Comparison of muscle activity, strength, and balance, before and after a 6-month training using the FIFA11+ program (part 2)

Takeshi Oshima1, Junsuke Nakase1, Anri Inaki2, Takafumi Mochizuki3, Yasushi Takata1, Kengo Shimozaki1, Seigo Kinuya2 and Hiroyuki Tsuchiya1

Abstract
Background: Sports injury prevention training programs have been reported to be effective in decreasing the incidence of injuries. The aim of this study was to evaluate the effects of a 6-month training period, using part 2 of the FIFA11+ program (the Fédération Internationale de Football), on the activation and strength of core and lower limb muscles and on static and dynamic balance performance. Study Design: Case series; level of evidence, 4. Methods: Eight college male soccer players, aged mean 20.4 ± 0.5 years old, completed the FIFA11+ program at least three times per week for 6 months. The following variables were measured both before and after the 6-month training program: activities of more than 30 muscles (core and lower limb muscles), measured using the standardized uptake values of 18F-fluorodeoxyglucose on positron emission tomography; isokinetic strength of the knee flexor and extensor and hip abductor muscles, measured at 60°/s; static balance over a 60-s period, measured using a gravicorder; and dynamic balance, measured using the star excursion balance test. Results: Training improved the activity levels of core (obliquus externus abdominis and erector spinae) and lower limb (tibialis anterior) muscles (p ≤ 0.03), corrected the between-limb difference in the activation of the semimembranosus and improved dynamic balance, with a greater training effect on the nondominant limb (p ≤ 0.02). Training also improved the knee flexor force of the nondominant lower limb (p = 0.02). Conclusion: Routine performance of the FIFA11+ program can improve the activation of core and lower limb muscles, with a concomitant improvement in dynamic balance. These improvements could be beneficial in lowering the risk of sports-related injuries.

Keywords
18F-fluorodeoxyglucose, muscle activity, muscle strength, PET-CT, postural balance, sports injuries

Date received: 9 September 2019; Received revised 10 November 2019; accepted: 11 November 2019

Introduction
Sports injury prevention training programs have been reported to be effective in decreasing the incidence of injuries, regardless of sport activity level, sex, and age.1,2 “FIFA11+” is one of the most effective prevention programs, which the Fédération Internationale de Football Association (FIFA) Medical and Assessment Research Center have developed. The FIFA11+ consists of three parts: basic running (part 1); three levels of difficulty of six exercises aiming to increase muscular strength (core

1 Department of Orthopaedic Surgery, Graduate School of Medical Science, Kanazawa University, Kanazawa, Japan
2 Department of Nuclear Medicine/Biotracer Medicine, Graduate School of Medical Science Kanazawa University, Kanazawa, Japan
3 Kanazawa Advanced Medical Center, Kanazawa, Japan

Corresponding author:
Junsuke Nakase, Department of Orthopaedic Surgery, Graduate School of Medical Science, Kanazawa University, 13-1 Takara-machi, Kanazawa 920-8641, Japan.
Email: nakase1007@yahoo.co.jp

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
and lower limbs), balance, muscle control (plyometrics), and core stability (part 2); and running (e.g. straight-line running or cutting activities) (part 3).

To quantify the change in muscle activity after performing the FIFA11+ (part 2) program, previous studies have used whole-body positron emission tomography–computed tomography (PET-CT) with glucose uptake in skeletal muscle being. PET-CT provides a relatively noninvasive and accurate three-dimensional observation of muscle activity within the body simultaneously. As active muscle cells exhibit increased glucose uptake, the use of 18F-fluorodeoxyglucose (FDG) permits the observation of glucose metabolism of the skeletal muscles. Unlike glucose, FDG does not exhibit the usual glycolytic pathway but accumulates within the exercising muscle tissue. The accumulation of FDG in muscle provides a parameter of glucose intake therefore the intensity of muscle activity. To our knowledge, FDG-PET is the only method that can provide a reliable cumulative index of muscle activity for between-muscle comparison.

In recent years, some studies reported various improvements in the neuromuscular control and strength of muscles with training using the FIFA11+. A review of the studies reporting on the acute or chronic effects of the FIFA11+ on performance and physiological measures for an intervention period of 9–10 weeks has yielded positive effects. However, the effect of long-term, routine performance of the FIFA11+ program on the metabolism of skeletal muscles remains unclear. The aim of our study was to investigate the change in muscle activity, muscle strength, and dynamic balance after performing part 2 of the FIFA11+ for 6 months. We hypothesized that this long-term training would improve the activation of various skeletal muscles of the core and lower limbs with a concomitant improvement in the dynamic balance and muscle strength.

Materials and methods

Eight collegiate male soccer players were recruited for this case series study. All participants were considered to be healthy after a review of medical history and physical examination. None was taking medication at the time of the study. All participants provided informed consent, and the study was approved by our institutional ethics review board.

Participants were asked to avoid strenuous physical activity for at least 1 day prior to testing and to refrain from eating and drinking for at least 6 h before testing. PET-CT images were obtained as per previously described methods using the PET-CT system (Discovery PET/CT 690; GE Healthcare, Milwaukee, Wisconsin, USA). After obtaining baseline (pretraining) PET-CT images, participants completed the training protocol which consisted of completing part 2 of the FIFA11+ program, ≥3 times per week, for six consecutive months. The participants were contacted at least one time per month to confirm that they were continuing the training protocol. PET-CT images were obtained at the end of the training period using the same protocol at baseline.

Regions of interest (ROIs) on the images were manually segmented in 30 skeletal muscles, located in 5 areas of the body: trunk, pelvis, thigh, lower leg, and the foot (Table 1). All ROIs were identified by one experienced nuclear medicine specialist, who was blinded from all other results, from the plain CT images obtained concurrently. The standardized uptake value (SUV) of FDG was calculated by overlapping the defined ROI and fusion PET-CT images to outline the area of muscles with care not to include large vessels. The FDG uptake was normalized to the unit volume of muscle as follows: (mean ROI count (counts per second/pixel) × calibration factor (counts per second/Bq))/(injected dose (Bq)/body weight (g)). ROIs were defined for the skeletal muscles previously described, bilaterally, and the mean SUV was compared for the dominant and nondominant side of the body (where the dominant side was identified by asking participants which leg they preferred to kick a ball). The mean SUV for the trunk was calculated as follows: ([left mean SUV × left muscle area] + [right mean SUV × right muscle area])/(left muscle area + right muscle area).

Static balance was measured using a gravicorder (Gravicorder GS-31; Anima, Tokyo, Japan). Postural sway was measured for 60 s at a sampling rate of 20 Hz under the following conditions: two-leg stance with eyes opened and then with eyes closed; single leg standing with eyes opened. Two variables of balance were measured: the locus length per time (LG) provided a measure of attitude control and the environmental area (AR) provided a measure of equilibrium control. All balance measurements were repeated twice with a 1-min rest between measurements; data from the second measurement which has been reported to be more accurate were used for the analysis.

Dynamic postural control was evaluated using the star excursion balance test (SEBT). Participants were asked to reach as far as possible along the designated line for each of the following eight directions: anterolateral, anterior, anteromedial, medial, posteromedial, posterior, posterolateral, and lateral. The test was performed twice, once in a clockwise direction (reaching with the right leg) and once in a counterclockwise direction (reaching with the left leg). The average length of three reaches performed in each direction was used for the analysis and this distance was normalized to the leg length (measured from the anterior superior iliac spine to the distal tip of the medial malleolus).

The maximal knee flexion, extension muscle strength, and the maximal isokinetic hip abductor strength were tested at full force at a speed of 60° s⁻¹ for three times using an isokinetic Biodex System 4 (Biodex Medical Systems, Shirley, New York, USA). For all strength measurements, the averaged value of the three trials was used for the analysis and values were normalized to body weight. The ratio of the stronger-to-weaker leg was
calculated as an index of between-limb strength imbalance and was also converted to a percentage difference using a previously described method.\(^{14}\)

All statistical analyses were performed using Stata for Mac Version 15 (Stata Statistical Software 2017; StataCorp LLC, College Station, Texas, USA). All data are presented as mean (standard deviation). Wilcoxon signed-rank test was used to evaluate differences in the mean SUV and static balance before and after training. Paired \( t\)-tests were used to evaluate the differences in muscle strength and dynamic balance before and after training. The sample size was confirmed using a power analysis of 0.75, with an \( \alpha \) value of 0.05 and an effect size of 1.0.

### Results

The relevant characteristics of the participants at pretraining were as follows: age, 20.4 ± 0.5 years old; height, 175.4 ± 6.2 cm; weight, 68.6 ± 5.1 kg; body mass index (BMI), 22.3 ± 1.3 kg m\(^{-2}\); and leg length, 89.4 ± 3.8 cm. After training, the weight was 70.1 ± 4.6 kg (\( p = 0.246 \)) and the BMI was 22.8 ± 0.8 kg m\(^{-2}\) (\( p = 0.250 \)), and there was no significant difference between pre- and post-training.

Representative whole-body PET images of pre- and post-training are shown in Figure 1 with the mean SUVs reported in Table 1. A significant pre- to post-training increment in mean SUV was identified for two core muscles: the obliquus externus abdominis (\( p = 0.036 \)) and erector spinae (\( p = 0.025 \)). The pre- to post-training significant change in the mean SUVs for the muscles of the dominant and nondominant lower limbs was detected. Compared to the nondominant lower limb, the mean SUV of the dominant lower limb was greater for the tibialis anterior (\( p = 0.017 \)) and lesser for the triceps surae (\( p = 0.036 \)) and erector spinae (\( p = 0.025 \)). A similar result was identified for the nondominant lower limb. There were an increment in the tibialis anterior SUV (\( p = 0.025 \)) and a decrement in the triceps surae SUV (\( p = 0.025 \); Table 1). The significant side-to-side difference of SUV was detected in semimembranosus in

| Body area | Muscles | Pretraining SUV | Post-training SUV | \( p \) Value |
|-----------|---------|----------------|------------------|--------------|
|           |         | Dominant leg   | Nondominant leg  | Dominant leg | Nondominant leg |
| Trunk     | Rectus abdominis | 0.90 ± 0.35 | 1.03 ± 0.40 | n.s.          |
|           | Obliquus externus abdominis | 0.75 ± 0.26 | 1.06 ± 0.38 | 0.036          |
|           | Obliquus internus abdominis | 0.69 ± 0.14 | 0.76 ± 0.81 | n.s.          |
|           | Transversus abdominis | 0.62 ± 0.08 | 0.59 ± 0.14 | n.s.          |
|           | Psoas major | 0.94 ± 0.31 | 0.87 ± 0.20 | n.s.          |
|           | Quadratus lumborum | 0.85 ± 0.33 | 0.99 ± 0.32 | n.s.          |
|           | Erector spinae | 0.67 ± 0.16 | 0.80 ± 0.31 | 0.025         |
| Pelvis    | Gluteus maximus | 1.54 ± 0.78 | 1.25 ± 0.78 | n.s.          |
|           | Gluteus medius | 2.18 ± 1.17 | 2.29 ± 0.82 | n.s.          |
|           | Gluteus minimus | 3.13 ± 0.60 | 3.51 ± 0.83 | n.s.          |
|           | Piriformis | 2.95 ± 1.70 | 2.37 ± 0.88 | 0.025         |
| Thigh     | Quadriceps femoris | 1.00 ± 0.31 | 1.01 ± 0.38 | n.s.          |
|           | Sartorius | 0.76 ± 0.21 | 0.77 ± 0.20 | n.s.          |
|           | Gracilis | 1.16 ± 0.43 | 1.14 ± 0.40 | n.s.          |
|           | Semimembranosus | 0.74 ± 0.14 | 0.59 ± 0.10 | n.s.          |
|           | Semitendinosus | 1.19 ± 0.31 | 1.09 ± 0.30 | n.s.          |
|           | Biceps femoris | 0.59 ± 0.08 | 0.63 ± 0.10 | n.s.          |
|           | Adductor complex | 0.81 ± 0.18 | 0.82 ± 0.18 | 0.025         |
| Lower leg | Tibialis anterior | 1.06 ± 0.59 | 1.00 ± 0.36 | 0.017         |
|           | Flexor digitorum longus | 1.28 ± 0.26 | 1.20 ± 0.35 | 0.025          |
|           | Tibialis posterior | 1.34 ± 0.84 | 1.37 ± 0.79 | n.s.          |
|           | Flexor hallucis longus | 1.23 ± 0.13 | 1.30 ± 0.58 | 0.025         |
|           | Peroneus | 1.50 ± 0.89 | 1.32 ± 0.36 | 0.025         |
|           | Triceps surae | 1.39 ± 0.40 | 1.24 ± 0.25 | 0.017         |
| Foot      | Abductor hallucis | 1.36 ± 0.42 | 1.45 ± 0.44 | 0.036         |
|           | Quadratus plantae | 1.06 ± 0.20 | 1.29 ± 0.43 | 0.036         |
|           | Flexor digitorum brevis | 1.43 ± 0.42 | 1.61 ± 0.58 | 0.025         |
|           | Abductor digiti minimi | 1.13 ± 0.44 | 1.45 ± 0.55 | 0.025         |
|           | Flexor hallucis brevis | 2.12 ± 0.65 | 2.24 ± 0.57 | 0.025         |
| Intersseous | 2.02 ± 0.61 | 2.20 ± 1.11 | 2.38 ± 1.50 | 2.20 ± 1.31 | n.s.          |

SUV: standardized uptake value; n.s.: not significant.

*a Value in comparison between pre- and post-training.
pretraining. Pretraining, the mean SUV of the semimembranosus muscle was higher for the dominant than nondominant lower limb ($0.74 \pm 0.14$ vs. $0.59 \pm 0.10$, respectively, $p = 0.012$). There was no significant difference observed in the activation of the semimembranosus between the dominant and nondominant sides after training ($0.62 \pm 0.08$ vs. $0.60 \pm 0.12$, respectively, $p = 0.889$).

There were no significant differences between pre- and post-training values in the mean LG and AR (Supplemental Table 1). In the SEBT, for the dominant leg, the standing reach distance increased significantly, pre- to post-training, in the anterior-lateral direction ($p = 0.023$; Supplemental Table 2). A greater improvement in dynamic balance on the nondominant leg was observed, with an increase in the reach distance across multiple directions, as follows: medial ($p = 0.002$), posterior-medial ($p = 0.030$), and posterior ($p = 0.022$). The pre- to post-training changes in muscle strength are reported in Supplemental Table 3. For the nondominant leg, knee flexion force increased from $1.24 \pm 0.15$ Nm kg$^{-1}$ to $1.39 \pm 0.14$ Nm kg$^{-1}$ ($p = 0.023$). There was no effect of training observed on knee extensor and hip abductor strengths, hamstring-to-quadriceps ratio, and between-limb imbalance index (Supplemental Table 4).

**Discussion**

Our results indicate an increase in the activation of various skeletal muscles of the core and lower limbs after a 6-month training using part 2 of the FIFA 11+ program. We measured increment in the uptake of glucose for core and lower muscles: obliquus externus abdominis, erector spinae, and tibialis anterior. There was a decrement in the glucose uptake of the triceps surae and glucose uptake increment in the tibialis anterior. We also observed an improvement in the between-limb imbalance of the glucose uptake in the semimembranosus after training. From a functional perspective, training produced a greater improvement in dynamic balance on the nondominant compared to the dominant lower limb. This study is the first to report changes in muscle activities and improvements in balance and muscle strength with long-term training using part 2 of the FIFA 11+ program.

Glucose enters the muscle cell by facilitated diffusion using the glucose transporter-4 (GLUT4). Specifically, exercise stimulates an increase in the expression of GLUT4 in skeletal muscles similar to the findings of Reichkendler et al. after an 11-week program of daily moderate- and high-dose aerobic exercise.15 An increase in GLUT4 levels in skeletal muscles has also been shown to be a key adaptation to regular exercise training.16 Thus, FDG accumulation in the muscle can be used as a measure of the change in glucose uptake with training and can provide a proxy measure of muscle activity.17

By comparing the change in FDG accumulation of each muscle from pre- to post-training, we demonstrated that routine training using part 2 of the FIFA11+ program improved muscle metabolism and activation. These results are consistent with previous studies.3,4 These adaptations are important when we consider the positive effects of core and lower limb strength on balance. Previous studies reported on the improvement in two-leg standing balance with eyes closed after performing the FIFA11+ program18 and in the functional reach test after performing a core stability training program which increased the strength of the trunk flexors ($p < 0.001$), extensors ($p < 0.001$), and lateral flexors ($p < 0.001$).19 Considering the effect of core stability on balance, Willson et al. suggested that appropriate core strength training could reduce sports-related injuries.20 In the present study, increasing in the mean SUVs of the obliquus externus abdominis and erector spinae muscles was observed after training. A concomitant improvement was also observed in dynamic balance. Taken
together, these are indicative of the effectiveness of part 2 FIFA11+ program in improving core strength.

With regard to lower limb muscle activation, Day et al. reported an increased activity of the tibialis anterior during active swaying, which they associated with the higher proprioceptive demands of balancing under more challenging sensory conditions and the proprioceptive role of the tibialis anterior.21 Similarly, Earl and Hertal reported an increase in the general activity of lower limb muscles (vastus medialis obliquus, vastus lateralis, medial hamstring, biceps femoris, and tibialis anterior) during the SEBT ($p < 0.05$), with the exception of the triceps surae muscles ($p = 0.08$).22 We demonstrated comparable findings post-training, hence supporting the effectiveness of the FIFA11+ (part 2) in improving balance.23

The balance of muscle strength is also an important component with regard to injury prevention. For the lower limb, the hamstring-to-quadriceps strength ratio is an important factor of injury.24 Previous studies have reported on the effectiveness of the complete FIFA 11+ program in improving knee flexor strength and, thus, the hamstring-to-quadriceps strength ratio.6 Between-limb strength imbalances might also be an important factor for a lower leg injury.25 A prospective study provided evidence that a between-limb imbalance in eccentric knee flexor strength will increase the risk of hamstring injuries.26

Overall, our findings are consistent with previous reports on the effectiveness of performing the complete FIFA 11+ program in improving balance and muscle strength and lowering the incidence of sports injuries.6,8,23 The methods we used, and PET-CT, in particular, could be useful for evaluating the effectiveness of training programs and identifying the underlying pathways.

We note the following limitations of our study. First, the FDG-PET method accounts only for muscle glucose uptake. Other substrates, such as free fatty acids, muscle glycogen, and lactate, are also metabolized in active muscle cells. That being said, studies have confirmed that glucose oxidation increases with exercise intensity and glucose uptake. The second limitation was related to our ROI definition method. Since FDG uptake was measured at an arbitrary site on the target muscle, it may not reflect the uptake of glucose for the entire muscle. However, data from our previous studies suggest that this will not be of significant differences.3,4

The aim of our study was to confirm that improvements in muscle metabolism are an important underlying pathway for the previously reported effectiveness of the FIFA11+ training program. In this study, the application of PET-CT to determine muscle metabolism and our findings of an increase in glucose uptake post-training are novel.

Conclusions

Routine performance of the FIFA11+ (part 2) program increased glucose uptake. This is related to muscle activity of core and lower limb muscles and improvements in dynamic balance and knee flexor strength. We speculate that these improvements could be beneficial in lowering the risk of sports-related injuries. The PET-CT could be useful for evaluating and improving the sports injury prevention training programs with identifying the underlying pathways.

Acknowledgements

The authors would like to express their appreciation for the outstanding efforts and positive attitude of the participants. In addition, they are extremely grateful for the technical assistance with the measurement provided by physical therapists of our hospital.

Author contributions

TO and JN conceptualized the study. TO and AI involved in data curation. TO, AN, and TM involved in formal analysis. TO, YT, and KS investigated the study. TO, AI, TM, and JN involved in methodology. SK and HT involved in project administration. TO, YT, KS, and JN involved in resource collection. SK and HT supervised the study. TO, AI, and TM validated the study. TO helped in writing the original article. TO, JN, SK, and HT reviewed and edited the manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Takeshi Oshima @ https://orcid.org/0000-0002-8869-4603

Supplemental material

Supplemental material for this article is available online.

Ethical approval

This study was approved by the ethics committee of Kanazawa University (approval number: 1286).

References

1. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. Am J Sports Med 2005; 33(7): 1003–1010.
2. Zebis MK, Andersen LL, Brandt M, et al. Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: a randomised controlled trial. Br J Sports Med 2016; 50(9): 552–557.
3. Nakase J, Inaki A, Mochizuki T, et al. Whole body muscle activity during the FIFA 11+ program evaluated by positron emission tomography. PLoS One 2013; 8(9): e73898.
4. Takata Y, Nakase J, Inaki A, et al. Changes in muscle activity after performing the FIFA 11+ programme part 2 for 4 weeks. *J Sports Sci* 2016; 34(20): 2011–2017.

5. Ohnuma M, Sugita T, Kokubun S, et al. Muscle activity during a dash shown by 18F-fluorodeoxyglucose positron emission tomography. *J Orthop Sci* 2006; 11(1):42–45.

6. Impellizzeri FM, Bizzini M, Dvorak J, et al. Physiological and performance responses to the FIFA 11+ (part 2): a randomised controlled trial on the training effects. *J Sports Sci* 2013; 31(13): 1491–1502.

7. Daneshjoo A, Mokhtar AH, Rahnama N, et al. The effects of injury preventive warm-up programs on knee strength ratio in young male professional soccer players. *PLoS One* 2012; 7(12): e50979.

8. Barenco N, Meneses-Echávez J, Ramírez-Vélez R, et al. The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *Int J Environ Res Public Health* 2014; 11(11): 11986–12000.

9. Imaoka K, Murase H and Fukuhara M. Collection of data for healthy subjects in stabilometry. *Equilib Res* 1997; 56(12 Suppl): 1–84.

10. Okuda K, Abe N, Katayama Y, et al. Effect of vision on postural sway in anterior cruciate ligament injured knees. *J Orthop Sci* 2005; 10(3): 277–283.

11. Demura S, Yamaji S, Noda M, et al. Examination of parameters evaluating the center of foot pressure in static standing posture from the viewpoints of trial-to-trial reliability and interrelationships among parameters. *Equilib Res* 2001; 60(1): 44–55.

12. Hertel J, Miller SJ and Denegar CR. Intra-tester and inter-tester reliability during the star excursion balance tests. *J Sport Rehabil* 2000; 9(2): 104–116.

13. Tankevicius G, Lankaite D, and Krisciunas A. Test-retest reliability of biodex system 4 pro for isometric ankle-eversion and -inversion measurement. *J Sport Rehabil* 2013; 22(3): 212–215.

14. Impellizzeri FM, Bizzini M, Rampinini E, et al. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clin Physiol Funct Imaging* 2008; 28(2): 113–119.

15. Reichkendler MH, Auerbach P, Rosenkilde M, et al. Exercise training favors increased insulin-stimulated glucose uptake in skeletal muscle in contrast to adipose tissue: a randomized study using FDG PET imaging. *Am J Physiol Metab* 2013; 305(4): E496–E506.

16. Richter EA and Hargreaves M. Exercise, GLUT4, and skeletal muscle glucose uptake. *Physiol Rev* 2013; 93(3): 993–1017.

17. Bojsen-Møller J, Kalliokoski KK, Seppänen M, et al. Low-intensity tensile loading increases intratendinous glucose uptake in the achilles tendon. *J Appl Physiol* 2006; 101(1): 196–201.

18. Kaji A, Sasagawa S, Kubo T, et al. Transient effect of core stability exercises on postural sway during quiet standing. *J Strength Cond Res* 2010; 24(2): 382–388.

19. Granacher U, Lacroix A, Muehlbauer T, et al. Effects of core instability strength training on trunk muscle strength, spinal mobility, dynamic balance and functional mobility in older adults. *Gerontology* 2013; 59(2): 105–113.

20. Willson JD, Dougherty CP, Ireland ML, et al. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg* 2005; 13(5): 316–325.

21. Day JT, Lichtwark GA, and Cresswell AG. Tibialis anterior muscle fascicle dynamics adequately represent postural sway during standing balance. *J Appl Physiol* 2013; 115(12): 1742–1750.

22. Earl JE and Hertel J. Lower-extremity muscle activation during the star excursion balance tests. *J Sport Rehabil* 2001; 10(2): 93–104.

23. Daneshjoo A, Mokhtar AH, Rahnama N, et al. The effects of comprehensive warm-up programs on proprioception, static and dynamic balance on male soccer players. *PLoS One* 2012; 7(12): e51568.

24. Croisier J-L, Ganteaume S, Binet J, et al. Strength Imbalances and prevention of hamstring injury in professional soccer players. *Am J Sports Med* 2008; 36(8): 1469–1475.

25. Yeung SS, Suen AMY, and Yeung EW. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *Br J Sports Med* 2009; 43(8): 589–594.

26. Bourne MN, Opar DA, Williams MD, et al. Eccentric knee flexor strength and risk of hamstring injuries in rugby union. *Am J Sports Med* 2015; 43(11): 2663–2670.