Available online at www.sciencedirect.com
SciVerse ScienceDirect
Journal of Sport and Health Science 3 (2014) 227−232
www.jshs.org.cn

Original article

Lower extremity injury in female basketball players is related to a large difference in peak eversion torque between barefoot and shod conditions

Jennifer M. Yentes [a], Max J. Kurz [b], Nicholas Stergiou [a,c,*]

[a] Nebraska Biomechanics Core Facility, Department of Health, Physical Education and Recreation, University of Nebraska at Omaha, Omaha, NE 68182, USA
[b] Munroe-Meyer Institute, Department of Physical Therapy, University of Nebraska Medical Center, Omaha, NE 68198, USA
[c] College of Public Health, Department of Environmental Health, Occupational Health and Toxicology, University of Nebraska Medical Center, Omaha, NE 68198, USA

Received 13 July 2012; revised 30 August 2012; accepted 12 November 2012

Abstract

Background: The majority of injuries reported in female basketball players are ankle sprains and mechanisms leading to injury have been debated. Investigations into muscular imbalances in barefoot versus shod conditions and their relationship with injury severity have not been performed. The purpose of this study was to investigate the effects of wearing athletic shoes on muscular strength and its relationship to lower extremity injuries, specifically female basketball players due to the high incidence of ankle injuries in this population.
Methods: During pre-season, 11 female collegiate basketball players underwent inversion and eversion muscle strength testing using an isokinetic dynamometer in both a barefoot and shod conditions. The difference between conditions was calculated for inversion and eversion peak torque, time to peak torque as well as eversion-to-inversion peak torque percent strength ratio for both conditions. Lower extremity injuries were documented and ranked in severity. The ranked difference between barefoot and shod conditions for peak torque and time to peak torque as well as percent strength ratio was correlated with injury ranking using a Spearman rho correlation (ρ) with an α level of 0.05.
Results: The ranked differences in barefoot and shod for peak eversion and inversion torque at 120°/s were correlated with their injury ranking. Ranking of the athletes based on the severity of injuries that were sustained during the season was found to have a strong, positive relationship with the difference in peak eversion torque between barefoot and shod ($\rho = 0.78$; $p = 0.02$).
Conclusion: It is possible that a large discrepancy between strength in barefoot and shod conditions can predispose an athlete to injury. Narrowing the difference in peak eversion torque between barefoot and shod could decrease propensity to injury. Future work should investigate the effect of restoration of muscular strength during barefoot and shod exercise on injury rates.

Keywords: Ankle sprain; Isokinetic dynamometer; Muscular imbalance; Strength

1. Introduction

More than 60% of all college women's basketball injuries occur in the lower extremities.[1] Over a 16-year period, 24.6% of these injuries were due to ankle ligament sprains during games and practices. Ankle ligament sprains were the second ranked injury leading to 10 or more days of activity loss, with knee internal derangement being the first leading cause.[1] Furthermore, a history of ankle sprains would leave a player five times more likely to sustain another ankle injury.[1] The incidence of injury in female high school basketball players

* Corresponding author. Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, Omaha, NE 68182, USA.
E-mail address: nstergiou@unomaha.edu (N. Stergiou)
Peer review under responsibility of Shanghai University of Sport

Production and hosting by Elsevier

2095-2546
http://dx.doi.org/10.1016/j.jshs.2012.11.004

demonstrates a similar pattern, with ankle sprains as the leading injury sustained.[2]

Several investigations into the primary etiology of ankle sprains have been conducted to probe the biomechanical mechanisms that may be responsible for the high incidence of ankle ligament sprains in female basketball players. Baumhauer et al.[3] concluded that eversion-to-inversion strength ratio was a predictive measure of ankle injury. This finding has not been consistently supported, as these results have not been clearly replicated.[4,5] Hence, several other measures have been evaluated including ankle strength,[4-7] postural sway,[6,7] proprioception,[5] shoe height,[8,9] and peroneal reaction time.[10,11] Fong et al.[12] recently listed the two main causes to ankle sprains as improper foot positioning during heel strike and delayed reaction time of the peroneal musculature. Even still, the etiology of ankle sprains has yet to be clearly defined.

There is strong evidence that shoes can control the motion and position of the foot and provide cushion.[13−16] However, despite the advances in shoe construction, lower extremity injuries are still being reported in large numbers.[1] Prevention of injury may be dependent on intrinsic muscular strength of the ankle complex. In terms of foot and ankle musculature, the tibialis anterior (invertor) and triceps surae could be considered as larger muscles, that are most responsive to movement in the sagittal plane and not as responsive to movement in the frontal plane.[17] Smaller musculature about the ankle and foot provide stability quickly and easily to the ankle joint complex by reacting faster to joint movement changes.[17] Nigg[18] has demonstrated that increased strength in these smaller, intrinsic muscles may lead to improved performance and protection, while the opposite can also be true. Therefore the strength of these smaller, intrinsic muscles may have an important relationship with susceptibility to lower extremity injury.

Avoidance of excessive movement about the ankle is provided by the ankle musculature, but only if the musculature is properly activated. This is especially true for smaller intrinsic muscles which provide stability to the ankle joint complex by reacting faster to joint movement changes.[17,18] Essentially, deconditioned musculature may not only cause a decrease in the force production to control excessive subtalar motion, but also may delay neuromuscular responses.[11] Support for this notion has been demonstrated when soccer and cross-country runners with and without ankle instability were tested for central and peripheral reaction times. It was found that players with severe ankle instability demonstrated peripheral latency of peroneal muscles.[11] When activated, the ankle and foot musculature take considerable milliseconds (i.e., 92−133 ms) after the latency period before maximal muscular strength can be developed.[8] It is possible that deconditioning or atrophy of the muscular structure of the foot and ankle would cause a delay in peripheral reaction, leading to increased latency response of muscle activation and eventually a decrease in the ability to quickly generate force.[19,20] It has also been suggested that decreased sensations provided by wearing shoes may promote the skeletal musculature of the foot and ankle to become deconditioned.[21] This is not to say that if a shoe provides artificial strength, that barefoot play is recommended, rather the goal is to identify a testing method that will allow for identification of athletes predisposed for injury.

Therefore, the purpose of this study was to investigate the effects of wearing athletic shoes on muscular strength and its relationship to lower extremity injuries, specifically female basketball players due to the high incidence of ankle injuries in this population. It was hypothesized that individuals that demonstrated similar ankle eversion strength between barefoot and shod conditions would be less susceptible to injury. Ankle evertor musculature provides support and functions as a dynamic stabilizer of the ankle against inversion; thus playing an important role in preventing inversion ankle sprains and/or lower extremity injury. In order to test this hypothesis, ankle inversion and eversion peak torque in both barefoot and shod conditions was measured prior to a college basketball season. Injuries were then measured prospectively and were recorded throughout the season. At the end of the season, athletic trainers ranked the athletes in terms of injury severity. Ranked differences in peak torque of the athletes were then correlated with ranked injury severity. Thus, a unique feature of this study is its prospective nature and such studies are scarce in the literature.

2. Methods

Eleven female basketball players (age: 20.4 ± 3.2 years; height: 172.0 ± 7.6 cm; mass: 73.5 ± 15.9 kg) from the University of Nebraska at Omaha were consented and participated in the study. The participants were healthy and free from any present musculoskeletal injury. All testing was conducted during the basketball pre-season. All procedures were approved by the University's Institutional Review Board.

Prior to testing, subjects warmed up on a Monarch stationary bicycle at a self-selected pace and resistance for a minimum of 10 min. Eversion and inversion muscular strength when barefoot (barefoot condition) and while wearing their own high-top, basketball shoes (shod condition) were recorded using an isokinetic dynamometer (Biodex System 2.0; Biodex Medical Systems, Shirley, New York, USA). The subjects wore their own shoes to minimize any shoe-type effect by introducing discomfort or lack of adaptability due to the usage of a new shoe. Each subject was seated, with the trunk, thigh, and shank secured. Standard positioning for the ankle inversion and eversion testing was used according to the manufacturer's guidelines. Subjects were seated and their right leg was raised so that the shank was perpendicular to the footplate attachment. With the shank supported, the right foot was secured into the footplate in neutral position and zero degrees plantarflexion. Isokinetic testing of the right ankle was administered at 120°/s within a comfortable range of motion (mean ± SD) for barefoot condition (76.8° ± 12.1°) and shod condition (71.1° ± 16.7°). Three maximal repetitions were performed. A minimum of 24 h of rest was required before the subject returned to undergo testing under the second condition. Presentation of barefoot and shod conditions was randomized between subjects. Prior to each recorded performance, the subject was allowed to perform submaximal and maximal repetitions to prepare for each tested velocity. Verbal encouragement and visual feedback of the results were given in order to obtain maximal effort. After all testing was completed three subjects (subjects 2, 6, and 10) were eliminated from the analysis due to errors in data collection.

Inversion and eversion peak torque and time to peak torque was recorded for barefoot and shod conditions and the difference between conditions was calculated. A positive (+) difference indicated that the barefoot condition demonstrated greater torque and a negative (−) difference indicated that the shod condition demonstrated greater torque. A difference near zero would indicate similar torque values in both the barefoot and shod conditions. For purposes of this study, either a large+ or large − difference in peak torque between conditions was considered detrimental. This is because, whether or not + or −, the shoes had an affect on performance. In one case, a large + difference, in the shoe condition the athlete was weaker and for a large − difference the shoe has made the athlete artificially stronger. Therefore, the absolute values of the differences were then ranked. The largest absolute difference between barefoot and shod conditions was ranked as a 1 and the smallest absolute difference was ranked as an 8. For time to peak torque + difference indicated that the barefoot condition demonstrated a greater amount of time to reach peak and a − difference indicated that the shod condition demonstrated a greater amount of time to reach peak torque.

In addition, eversion-to-inversion peak torque percent strength ratios were also calculated for both barefoot and shod conditions. The eversion peak torque is divided by the inversion peak torque and multiplied by 100. These were calculated in order to compare our results to previous studies that have investigated the relationship between percent strength ratios and injury occurrences. Percent strength ratios were ranked for both the barefoot and shod conditions from largest percentage to smallest. The largest percentage was ranked as a 1 with the smallest percentage ranked as an 8.

During the basketball season, injuries were recorded (Table 1). An injury was defined as a lower extremity impairment that caused a functional limitation of play or caused the athlete to miss practice(s) or game(s). The University athletic trainers provided diagnosis and reporting of injuries. The university athletic trainers completed ranking of the athletes based on the severity of injuries that were sustained during the season. To maximize objectivity, injuries were first divided into ankle/foot complex injuries and all other lower extremity injuries. Ankle/foot complex injuries were ranked first and severity was based on the number of practices and games missed. After the ranking of all ankle/foot complex injuries all other lower extremity injuries were ranked. Severity of lower extremity injuries was based on the total number of practices and games missed, as with the ankle/foot complex. An injury ranking of 1 would indicate the most severe injury and a ranking of 8 would indicate no injuries.

Peak torque, time to peak torque, and percent strength ratio were checked for normality using Shapiro−Wilk's W test. Thus, mean difference between conditions was investigated by employing dependent t tests. The ranked difference between barefoot and shod conditions for inversion and eversion, time to peak torque as well as the ranked percent strength ratio for both conditions was correlated with injury ranking using a Spearman rho correlation (ρ). Based on the hypothesis, a positive relationship would be present. An individual with an injury ranking of 1 would have a large difference in torque or large percent strength ratio; whereas, an individual with an injury ranking of 8 would have a difference in torque near zero or a small percent strength ratio. Strengths of correlations were defined as follows: ±1.00 to 0.80 = very strong; ±0.79 to 0.60 = strong; ±0.59 to 0.40 = moderate; ±0.39 to 0.20 = weak; ±0.19 to 0 = no relationship.[22] All statistical analysis was done using SPSS 16.0 (IBM Corporation, Armonk, NY, USA). The α level was set at 0.05.

Table 1
Athletes' injuries documented and ranking based upon severity.

Subject number	Injury(ies)	Practices/ games missed	Ranking
1	L-knee, 3° ACL	10/20	6
3	No injuries	0/0	8
4	L-hip, trochanteric bursitis	0/0	7
5	L-ankle, ATF sprain	1/0	3
	R-knee, plica irritation	0/0	
	L-knee, patellar tendinitis	0/0	
7	L-foot, accessory navicular w/avulsion fracture	4/10	1
	R-hip, trochanteric bursitis	0/0	
8	L-ankle, peroneal subluxation	3/0	2
9	L-ankle, 1° ATF sprain and peroneal tendinitis	0/0	4
11	R-low leg, tib-fib strain	0/0	4
	R-knee, contusion	0/0	
	R-hip, IT strain	0/0	

Abbreviations: ACL = anterior cruciate ligament; ATF = anterior talofibular ligament; IT = iliotibial tract.

3. Results

There were no significant differences in peak torque between barefoot and shod conditions for either inversion or eversion (Table 2). There was no significant difference in time to peak torque or eversion-to-inversion percent strength ratio between barefoot and shod conditions. Ranking of the athletes based on the severity of injuries that were sustained during the season was found to have a moderate to strong positive relationship with the difference in peak eversion torque between barefoot and shod conditions ($\rho = 0.78$, $p = 0.02$). There was

Table 2
Mean ± SD differences condition for each dependent variable.

Variable	Barefoot	Shod	p value
Peak eversion (N × m)	13.7 ± 4.6	13.3 ± 2.9	0.704
Peak inversion (N × m)	10.1 ± 4.9	11.1 ± 4.1	0.698
Time to peak eversion (ms)	280.8 ± 64.1	257.0 ± 68.0	0.290
Time to peak inversion (ms)	288.8 ± 145.1	208.9 ± 35.0	0.168
Eversion-to-inversion percent strength ratio (%)	154.3 ± 54.8	119.7 ± 16.6	0.248

no significant correlation with the difference in inversion peak torque in barefoot and shod conditions (Table 3). Ranking of the athletes based on the severity of their injuries sustained during the basketball season did not demonstrate significant correlations with time to peak torque or eversion-to-inversion percent strength ratio while barefoot or shod (Table 3).

4. Discussion

The current study investigated the relationship of the rank of lower extremity injuries sustained during a collegiate basketball season and the ranked difference in peak eversion and inversion torque between barefoot and shod conditions in female basketball players. In agreement with the proposed hypothesis, the ranked difference between barefoot and shod conditions for peak eversion torque at 120°/s demonstrated strong correlations with ranked lower extremity injuries. Collegiate female basketball players that demonstrated a large difference in peak eversion torque between barefoot and shod conditions demonstrated a greater tendency for lower extremity injuries during a collegiate basketball season. These findings indicate that the difference in evertor musculature performance between barefoot and shod conditions may play an important role in preventing lower extremity injuries.

In addition to acting as a dynamic stabilizer of the ankle, the peroneal musculature provides support to the lateral ligaments of the ankle and functions as a static stabilizer of the ankle against inversion. To prevent ankle inversion injury, it has been hypothesized that preactivated evertor musculature can be employed as a strategy to stiffen the structures about the subtalar joint.[23] Ashton-Miller et al.[23] provided evidence that if the evertor musculature was fully activated, without the use of high-top shoes, an orthosis or athletic tape, that this muscle group could enhance passive resistance at an inversion angle of 15°. In some cases, the evertor musculature alone was able to generate three times the amount of torque without the use of high-top shoes, orthoses and/or athletic tape.[23] Ottaviani et al.[9] have further extended this notion by hypothesizing that for any given body size, increased muscular strength of the evertor muscle group would allow for greater resistance to inversion about the subtalar joint. On the other hand, extreme peak eversion torque has been related with complications in the Achilles tendon, by forcing the Achilles tendon laterally and distributing stress unevenly across the tendon.[24] It is apparent that the evertor musculature play an important role in preventing ankle injury; however, there is also evidence that too much of a contribution from the evertors may also lead to injury.

Table 3
Results of the Spearman rho correlation.

Variable	ρ	ρ^2	p value	Strength
Difference in eversion peak	0.78	0.60	0.02	Strong
Difference in inversion peak	0.06	0	0.89	No relationship
Difference in time to peak eversion	0.30	0.09	0.48	Weak
Difference in time to peak inversion	0.22	0.05	0.61	Weak
ETI percent strength ratio while barefoot	0.32	0.10	0.44	Weak
ETI percent strength ratio with shoes	0.10	0.01	0.82	No relationship

Note: Ranking of the athletes based on the severity of injuries that were sustained during the season was correlated (ρ) with the ranked difference in peak torque between barefoot and shod conditions. A positive correlation would indicate that athletes with the most severe injuries to the ankle/foot complex were related to large differences in peak torque between conditions or a large percent strength ratio.
Abbreviation: ETI = eversion-to-inversion.

Previous studies have found no significant differences in peak eversion torque between subjects with and without ankle instability[3,4,6] and between dominant and non-dominant limbs.[7] However, we were unable to find a study that investigated the difference in peak eversion torque between barefoot and shod conditions correlated with ranked injuries sustained within a competitive season. It is possible that a large difference between barefoot and shod conditions would predispose an athlete to lower extremity injury. When an athlete is stronger in the barefoot condition than the shod condition, the shoe is making them weaker. Wearing shoes can lead to deconditioning in intrinsic ankle musculature through underutilization.[17,25] Habitually barefoot runners demonstrate altered mechanics[26,27] and possibly lower injury rates[21] yet, there is no clear evidence.[17] Based on previous findings, it is believed that persons that wear shoes more often lose sensory feedback that is needed to produce protective adaptations to movement, such as diminishing impact through the medial arch or alteration of mechanics.[21] Further, decreased proprioception due to previous ankle injury in addition to weakness exhibited in the peroneal longus and brevis muscles (ankle evertors) is also related with a history of ankle injury.[5] Prolonged peroneal reaction times have been targeted as a main cause of ankle instability,[10,11] leading to delayed generation of peak torque.[8] Neuromuscular deficits would then lead to a compromise in the protective effect of the evertor musculature on ankle joint stability.[4] Although, barefoot play is not feasible, it is possible that training of intrinsic musculature under barefoot conditions would be advantageous to the athlete during shod play.

Conversely, when the athlete is stronger in the shod condition than in the barefoot condition, the shoe provides artificial strength. Rehabilitation of foot musculature is possible,[21] allowing for the skeletal muscle to adapt to barefoot conditions. Indirect evidence is supportive by suggesting that using a wobble board-based balance training program in healthy adolescents led to a reduction in sports-related injuries through increased strength of muscles crossing the ankle joint complex.[28] A similar study investigating the effect of proprioceptive balance board training in adult athletes on ankle sprain re-injury is currently being conducted.[29] Future work should investigate the ability of rehabilitation of intrinsic foot musculature and its association with lower extremity injury in female basketball players. It is possible that by increasing the strength of intrinsic musculature while barefoot, the ankle would better react to movement.

Previous studies have attempted to relate occurrences of injury to muscular imbalances, specifically eversion-to-inversion strength ratio.[3,4] Many of these studies have demonstrated that no differences in eversion-to-inversion strength ratios exist between persons with and without ankle instability.[4-6] To our knowledge, our study is the first study that has related muscular imbalances between barefoot and shod conditions to lower extremity injuries. In agreement with these previous studies, we did not find a significant association between injury and the difference between barefoot and shod conditions for eversion-to-inversion strength ratio (Table 3).

Limitations of this study include the investigation of concentric torques only. Future work should investigate the difference in eccentric peak torque during barefoot and shod conditions as well. Previous work has demonstrated that subjects with and without a history of injury demonstrate a lack of difference in eccentric peak in-eversion torque.[4,6] It is possible that a difference would exist in these individuals if tested with and without shoes. In addition, the injuries reported in this current study were constrained to the lower extremity. The correlation between the difference in peak eversion torque in barefoot and shod conditions may have been stronger if injury reporting was limited to only the ankle joint. In an attempt to overcome this limitation, we ranked ankle/foot complex injuries first, followed by all other lower extremity injuries. This would indicate that an injury ranking of 1 would be the most severe ankle/foot complex injury. Nevertheless, the strong correlation exists even with reporting all lower extremity injuries. Further, previous injury was not recorded. It is feasible that previous injury to the lower extremity predisposed individuals to current injury.

5. Conclusion

This study was the first to investigate the ranked differences in ankle strength between barefoot and shod conditions and their relationship to ranking of the athletes based on the severity of lower extremity injuries that were sustained during a collegiate basketball season. A unique feature of this study is its prospective nature and such studies are scarce in the literature. We found that the difference between barefoot and shod peak eversion torque at 120°/s was significantly and strongly related with lower extremity injury severity. It is possible that a large discrepancy between strength in barefoot and shod conditions can predispose an athlete to injury. Future work should investigate the effect of restoration of muscular strength during barefoot and shod exercise on injury rates. Based on the findings of this current work, by narrowing the difference in peak eversion torque between barefoot and shod conditions would decrease injury severity in female basketball players.

References

1. Agel J, Olson DE, Dick R, Arendt EA, Marshall SW, Sikka RS. Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988−1989 through 2003−2004. *J Athl Train* 2007;**42**:202−10.
2. Gomez E, DeLee JC, Farney WC. Incidence of injury in Texas girls' high school basketball. *Am J Sports Med* 1996;**24**:684−7.
3. Baumhauer JF, Alosa DM, Renström AF, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. *Am J Sports Med* 1995;**23**:564−70.
4. Beynnon BD, Renström PA, Alosa DM, Baumhauer JF, Vacek PM. Ankle ligament injury risk factors: a prospective study of college athletes. *J Orthop Res* 2001;**19**:213−20.
5. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train* 2002;**37**:487−93.
6. Wang H, Chen C, Shiang T, Jan M, Lin K. Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Arch Phys Med Rehabil* 2006;**87**:821−5.
7. Bernier JN, Perrin DH, Rijke A. Effect of unilateral functional instability of the ankle on postural sway and inversion and eversion strength. *J Athl Train* 1997;**32**:226−32.
8. Ottaviani RA, Ashton-Miller J, Kothari SU, Wojtys EM. Basketball shoe height and the maximal muscular resistance to applied ankle inversion and eversion moments. *Am J Sports Med* 1995;**23**:418−23.
9. Ottaviani RA, Ashton-Miller J, Wojtys EM. Inversion and eversion strengths in the weightbearing ankle of young women. Effects of plantar flexion and basketball shoe height. *Am J Sports Med* 2001;**29**:219−25.
10. Konradsen L, Ravn JB. Prolonged peroneal reaction time in ankle instability. *Int J Sports Med* 1991;**12**:290−2.
11. Konradsen L, Ravn JB. Ankle instability caused by prolonged peroneal reaction time. *Acta Orthop Scand* 1990;**61**:388−90.
12. Fong DT, Chan Y, Mok K, Yung PS, Chan K. Understanding acute ankle ligamentous sprain injury in sports. *Sports Med Arthrosc Rehabil Ther Technol* 2009;**1**:14.
13. Bates BT, Osternig LR, Mason BR, James SL. Functional variability of the lower extremity during the support phase of running. *Med Sci Sports* 1979;**11**:328−31.
14. Braunstein B, Arampatzis A, Eysel P, Brüggemann G. Footwear affects the gearing at the ankle and knee joints during running. *J Biomech* 2010;**43**:2120−5.
15. Divert C, Mornieux G, Freychat P, Baly L, Mayer F, Belli A. Barefoot-shod running differences: shoe or mass effect? *Int J Sports Med* 2008;**29**:512−8.
16. Morio C, Lake MJ, Gueguen N, Rao G, Baly L. The influence of footwear on foot motion during walking and running. *J Biomech* 2009;**42**:2081−8.
17. Nigg BM. Biomechanical considerations on barefoot movement and barefoot shoe concepts. *Footwear Sci* 2009;**1**:73−9.
18. Nigg BM. Der MBT Schuh und seine biomechanische/therapeutische Wirkungsweise (the MBT shoe and its biomechanical and therapeutical effects). *Med Orthop Technik* 2005;**3**:77−8.
19. Lajtai G, Wieser K, Ofner M, Raimann G, Aitzetmüller G, Jost B. Electromyography and nerve conduction velocity for the evaluation of the infraspinatus muscle and the suprascapular nerve in professional beach volleyball players. *Am J Sports Med* 2012;**40**:2303−8.
20. Visser J, de Visser M, Van den Berg-Vos RM, Van den Berg LH, Wokke JHJ, de Jong JMBV, et al. Interpretation of electrodiagnostic findings in sporadic progressive muscular atrophy. *J Neurol* 2008;**255**:903−9.
21. Robbins SE, Hanna AM. Running-related injury prevention through barefoot adaptations. *Med Sci Sports Exerc* 1987;**19**:148−56.
22. Safrit MJ, Wood TM. *Introduction to measurement in physical education and exercise science*. 3rd ed. St. Louis: McGraw-Hill; 1995.
23. Ashton-Miller J, Ottaviani RA, Hutchinson C, Wojtys EM. What best protects the inverted weightbearing ankle against further inversion? Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses. *Am J Sports Med* 1996;**24**:800−9.
24. Clement DB, Taunton JE, Smart GW, McNicol KL. A survey of overuse running injuries. *Phys Sportsmed* 1981;**9**:47−58.

25. Landry SC, Nigg BM, Tecante KE. Standing in an unstable shoe increases postural sway and muscle activity of selected smaller extrinsic foot muscles. *Gait Posture* 2010;**32**:215−9.
26. Lieberman DE, Venkadesan M, Werbel WA, Daoud AI, D'Andrea S, Davis IS, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature* 2010;**463**:531−5.
27. Squadrone R, Gallozzi C. Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. *J Sports Med Phys Fitness* 2009;**49**:6−13.
28. Emery CA, Cassidy JD, Klassen T, Rosychuk RJ, Rowe BH. The effectiveness of a proprioceptive balance training program in healthy adolescents. A cluster randomized controlled trial. *CMAJ* 2005;**172**:749−55.
29. Hupperets MD, Verhagen EA, van Mechelen W. The 2BFit study: is an unsupervised proprioceptive balance board training programme, given in addition to usual care, effective in preventing ankle sprain recurrences? Design of a randomized controlled trial. *BMC Musculoskelet Disord* 2008;**9**:71.