howatson et al.24) using the same protocol. The trend to rise in the soreness that peaked at 48 hours have been observed in many other damaging models18, 56, 57).

Knee ROM demonstrated a reduction at 24 hours. Further, the ROM remained decreased even at 48 and 72 hours following EIMD. This result is similar to previous studies which suggest ROM decreased, after the exercise protocol and did not recover for the next 3 days58, 59). The cause of decreased ROM following eccentric exercise is not well explained. However, earlier studies have suggested that shortened non-contractile components, change in calcium homeostasis due to muscle damage, decreased strength, and/or swelling may be responsible for decreased ROM12, 60).

Thigh Circumference demonstrated a peak increase at 24 hours (3.2%), consistent with the findings of Howatson et al.24) who used the same protocol and reported an increase in limb girth of 3% at 24 hours. The present study demonstrated reduction of swelling at 48 hours (2.5%) and at 72 hours (0.2%).

Maximal Voluntary Contraction showed a significant drop at 24 hours, gradually recovering at 48 hours and the recovery continuing up to 72 hours in both quadriceps and hamstrings. Measurement of the maximal force during isometric contractions is the most common method of assessing muscle function following eccentric exercise and is considered a reliable indicator of muscle damage9).

CK showed peak activity at 24 hours following exercise, gradually recovering at 48 and 72 hours. This trend was similar to the results of Howatson et al.24) utilizing the same protocol for EIMD. The CK response peaking at 24 h post-exercise was in accordance with previous study using a similar protocol to induce damage47, 61). It would appear that other lower limb exercise such as downhill running62) also follows a similar trend to this investigation.

LDH showed a rise of 68% the baseline values at 24 hours, gradually decreasing to 40.2% and 1% from the baseline at 48 and 72 hours, respectively. Armstrong et al.[63] reported that LDH showed a significant secondary late phase elevations at 24–48 hours post downhill running. However, Sudhakar and Naiya[64] in their study found that that serum LDH level peaked at 48 hours after the EIMD which is different from the findings of this study.

In a 20 m sprint after 24 hours, the sprint time increased by 6.6%. At 48 hours, the sprint times improved showing an increase of 4.6% from the baseline values. At 72 hours, the sprint times remained elevated by 1.2%. These findings are consistent with Highton et al.[7] and Twist and Eston[57], who reported that sprint times was significantly increased at 24 and 48 hours following EIMD before returning to baseline levels at 72 hours. But they have measured 5 m and 10 m sprint performance. On the other hand, contrary to these studies Semark et al.[41] reported no significant impairment in sprint running performance over 5 m, 10 m, 20 m, and 30 m following 70 drop jumps and reported that there was insufficient muscle damage to impair sprint performance.

Agility showed a significant reduction following repeated sprints in this study. This is similar to the of study done by Highton et al.[7] who has reported a significant reduction in the agility performance following plyometric exercise and suggested that the reduction in agility performance may be due to a reduction in both strength and running speed. This study also showed that increase in sprint (6.6%) is not exclusively responsible for decrements in agility performance (4.2%).

Vertical Jump demonstrated a significant drop in both squat and counter-movement jump performance following repeated sprints. The squat jump performance showed a decrease of 7.1% in both 24 and 48 hours and 1.1% at 72 hours and the counter-movement jump performance showed a decline of 11.6% at 24 hours, 11.1% at 48 hours and 3.8% at 72 hours following damaging protocol. The result of our study is in accordance with the study done by Sarabon et al.[65], which showed a more pronounced drop in counter-movement jump height in relation to squat jump height 24 hours following EIMD. However, in their study the recovery was slower for squat jump as compared to counter-movement jump, which is contrary to our study which suggests a comparatively slower return for the counter-movement jump. This may be because of different damaging protocol used as their protocol emphasized damage of the hamstring muscles and ours on the quadriceps. Another study also observed a prolonged reduction in vertical jump height, by 11% in squat jump performance after 50 drop-jumps[47].

Static balance revealed similar results to the study of Twist et al.[66] who reported a significant impairment in unilateral balance from baseline at 24 hours following plyometric exercise and no significant impairment at 48 and 72 hours following plyometric exercise. However, Sarabon et al.[65] found no significant impairment on unilateral quite stance following drop jumps and leg curls emphasizing hamstring damage. The authors state that the reason for the non-significant changes might have been due to very less involvement of hamstring muscle during single leg stance. They further suggested that decreased hamstring muscle function may be due to minimal muscle activation and more degree of freedom of hip and thigh muscles. Twist et al.[66] proposed that balance performance was exacerbated by both central and peripheral mechanisms. Olmsted et al.[67] suggests that static postural impairment is caused by impairment of proprioception and neuromuscular control.

This is the preliminary study to investigate the effect of EIMD on dynamic balance. The results suggest that the dynamic balance recorded by SEBT declined significantly at 24 hours in all the directions. The balance recovered significantly in posteromedial and posterolateral directions and non-significantly in anterior directions at 48 hours. At 72 hours balance improved significantly in all the directions and reached close to the baseline. Late recovery in anterior directions may be because the muscle damage was more in the quadriceps which is found to be more active during the anterior directions[68]. To perform the anterior direction, subject leaned backward, extending the trunk, to maintain their balance. Gravity action on the upper body creates a larger knee-flexion moment, which must be controlled by the extension moment produced by the quadriceps.

Lephart et al., Balter et al., and Paterno et al.[69–71] found that training experiences that improve joint strength, ROM and neuromuscular coordination, are also likely to lead to improved balance. This suggests that if there is impairment in neuromuscular coordination, reduction in the strength, ROM, and the balance is likely to be affected. Further Olmsted et al.[67] believed that dynamic postural impairment may be influenced by impaired neuromuscular control, proprioception, ROM and joint strength. Palmieri et al.[72] suggested that balance is influenced by sensory information obtained from the somatosensory, visual, and vestibular systems and motor responses that affect coordination, joint range of motion (ROM), and strength.

Previous researches suggest that eccentric exercise causing fatigue lead to desensitization of intramuscular receptors (muscle spindles and Golgi tendon organs) which consequently result in balance impairment[35, 73, 74]. Moreover, the resting tension of the muscle is altered by repeated muscle contractions during sprints thereby, further modifying the proprioceptive control[74, 75]. Studies have alluded that muscle damage results in change in kinaesthesia[34], muscle spindle activity[76] and reflex sensitivity[77] which increases muscle stiffness affecting performance of skilled movements. These findings on proprioceptive and kinaesthetic control concur with the results of the present study that also recorded deterioration in balance from 24–48 hours. Investigations studying the central responses to eccentric exercise state that soreness significantly influences proprioception[74, 78].

Muscle strength showed a significant drop at 24 hours, gradually recovering at 48 hours and continuing up to 72 hours, in both quadriceps and hamstring. In this study force loss showed the same temporal trend of recovery as that of balance performance. Hence, it may be that impairment in balance is because of a reduction in maximum voluntary contraction of quadriceps and hamstrings. Hesari et al.[68] demonstrated that there was co-contraction of the quadriceps and hamstring during all directions of excursion. The quadriceps muscle showed maximum activation during the anterior excursion; vastuslateralis during the posteromedial excursion and biceps femoris during the posterolateral excursion. In the current study, the decline in activity of both quadriceps and hamstrings might have led to decrements in balance performance as shown by a decrease in the normalized reaching distance. The results also demonstrated decreased in ROM at 24 hours, the ROM remains decreased even at 48 and 72 hours following EIMD. Gribble et al.79) in their review article suggests that knee movements in the sagittal plane strongly influence SEBT performance. Differences in sagittal plane knee ROM have been demonstrated among the different reach directions80). The anterior, and posteromedial directions produced more knee flexion and it was less in the posterolateral direction. Therefore, we suggest that alteration in ROM as found in the present study might have affected the normalized reach distances.

The findings of this study would benefit sports physiotherapist, athletic and fitness trainers quantify balance after EIMD in order to reduce musculoskeletal injuries and improve performance. The study highlights the fact that even trained and reasonably well-conditioned players still experience EIMD, despite being familiar to the exercise stress. Athletes should make effort to prevent the onset of EIMD that might compromise the efficiency of training. In EIMD, an adequate recovery (>72 hours) with regeneration techniques11) should be provided. Further application of this study is that athletic trainers may use these tests to check for athletes' readiness for return to sports.

The Stork balance test and SEBT measurements may be considered as limitations of this study because they could not quantify postural sway. Force platform is considered as gold standard for measuring static balance81) and although no gold standard has been defined for dynamic balance, more sophisticated techniques such as dynamic postural control index and the time-to-stabilization test for dynamic balance are available. SBT and SEBT require minimal equipment and are clinically friendly. Additionally, specific components of balance (e.g., proprioception, vision) were also not examined in this study. Future researches must be conducted to address these issues and include ultrasonography, MRI images, and EMG techniques to establish an advanced understanding of the physiological manifestations of EIMD. Other blood markers such as plasma interleukines, TNF-α and CRP may be used for a comprehensive evaluation of the inflammatory responses after EIMD.

In the conclusion, both the physical and balance performance studied were affected following repeated sprint protocol in soccer players. Similar changes were found in CK activity, MVC, ROM and balance performance with time suggesting a correlation between the biochemical markers and neuromuscular changes. Moreover, the study found EIMD can be induced even in an athletic population; therefore, the trainer should be careful while adding intense eccentric contractions during the training. It is recommended that the balance performance of an athlete be continually assessed following EIMD so as to determine the appropriate return to sport decision thereby, minimizing the risk of further injury.

ACKNOWLEDGEMENT

The Project was fully financially supported by King Saud University, through Vice Deanship of Research Chairs, Rehabilitation Research Chair.

REFERENCES

1) Sirotic AC, Coutts AJ: Physiological and performance test correlates of prolonged, high-intensity, intermittent running performance in moderately trained women team sport athletes. J Strength Cond Res, 2007, 21: 138–144. [Medline] [CrossRef]
2) Spencer M, Bishop D, Dawson B, et al.: Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. Sports Med, 2005, 35: 1025–1044. [Medline] [CrossRef]
3) Svensson M, Drust B: Testing soccer players. J Sports Sci, 2005, 23: 601–618. [Medline] [CrossRef]
4) Fridén J, Lieber RL: Eccentric exercise-induced injuries to contractile and cytoskeletal muscle fibre components. Acta Physiol Scand, 2001, 171: 321–326. [Medline] [CrossRef]
5) Paul GL, DeLany JP, Snook JT, et al.: Serum and urinary markers of skeletal muscle tissue damage after weight lifting exercise. Eur J Appl Physiol Occup Physiol, 1989, 58: 786–790. [Medline] [CrossRef]
6) Fridén J, Sjöström M, Ekblom B: Myofibrillar damage following intense eccentric exercise in man. Int J Sports Med, 1983, 4: 170–176. [Medline] [CrossRef]
7) Highton JM, Twist C, Eston RG: The effects of exercise-induced muscle damage on agility and sprint running performance. J ExercSci Fit, 2009, 7: 24–30. [CrossRef]
8) Lovering RM, De Deyne PG: Contractile function, sarcolemma integrity, and the loss of dystrophin after skeletal muscle eccentric contraction-induced injury. Am J Physiol Cell Physiol, 2004, 286: C230–C238. [Medline] [CrossRef]
9) Clarkson PM, Hubal MJ: Exercise-induced muscle damage in humans. Am J Phys Med Rehabil, 2002, 81: S52–S69. [Medline] [CrossRef]
10) Clarkson PM, Nosaka K, Braun B: Muscle function after exercise-induced muscle damage and rapid adaptation. Med Sci Sports Exerc, 1992, 24: 512–520. [Medline] [CrossRef]
11) Cheung K, Hume P, Maxwell L: Delayed onset muscle soreness: treatment strategies and performance factors. Sports Med, 2003, 33: 145–164. [Medline] [CrossRef]
12) Chleboun GS, Howell JN, Conatser RR, et al.: Relationship between muscle swelling and stiffness after eccentric exercise. Med Sci Sports Exerc, 1998, 30: 529–535. [Medline] [CrossRef]
13) Byrne C, Twist C, Eston R: Neuromuscular function after exercise-induced muscle damage: theoretical and applied implications. Sports Med, 2004, 34: 49–69. [Medline] [CrossRef]

14) Clarkson PM, Tremblay I: Exercise-induced muscle damage, repair, and adaptation in humans. J Appl Physiol 1985, 1988, 65: 1–6. [Medline]

15) Nonaka K, Akiyama J, Tatsuta N, et al.: Cool water immersion after downhill running suppresses exercise-induced muscle damage in the rat soleus muscle. J Phys Ther Sci, 2012, 24: 613–616.

16) Hortobágyi T, Hill JP, Houmard JA, et al.: Adaptive responses to muscle lengthening and shortening in humans. J Appl Physiol 1985, 1996, 80: 765–772. [Medline]

17) Howatson G, Gaze D, van Someren KA: The efficacy of ice massage in the treatment of exercise-induced muscle damage. Scand J Med Sci Sports, 2005, 15: 416–422. [Medline] [CrossRef]

18) Howatson G, Van Someren K, Hortobágyi T: Repeated bout effect after maximal eccentric exercise. Int J Sports Med, 2007, 28: 557–563. [Medline] [CrossRef]

19) McHugh MP, Connolly DA, Eston RG, et al.: Exercise-induced muscle damage and potential mechanisms for the repeated bout effect. Sports Med, 1999, 27: 157–170. [Medline] [CrossRef]

20) Nosaka K, Newton M: Difference in the magnitude of muscle damage between maximal and submaximal eccentric loading. J Strength Cond Res, 2002, 16: 202–208. [Medline]

21) Cha HG, Kim MK: Effects of the hold and relax-agonist contraction technique on recovery from delayed onset muscle soreness after exercise in healthy adults. J Phys Ther Sci, 2015, 27: 3275–3277. [Medline] [CrossRef]

22) Thompson D, Williams C, Kingsley M, et al.: Muscle soreness and damage parameters after prolonged intermittent shuttle-running following acute vitamin C supplementation. Int J Sports Med, 2001, 22: 68–75. [Medline] [CrossRef]

23) Lakomy J, Haydon DT: The effects of enforced, rapid deceleration on performance in a multiple sprint test. J Strength Cond Res, 2004, 18: 579–583. [Medline]

24) Howatson G, Milak A: Exercise-induced muscle damage following a bout of sport specific repeated sprints. J Strength Cond Res, 2009, 23: 2419–2424. [Medline] [CrossRef]

25) Stølen T, Chamari K, Castagna C, et al.: Physiology of soccer: an update. Sports Med, 2005, 35: 501–536. [Medline] [CrossRef]

26) Greg G: Complete Conditioning for Football. 2009, 19: 45–51.

27) Paillard T, Noé F, Rivière T, et al.: Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. J Athl Train, 2006, 41: 172–176. [Medline]

28) Kisner C, Colby LA: Exercise for impaired balance. In: Therapeutic exercise: Foundation and Techniques. Philadelphia: F.A. Davis, 2007, pp 678–679.

29) Guskiewicz KM: Regaining postural stability and balance. New York: McGraw Hill, 2011, pp 145–170.

30) Winter DA, Patla AE, Frank JS: Assessment of balance control in humans. Med Prog Technol, 1990, 16: 31–51. [Medline]

31) Carcia C, Eggen J, Shultz S: Hip-abductor fatigue, frontal-plane landing angle, and excursion during a drop jump. J Sport Rehabil, 2005, 14: 321–331. [CrossRef]

32) Gulick DT, Kimura IF: Delayed onset muscle soreness: what is it and how do we treat it? J Sport Rehabil, 1996, 5: 234–243. [CrossRef]

33) Page P: Pathophysiology of acute exercise-induced muscular injury: clinical implications. J Athl Train, 1995, 30: 29–34. [Medline]

34) Eston R, Byrne C, Twist C: Muscle function after exercise-induced muscle damage: considerations for athletic performance in children and adults. J ExercSci Fit, 2003, 1: 85–96.

35) Saxton JM, Clarkson PM, James R, et al.: Neuromuscular dysfunction following eccentric exercise. Med Sci Sports Exerc, 1995, 27: 1185–1193. [Medline] [CrossRef]

36) Hrysomallis C: Balance ability and athletic performance. Sports Med, 2011, 41: 221–232. [Medline] [CrossRef]

37) Hrysomallis C: Relationship between balance ability, training and sports injury risk. Sports Med, 2007, 37: 547–556. [Medline] [CrossRef]

38) Tokmakidis SP, Kokkinidis EA, Smilios I, et al.: The effects of ibuprofen on delayed muscle soreness and muscular performance after eccentric exercise. J Strength Cond Res, 2003, 17: 53–59. [Medline]

39) Aminian-Far A, Hadian MR, Olyaei G, et al.: Whole-body vibration and the prevention and treatment of delayed-onset muscle soreness. J Athl Train, 2011, 46: 43–49. [Medline] [CrossRef]

40) Bohannon RW: Test-retest reliability of hand-held dynamometry during a single session of strength assessment. Phys Ther, 1986, 66: 206–209. [Medline]

41) Semark A, Noakes TD, St Clair Gibson A, et al.: The effect of a prophylactic dose of flurbiprofen on muscle soreness and sprinting performance in trained subjects. J Sports Sci, 1999, 17: 197–203. [Medline] [CrossRef]

42) Nosaka K, Sakamoto K, Newton M, et al.: How long does the protective effect on eccentric exercise-induced muscle damage last? Med Sci Sports Exerc, 2001, 33: 1490–1495. [Medline] [CrossRef]

43) Roschel H, Batista M, Monteiro R, et al.: Association between neuromuscular tests and kumite performance on the Brazilian karate national team. J Sports Sci Med, 2009, 8: 20–24. [Medline]

44) Noorul HR, Pieter W, Erie ZZ: Physical fitness of recreational adolescent taekwondo athletes. Braz J Biomotricity, 2008, 2: 230–240.

45) DizonJM, Grimmer-Somers K: Making Filipino taekwondo athletes internationally competitive: an international comparison of anthropometric and physiologic characteristics. J Sports Med Doping Stud, 2012, 2: 1–7. [CrossRef]

46) Markovic G, Jukic I, Milanovic D, et al.: Effects of sprint and plyometric training on muscle function and athletic performance. J Strength Cond Res, 2007, 21: 543–549. [Medline]

47) Byrne C, Eston R: The effect of exercise-induced muscle damage on isometric and dynamic knee extensor strength and vertical jump performance. J Sports Sci, 2002, 20: 417–425. [Medline] [CrossRef]

48) Rahnama N, Bambaeichi E, Daneshjoo A: The epidemiology of knee injuries in Iranian male professional soccer players. Sport Sci Health, 2009, 5: 9–14. [CrossRef]

49) Kilding AE, Tunstall H, Kuzmic D: Suitability of FIFA's "The 11" training programme for young football players —impact on physical performance. J Sports Sci Med, 2008, 7: 320–326. [Medline]

50) Katis A, Kellis E: Effects of small-sided games on physical conditioning and performance in young soccer players. J Sports Sci Med, 2009, 8: 374–380. [Medline]

51) Amiri-Khorasani M, Sahebozamani M, Tabrizi KG, et al.: Acute effect of different stretching methods on Illinois agility test in soccer players. J Strength Cond Res, 2010, 24: 2698–2704. [Medline] [CrossRef]

52) Melrose DR, Spaniol FJ, Bohling ME, et al.: Physiological and performance characteristics of adolescent club volleyball players. J Strength Cond Res, 2007, 21: 481–486. [Medline]

53) Plisky PJ, Rauh MJ, Kaminski TW, et al.: Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther, 2006, 36: 911–919. [Medline] [CrossRef]

54) Gribble PA, Hertel J: Considerations for normalizing measures of the Star Excursion Balance Test. Meas Phys Educ Exerc Sci, 2003, 7: 89–100.

55) Verma S, Moiz JA, Shareef MY, et al.: Physical performance and markers of muscle damage following sport-specific sprints in male collegiate soccer players: repeated bout effect. J Sports Med Phys Fitness, 2016, 56: 765–774. [Medline]

56) Thompson D, Nicholas CW, Williams C: Muscular soreness following prolonged intermittent high-intensity shuttle running. J Sports Sci, 1999, 17: 387–395. [Medline] [CrossRef]

57) Twist C, Eston R: The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. Eur J Appl Physiol, 2005, 94: 652–658. [Medline] [CrossRef]

58) Zainuddin Z, Newton M, Sacco P, et al.: Effects of massage on delayed-onset muscle soreness, swelling, and recovery of muscle function. J Athl Train, 2005, 40: 174–180. [Medline]

59) Hilbert JE, Sforzo GA, Swensen T: The effects of massage on delayed onset muscle soreness. Br J Sports Med, 2003, 37: 72–75. [Medline] [CrossRef]

60) Jones DA, Newham DJ, Clarkson PM: Skeletal muscle stiffness and pain following eccentric exercise of the elbow flexors. Pain, 1987, 30: 233–242. [Medline] [CrossRef]

61) Miyama M, Nosaka K: Muscle damage and soreness following repeated bouts of consecutive drop jumps. Adv Exerc Sports Physiol, 2004, 10: 63–69.

62) Eston RG, Mickleborough J, Baltzopoulos V: Eccentric activation and muscle damage: biomechanical and physiological considerations during downhill running. Br J Sports Med, 1995, 29: 89–94. [Medline] [CrossRef]

63) Armstrong RB, Ogilvie RW, Schwane JA: Eccentric exercise-induced injury to rat skeletal muscle. J Appl Physiol, 1983, 54: 80–93. [Medline]

64) NaiyaA: Biochemical markers an indirect method for evaluating Delayed Onset Muscle Soreness among recreational athletes. Int J Biol Med Res, 2012, 3: 1624–1626.

65) Sarabon N, Panjan A, Rosker J, et al.: Functional and neuromuscular changes in the hamstrings after drop jumps and leg curls. J Sports Sci Med, 2013, 12: 431–438. [Medline]

66) Twist C, Gleeson N, Eston R: The effects of plyometric exercise on unilateral balance performance. J Sports Sci, 2008, 26: 1073–1080. [Medline] [CrossRef]

67) Olmsted LC, Carcia CR, Hertel J, et al.: Efficacy of the Star Excursion Balance Tests in detecting reach deficits in subjects with chronic ankle instability. J Athl Train, 2002, 37: 501–506. [Medline]

68) Hesari AF, Maoud G, Ortakand SM, et al.: The relationship between star excursion balance test and lower extremity strength, range of motion and anthropometric characteristics. Med Sportiva, 2013, 17: 24–28.

69) Lephart SM, Giraldo JL, Borsa PA, et al.: Knee joint proprioception: a comparison between female intercollegiate gymnasts and controls. Knee Surg Sports Traumatol Arthrosc, 1996, 4: 121–124. [Medline] [CrossRef]

70) Balter SG, Stokroos RJ, Akkermans E, et al.: Habituation to galvanic vestibular stimulation for analysis of postural control abilities in gymnasts. Neurosci Lett, 2004, 366: 71–75. [Medline] [CrossRef]

71) Paterno MV, Myer GD, Ford KR, et al.: Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther, 2004, 34: 305–316. [Medline] [CrossRef]

72) Palmieri RM, Ingersoll CD, Cordova ML, et al.: The effect of a simulated knee joint effusion on postural control in healthy subjects. Arch Phys Med Rehabil, 2003, 84: 1076–1079. [Medline] [CrossRef]

73) Johnston RB 3rd, Howard ME, Cawley PW, et al.: Effect of lower extremity muscular fatigue on motor control performance. Med Sci Sports Exerc, 1998, 30: 1703–1707. [Medline] [CrossRef]

74) Brockett C, Warren N, Gregory JE, et al.: A comparison of the effects of concentric versus eccentric exercise on force and position sense at the human elbow joint. Brain Res, 1997, 771: 251–258. [Medline] [CrossRef]

75) Gregory JE, Brockett CL, Morgan DL, et al.: Effect of eccentric muscle contractions on Golgi tendon organ responses to passive and active tension in the cat. J Physiol, 2002, 538: 209–218. [Medline] [CrossRef]

76) Riemann BL, Lephart SM: The sensorimotor system, part I: the physiologic basis of functional joint stability. J Athl Train, 2002, 37: 71–79. [Medline]

77) Rosker JS: Kinaesthesia and methods for its assessment: literature review. Sport Sci Rev, 2010, 19: 165–208.

78) Proske U, Weerakkody NS, Percival P, et al.: Force-matching errors after eccentric exercise attributed to muscle soreness. Clin Exp Pharmacol Physiol, 2003, 30: 576–579. [Medline] [CrossRef]

79) Gribble PA, Hertel J, Plisky P: Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. J Athl Train, 2012, 47: 339–357. [Medline]

80) Gribble PA, Hertel J, Denegar CR: Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. Int J Sports Med, 2007, 28: 236–242. [Medline] [CrossRef]

81) Riemann BL, Guskiewicz KM, Shields EW: Relationship between clinical and force plate measures of postural stability. J Sport Rehabil, 1999, 8: 71–82. [CrossRef]