MedicalExpress

ORIGINAL RESEARCH

Analysis of acceleration time of ankle in long-distance runners and triathletes

Natália Mariana Silva Luna[I,II], Angélica Castilho Alonso[I,II], Danilo Bocalini[II], Gabriela Borin[I], Guilherme Carlos Brech[I], Júlia Maria D'Andréa Greve[I]

[I] Hospital das Clínicas (HC), Faculdade de Medicina (FMUSP), Instituto de Ortopedia e Traumatologia (IOT), Laboratório de Estudos do Movimento (LEM)), São Paulo, Brazil
[II] Universidade São Judas Tadeu (USIT), Graduate Program in Aging Science, São Paulo, Brazil

INTRODUCTION: Adequate muscle reaction time is essential for protecting the joints against injuries during sports activities. This phenomenon of time of acceleration has been investigated through methodologies such as trapdoor experiments and electromyography. However, isokinetic analysis is an assessment method that is more dynamic and shows behavior closer to the functionality of the sport. Sports that involve running, such as long distance running and triathlon, have high lower-limb injury rates, particularly in relation to the ankle joint. The objective of this study was to evaluate and compare isokinetic acceleration and deceleration times of the dorsiflexor and plantar flexor musculature of the ankle in long-distance runners, triathletes and non-athletic individuals.
METHOD: The sample comprised 75 individuals (men aged 18-42 years), divided into three groups: triathlete group, long-distance runner group and control group. The individuals were tested bilaterally on an isokinetic dynamometer. The evaluation modes used were (i) concentric/eccentric for plantar flexion and dorsiflexion, and (ii) eccentric/concentric for plantar flexion and dorsiflexion. We used (a) analysis of variance and Tukey's post hoc test; (b) Kruskal-Wallis and Müller-Dunn post hoc tsts; (c) Chi-square tests.
RESULTS: The acceleration time during concentric contraction was statistically different only between the control group and the long-distance runner group, such that the controls presented faster acceleraton.
CONCLUSION: This may signify a deficiency in their motor sensory control during concentric activity of the dorsiflexors.

KEYWORDS: Isokinetic, Running, Triathlon.

Lunal NMS, Alonso AC, Bocalini D, Borin G, Brech GC, Greve JMD. Analysis of acceleration time of ankle in long-distance runners and triathletes. MedicalExpress (São Paulo, online). 2017 Aug;4(4):M170404

Received for Publication on May 10, 2017; **First review** on June 23, 2017; **Accepted for publication** on July 18, 2017; **Online on** August, 14, 2017

E-mail: nmsluna@gmail.com

INTRODUCTION

Sports such as running, which have increased in popularity worldwide, have high lower-limb injury rates, particularly in relation to the ankle[1]. Among triathlon competitors, greater numbers of injuries can be seen;[2] most of these are in the lower limbs (59.5%) and occur during the running event (38%).[3,4]

An adequate muscle reaction time is essential for protecting the joints against injuries during sports activities that demand rapidly coordinated muscle action.[5] The muscle reaction mechanism is related to the arthrokinetic reflex,[6] which is influenced by velocity and acceleration; these, in turn, are important parameters in relation to motor function but have been less investigated than muscle strength and resistance.[7]

The phenomenon of acceleration has been investigated through methodologies such as trapdoor experiments and electromyography.[8-10] However, isokinetic analysis is an assessment method that is more dynamic[11] and shows a behavior that is closer to the functionality of the sport.

DOI: 10.5935/MedicalExpress.2017.04.04

Isokinetic evaluation defines the variable of acceleration time as "the time required to accelerate to a preset dynamometer speed".[11] This isokinetic variable has been correlated with the nerve conduction velocity.[7]

Because it is well established that the isokinetic muscle characteristics for any given sport reflect specific features and demands of the sport practice,[11-15] analysis of the variable "acceleration time" in running and triathlon athletes is essential in order to draw up further strategies for injury prevention programs. Moreover, there is a scarcity of data on this variable in isokinetic ankle tests, and such tests need to be reproducible for better sports practice.

Thus, the objective of this study was to evaluate and compare the acceleration and deceleration times of the dorsiflexor and plantar flexor musculature of the ankle, by means of isokinetic dynamometry, among long-distance runners, triathletes and non-athletic individuals.

METHODS

Ethics committee

This project was approved by the Ethics Committee for Research Project Analysis (CAPPesq) of the Clinical Board of Hospital das Clínicas, School of Medicine of the University of São Paulo, case # 932/08. All the participants were duly informed about the procedures and stages of the study and signed a free and informed consent statement.

Sample

The sample included 75 men aged 18 to 42 years, part of a larger study. Participants were divided into three groups: 26 triathletes (triathlete group - TG), 23 long-distance runners (long-distance runner group - LDRG) and 26 non-athletic individuals (control group - CG). Sample size calculation indicated that 22 individuals in each group allow (at a power of 90%) us to conclude that differences greater than or equal to two standard deviations would be statistically significant at a significance level of 5%.

Individuals in the two groups of athletes were contacted through sports advisors for triathlon and running and recruited following a selection of those candidates who met the required criteria. Individuals in the control group were recruited by publicizing the study among employees, undergraduate and graduate students at Hospital das Clínicas, School of Medicine of the University of São Paulo.

The inclusion criteria for each group were as follows:

1. Triathlete group (TG) – regular training in this sport for competitive purposes, (6.5 ± 5.6 years); weekly training volume (homogenous over the three months prior to the evaluations) of a minimum of 30 km of running (50.7 ± 16.0 km), 60 km of cycling (230.7 ± 84.1 km) and 5 km of swimming (9.3 ± 4.1 km).

2. Long-distance runner group (LDRG) – regular training in this sport for competitive purposes (6.8 ± 6.0 years); weekly training volume (homogenous over the three months prior to the evaluations) of a minimum of 60 km (104.2 ± 36.8 km).[15]

3. Control group (GC) – physical activity practice with the aim of maintaining aerobic physical conditioning, without any regular sports training aims; frequency of this physical activity from two to three times a week (2.7 ± 0.4 (homogenous over the three months prior to the evaluations).[16]

The exclusion criteria common to the three groups were the following: presence of ankle joint injuries over the last six months, injury defined as an event that put the athlete out of the sport for 24 hours or more consecutively;[17] presence of pain during the period when the tests were being done.

Table 1 describes the anthropometric data on the individuals of the three groups (weight, height and age).

Table 1 - Means, standard deviations and minimum and maximum ages (years), height (m) and body mass (kg) in the triathlete, long-distance runner and control groups.

	Minimum	Mean (SD)	Maximum
Age (years)			
Triathlete group	26	33.03±4.42	42
Long-distance runner group	17	28.86±7.63	41
Control group	19	28.73±6.50	40
Total	17	30.26±6.51	42
Height (m)			
Triathlete group	1.62	1.75±0.05	1.86
Long-distance runner group	1.61	1.71±0.05	1.80
Control group	1.62	1.76±0.06	1.85
Total	1.61	1.74±0.06	1.86
Weight (kg)			
Triathlete group	60.3	73.81±7.44	93.9
Long-distance runner group	50.8	64.22±6.69	84.0
Control group	59.3	74.95±10.05	98.0
Total	50.8	71.26±9.41	98.0

Procedures

The materials needed for carrying out the study were as follows: isokinetic dynamometer (Biodex System 3, with software version 3.2); ergometric bicycle (Moviment, model Biocycle 2600 Electromagnetic); weighing scales (Welmy); and goniometer (Carci).

To carry out the evaluations, appointments were made with the individuals for them to attend a single session. They were instructed to come wearing sports clothes and their usual sports footwear[18] and were required not perform any high intensity physical activity over the preceding 12 hours.

On the day of the evaluation, height and body mass were measured, followed by isokinetic evaluation (Biodex System 3, with the software version 3.2). Before the test, participants did a warm-up exercise on an ergometric bicycle for five minutes, consisting of submaximal effort bicycle (comfortable loading and cadence that would not cause fatigue).[16] Following this, the subjects performed the tests, which consisted of stretching of the dorsiflexor and plantar flexor muscles of the feet in three sets of 30 seconds.[19,20]

Before the tests were started, the isokinetic dynamometer was calibrated and positioned. Participants were placed in a seated position, with the leg to be tested supported in the distal region of the thigh and the sole of the foot supported on a rigid plate, with the knee flexed at 30°. The biological axis of ankle joint was aligned with the mechanical axis of the dynamometer. The rigid plate allowed a range of motion of 20° of plantar flexion from the neutral position of the ankle. The individual was kept in position by means of two belts across the chest and one across the pelvis, with velcro bands over the distal portion of the thigh and the metatarsal area of the dorsal region of the foot. The subjects were instructed to hold onto the lateral supports of the chair to improve their stability.

Once the subject had been positioned, he was allowed three submaximal repetitions of the routine to become familiar with the equipment.[21] The evaluation modes were performed in the following sequence of modes: (i) concentric/eccentric and (ii) eccentric/concentric for ankle.

In the first mode, the individuals were asked to use maximum force and speed to perform plantar flexion (plantar flexion concentric action) and resist dorsiflexion (plantar flexion eccentric action). In the second mode, the individuals were asked to resist plantar flexion movement (dorsiflexors eccentric action) and use maximum force and speed to contract the dorsiflexors (dorsiflexors concentric action).

All the tests were performed bilaterally and always started with the right leg. Each set of 30 repetitions was performed to attain an angular speed of 180°/second,[22] with a rest of 10 seconds between sets. While the tests were being performed, constant standardized verbal encouragement was given, so that the individuals would maintain maximum force during the contractions.[21]

The isokinetic variables analyzed were: acceleration time (time required to reach the angular velocity of 180°/second and deceleration time (time required for deceleration to an angular velocity of zero.

Statistical analysis

The normality of these variables was verified by the Kolmogorov-Smirnov test. The non-dominant and dominant limbs were compared using a t-test for the dependent samples in all groups with the objective of observing possible differences between them. The analyses did not discriminate between the limbs because no significant differences were found between them.

For normally distributed variables ANOVA and Tukey's post hoc test were used. For non-normal distributions, the Kruskal-Wallis and Müller-Dunn post hoc tests were used. Isokinetic performance was analyzed through Chi-square tests to compare the three groups for the eccentric contraction of plantar flexors. The statistical software SPSS (Statistical Package for Social Science, version 15.0 for Windows) was used for the analyses, and a value of $P \leq 0.05$ was considered statistically significant.

RESULTS

To analyze the isokinetic variables at the angular velocity of 180°/second, comparisons were made between the triathlete, long-distance runner and control groups.

Table 2 shows that the control group had a significantly shorter acceleration time compared to Long-distance runners for concentric dorsiflexion. No other differences were observed.

DISCUSSION

Acceleration time is the time needed to attain the pre-established angular velocity in the isokinetic evaluation; deceleration time is time required for deceleration to an angular velocity of zero.[7] The acceleration and deceleration times provide information on the neuromuscular condition and the velocity of regimentation of the muscle fibers.[7,11,22,23,24] So, deficits in these variables may suggest poor proprioception.[7,11,22]

In our study, the acceleration and deceleration times were analyzed for plantar flexion (concentric and eccentric action) and dorsiflexion (concentric and eccentric action) in athlete groups. A somewhat surprising statistical difference was observed for concentric dorsiflexion: controls exhibited a significantly faster acceleration when compared to long distance runners. No other statistical differences were found between the groups for acceleration and deceleration time during the concentric and eccentric contractions of the dorsiflexors and of the plantar flexors.

So, the results of our study are unexpected because one might intuitively expect athletes to perform better than

Table 2 – Means and standard deviations (SD) of the isokinetic variables at the velocity of 180°/second, in the eccentric-concentric mode (ECC/CO) and concentric-eccentric mode (CO/ECC), and comparison between the triathlete, long-distance runner and control groups.

	Triathlete group Mean ± SD	Long-distance runner group Mean ± SD	Control group Mean ± SD	P
	Eccentric/Concentric mode			
Acceleration time for concentric dorsiflexion (msec)	181.1 ± 48.0	183.7 ± 27.7	178.3 ± 105.9	0.003*
	Concentric/Eccentric mode			
Acceleration time for concentric plantar flexion (msec)	16.7 ± 4.7	17.2 ± 5.0	15.8 ± 4.9	0.37
Acceleration time for eccentric plantar flexion (msec)	307.7 ± 390.2	328.4 ± 351.3	413.5 ± 647.4	0.05

* Significant difference between long distance runners and controls.

untrained controls. This may signify a deficiency in their motor sensory control for this activity in the long-distance run and triathlon. Deficits in muscle reaction time can be correlated with alterations to the musculoskeletal system, which in turn compromise the protective effect of the leg muscles on the stability of this ankle joint.[4] In fact, in long-distance aerobic sports such as running and the triathlon, the lower limbs are often the sites of overload injuries.[31]

Adequate proprioception of the ankle is essential for promoting dynamic and functional stability of the ankle in extreme sports, such as long distance running and triathlon.[22] It seems that deficits of the proprioceptive system are the main causes of muscle weakness and postural instability.[25] This should also result in poor protection of the ankle against the indiscriminate mechanisms and so result in injuries.[25]

Few studies have used acceleration and deceleration times as variables during isokinetic evaluations.[7,11,22,23,24,26] Two of those studies addressed ankle and provide information about neuromuscular characteristics,[7,22] while the other studies analyzed other joints.[11,23,24,26]

van Cingel et al[7] reported that subjects with chronic ankle instability showed prolonged acceleration times for the evertor muscles (concentric action) at 30°/s and 120°/s as well as for the invertor muscles (concentric action) at 120°/s, when compared with control subjects. So, the authors suggested that these findings could be related to the inversion trauma and consequently slower motor nerve conduction velocity of the fibular nerve.[7]

Ben Moussa Zouita et al[22] examined isokinetic movements of ankle and reported that proprioceptive training exercises (during 8 weeks) resulted in decreased acceleration and deceleration times for the plantar flexors (concentric action).[22]

Two recent reports[27,28] assessed a parameter related to acceleration time, namely electromechanical delay, which represents the time required by the muscles to provide a protective response to an injury mechanism. The purpose of these studies was to investigate the effect of chronic ankle instability on electromechanical delay times before and after fatigue. They showed that fatigue increases electromechanical delay times, suggesting that fatigue creates a dangerous environment that may predispose to ankle injury.

Concentric and eccentric contractions of the dorsiflexors and the plantar flexors are a very important muscle action for long-distance runners and triathletes and must be effective and timely to ensure that synchrony of movement, joint alignment, postural stability, equilibrium between the acceleration and braking phases, and thus better absorption of the impact, are achieved.[29,30]

Muscle fatigue around the ankle has been correlated with the pathophysiology of stress fractures in sports that involve running[32] due to the loss of the eccentric contraction capacity of the dorsiflexors during heel strike[33] caused by a decline in proprioception of the mechanical stress on the cortical bone layer.[31] This phenomenon might also explain the difficulty encountered by the groups of athletes during the testing of the eccentric dorsiflexor at a 180°/s velocity, which was analyzed qualitatively and presented no statistically significant differences.

The results of our study may be important for guiding the training and physical preparation of runners and triathletes in relation to prevention of ankle lesions. These workouts need to encompass specific functional proprioceptive exercises that can focus on both the concentric and the eccentric contractions of ankle flexors and extensors.

Acceleration and deceleration time in the activity of dorsiflexors and plantar flexors certainly requires further investigation to be better understood. This is the first study that analyzes this variable in runners and triathletes. It is also necessary to address the position of the test and the angular velocities used, which were different from those used during running; this may explain the longer time taken to attain the angular velocity of the test. However, and despite the limitations of isokinetic evaluation (in terms of positioning and angular velocity), its use for analysis in athletes is well established because of the possibility of obtaining precise data on muscle performance.[34] However, it is difficult to compare the various reported isokinetic studies because of differences in the protocols: numbers of repetitions, velocity and type of contraction, as well as the individual's positioning and the brand of dynamometer used.[35]

In conclusion, statistical differences were found between the control vs. the long-distance runner group in relation to the acceleration time during concentric contraction of the dorsiflexors. This result may signify a deficiency in the motor sensory control during concentric and eccentric activity of the dorsiflexors and plantar flexors of the trained athletes.

ACKNOWLEDGEMENTS

The authors thank the participants in the study.

CONFLICT OF INTEREST

The authors of this study declare that they did not have any conflict of interest.

AUTHOR PARTICIPATION

NMS Luna: data collection and writing; AC Alonso: statistical analysis; D Bocalini and G Borin: Writing review; GC Brech: English review; JMD Greve: Guidance and final review.

ANÁLISE DE TEMPO DE ACELERAÇÃO DO TORNOZELO EM CORREDORES DE LONGA DISTÂNCIA E TRIATLETAS

INTRODUÇÃO: O tempo adequado de reação muscular é essencial para proteger as articulações contra lesões durante atividades esportivas. Este fenômeno de tempo de aceleração tem sido investigado por meio de metodologias como experimentos com trampolim e eletromiografia. No entanto, a análise isocinética é um método de avaliação que é mais dinâmico e mostra comportamento mais próximo da funcionalidade do esporte. Corrida de longa distância e triatlo têm altas taxas de lesão de membros inferiores, particularmente em relação à articulação do tornozelo. O objetivo deste estudo foi avaliar e comparar os tempos de aceleração e desaceleração isocinética do dorsiflexor e da musculatura flexora plantar do tornozelo em corredores de longa distância, triatletas e indivíduos não atléticos.

MÉTODO: A amostra incluiu 75 indivíduos (homens com idade entre 18-42 anos), divididos em três grupos: triatletas, corredores de longa distância e grupo controle. Os indivíduos foram testados bilateralmente em um dinamômetro isocinético. Os modos de avaliação utilizados foram: 1. concêntricos/excêntricos para flexão plantar e dorsiflexão; 2. excêntricos/concêntricos para flexão plantar e dorsiflexão. A análise estatística utilizou análise de variância e teste post hoc de Tukey; Testes post hoc de Kruskal-Wallis e Müller-Dunn e testes Qui-quadrado.

RESULTADOS: O tempo de aceleração durante a contração excêntrica foi estatisticamente diferente apenas entre o grupo controle e o grupo corredor de longa distância: os controles apresentaram aceleração mais rápida.

CONCLUSÃO: Este resultado pode indicar uma deficiência no controle sensorial do seu motor durante a atividade concêntrica dos dorsiflexores.

PALAVRAS-CHAVE: Isocinética, Corrida, Triatlo.

REFERENCES

1. Tessutti V, Ribeiro AP, Trombini-Souza F, Sacco, ICN. Attenuation of foot pressure during running on four different surfaces: asphalt, concrete, rubber, and natural grass. Journal of Sports Sciences. 2012;30(14):1545-50. DOI:10.1080/02640414.2012.713975
2. Strock GA, Cottrell ER, Lohman JM. Triathlon. Phys Med Rehabil Clin Am. 2006;17(3):553-64. DOI:10.1016/j.pmr.2006.05.010
3. Gosling CM, Forbes AB, McGivern J, Gabbe BJ. A profile of injuries in athletes seeking treatment during a triathlon race series. Am J Sports Med. 2010;38(5):1007-14. DOI:10.1177/0363546509356979
4. Willems TM, Witvrouw E, Delbaere K, Mahieu N, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. Am J Sports Med. 2005;33(3):415-23. DOI:10.1177/0363546504268137
5. Wilkerson GB, Nitz AJ. Dynamic ankle stability: mechanical and neuromuscular interrelationships. J Sports Rehabil. 1994;3(1):43-57. DOI:10.1123/jsr.3.1.43
6. Heilman AE, Braly WG, Bishop JO, Noble PC, Tullos HS. An anatomic study of subtalar instability. Foot Ankle. 1990;10(4):224-28.
7. van Cingel RE, Kleinrensink G, Uitterlinden EJ, Rooijens PP, Mulder PG, Aufdemkampe G, et al. Repeated Ankle Sprains and Delayed Neuromuscular Response: Acceleration Time Parameters. J Orthop Sports Phys Ther. 2006;36(2):72-9. DOI:10.2519/jospt.2006.36.2.72
8. Johnson MB, Johnson CL. Electromyographic response of peroneal muscles in surgical and nonsurgical injured ankles during sudden inversion. J Orthop Sports Phys Ther. 1993;18(3):497-501. DOI:10.2519/jospt.2006.36.2.72
9. Ebig M, Lephart SM, Burdett RG, Miller MC, Pincivero DM. The effect of sudden inversion stress on EMG activity of the peroneal and tibialis anterior muscles in the chronically unstable ankle. J Orthop Sports Phys Ther. 1997; 26(2):73-7. DOI:10.2519/jospt.1997.26.2.73
10. Vaes P, Van Gheluwe B, Duquet W. Control of acceleration during sudden ankle supination in people with unstable ankles. J Orthop Sports Phys Ther. 2001;31(12):741-52. DOI:10.2519/jospt.2001.31.12.741
11. Chen,WL; Su FC; Chou, YL. Significance of Acceleration Period in a Dynamic Strength testing Study J Orthop Sports Phys Ther. 1994;19(6):324-30. DOI:10.2519/jospt.1994.19.6.324
12. Madsen OR. Torque, total work, power, torque acceleration energy and acceleration time assessed on a dynamometer: reliability of knee and elbow extensor and flexor strength measurements. Eur J Appl Physiol Occup Physiol. 1996;74(3): 206-10.DOI:10.1007/BF00377442
13. Madsen OR. Trunk extensor and flexor strength measured by the Cybex 6000 dynamometer. Assessment of short-term and long-term reproducibility of several strength variables. Spine. 1996;21(23):2770-6. DOI:10.1097/00007632-199612010-00012
14. Crossley K, Bennel KL, Wrigley T, Oakes W. Ground reaction forces, bone characteristics and tibial stress fracture in male runners. Med. Sci. Sports Exerc. 1999;31(8):1088-93. DOI:10.1097/00005768-199908000-00002.
15. Haris Phuah A, Schache AG, Crossley KM, Wrigley TV, Creaby MW. Sagittal plane bending moments acting on the lower leg during running. Gait Posture. 2010;31(2): 218-22. DOI:10.1016/j.gaitpost.2009.10.009

16. Pincivero DM, Gandaio CM, Ito Y. Gender-specific knee extensor torque, flexor torque, and muscle fatigue responses during maximal effort contractions. Eur J Appl Physiol. 2003;89(2):134-41. DOI:10.1007/s00421-002-0739-5
17. Collins K, Wagner M, Peterson K, Storey M. Overuse injuries in triathletes: a study of the 1986 Seafair Triathlon. Am J Sports Med. 1989;17(5):675-80. DOI:10.1177/036354658901700515
18. Hreljac A, Marshall RN, Hume PA. Evaluation of lower extremity overuse injury potential in runners. Med. Sci. Sports Exerc. 2000;32(9):1635-41.
19. Horstmann T, Mayer F, Maschmann J, Niess A, Roecker K, Dickhuth HH. Metabolic reaction after concentric and eccentric endurance-exercise of the knee and ankle. Med. Sci. Sports Exerc. 2001;33(5):791-5.
20. Tang SFT, Chen C-K, Hsu R, Chou S-W, Hong W-H, Lew HL. Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercises in patients with patellofemoral pain syndrome: an electromyographic study. Arch Phys Med Rehabil. 2001;82(10):1441-5. DOI:10.1053/apmr.2001.26252
21. Calmels PM, Nellen M, van der Borne I, Jourdin P, Minaire P. Concentric and eccentric isokinetic assessment of flexor-extensor torque ratios at the hip, knee, and ankle in a sample population of healthy subjects. Arch Phys Med Rehabil. 1997;78(11):1224-30. DOI:10.1016/S0003-9993(97)90336-1
22. Ben Moussa Zouita A, Majdoub O, Ferchichi H, Grandy K, Dziri C, Ben Salah FZ. The effect of 8-weeks proprioceptive exercise program in postural sway and isokinetic strength of ankle sprains of Tunisian athletes. Ann Phys Rehabil Med. 2013;56(9-10): 634-43. DOI:10.1016/j.rehab.2013.08.003.
23. Baldon Rde M, Furlan L, Serrão FV. Influence of the hip flexion angle on isokinetic hip rotator torque and acceleration time of the hip rotator muscles. J Appl Biomech. 2013;29(5): 593-9. DOI:10.1123/jab.29.5.593.
24. Avila MA, Brasileiro JS, Salvini TF. Electrical stimulation and isokinetic training: effects on strength and neuromuscular properties of healthy young adults. Rev. bras. fisioter. 2008;12(6):435-40. DOI:10.1590/S1413-35552008005000006
25. Clark VM, Burden AM. A 4-week wobble board exercise programme improved muscle onset latency and perceveid stability in individuals with a functional unstable ankle. Physical Therapy in Sport. 2005;6(4):181-7. DOI: 10.1016/j.ptsp.2005.08.003
26. Camargo PR, Avila MA, Asso NA, Salvini TF. Muscle performance during isokinetic concentric and eccentric abduction in subjects with subacromial impingement syndrome. Eur J Appl Physiol. 2010;109(3):389-95. DOI:10.1007/s00421-010-1365-2
27. Flevas DA, Bernard M, Ristanis S, Moraiti C, Georgoulis AD, Pappas E. Peroneal electromechanical delay and fatigue in patients with chronic ankle instability. Knee Surg Sports Traumatol Arthrosc. 2017;25(6):1903-7. doi:10.1007/s00167-016-4243-6
28. Cavanagh PR, Komi PV. Electromechanical delay in human skeletal muscle under concentric and eccentric contractions. Eur J Appl Physiol Occup Physiol. 1979; 42(3):159-63.
29. McCrory JL, Martin DF, Lowery RB, Cannon DW, Curl WW, Read HM Jr, et al. Etiologic factors associated with Achilles tendinitis in runners. Med Sci Sports Exerc. 1999;31(10):1374-81. DOI:10.1097/00005768-199910000-00003
30. Novacheck TF. The biomechanics of running. Gait Posture. 1998;7(1):77-95. DOI:10.1016/S0966-6362(97)00038-6
31. Crossley K, Bennel KL, Wrigley T, Oakes W. Ground reaction forces, bone characteristics and tibial stress fracture in male runners. Med. Sci. Sports Exerc. 1999;31(8):1088-93. DOI:10.1097/00005768-199908000-00002
32. Christina KA, White SC, Gilchrist LA. Effect of localized muscle fatigue on vertical ground reaction and ankle joint motion during running. Hum Mov Sci. 2001;20(3):257-76. DOI:10.1016/S0167-9457(01)00048-3
33. Gerritsen KG, Van den Bogert AJ, Nigg BM. Direct dynamics simulation of the impact phase in heel-toe running. J Biomech. 1995;28(6):661-8. DOI:10.1016/0021-9290(94)00127-P
34. Fonseca et al., 2007 Fonseca ST, Ocarino JM, Silva PLP, Bricio RSB, Costa CA, Wanner LL. Characterization of professional soccer players' muscle performance. Rev Bras Med Esporte. 2007;13:143-7. DOI:10.1590/S1517-86922007000300003.
35. Oberg B, Bergman T, Tropp H. Testing of isokinetic muscle strength in the ankle. Med Sci Sports Exerc. 1987;19:318-22.