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Original Article

Sprinting, isokinetic strength, and range of motion of ankle joints in Turkish male and female national sprinters may have a relationship

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Aim: We aimed to observe the isokinetic muscular strength differences of the ankle-foot complex of sprinters of both sexes to understand the effectiveness of the ankle and subtalar ranges of motion on the sprint performances of elite athletes.

Materials and methods: Elite Turkish national sprinters (n = 11; 5 females and 6 males) were assessed regarding their ankle joint isokinetic performance (30°/s and 120°/s), joint ranges, and sprint times.

Results: A significant difference was observed between the average power of the right dorsiflexors ($P < 0.001$) of female athletes and the right invertors ($P < 0.05$) of male athletes at 120°/s for the 100-m sprint time. The average powers of the right ($P < 0.05$) and left ($P < 0.05$) evertors of the male athletes at 30°/s were significantly negatively correlated with sprint time. Additionally, only the plantar flexion range was significant for male athletes' sprint times, and the dominant invertors' peak torque at 120°/s in female athletes was significant ($P < 0.05$).

Conclusion: The strength of the nondominant side dorsiflexors of female athletes and the nondominant invertors of male athletes are important in decreasing the strength asymmetry to disregard the strength of the nondominant side in relation to sprint performance.

Key words: Sprint performance, sex, ankle muscles, peak torque, average power

Introduction

The strength of the athletes is the main factor that dominates the 100-m sprint running performance (1-3). This is especially important immediately following the beginning action of sprint running and during the support phase of sprinting (2). In the ankle joint, while the muscles carry on the responsibility of producing the maximal muscle power and the peak moment when the foot contacts the ground at midfoot strike, they are also responsible for positioning the foot in plantar flexion and inversion (1-5). This provides shortening in the duration of the support phase for faster forward acceleration and decreases the contact time for less friction between the foot and the ground (5,6). The antagonistic dorsiflexors and evertors are eccentrically contracting to control the concentrically contracted plantar flexors and invertors (2). The flexibility and the strength of the muscles are important for this cocontraction of the muscle groups to prepare the foot for push-off; the other hand, the leg muscles and the noncontractile tissues must also be flexible enough to store the elastic energy in the prestrectched antagonists (5). However, during this cocontraction in midfoot

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strike, the gastrocnemius muscle, as a biarticular plantar flexor, is also responsible in transmitting the power of the proximal muscles, mainly the hip and knee extensors, to the ankle joint for the powerful plantar flexion and knee extension necessary for the toe-off (3,7,8). The soleus muscle is the main plantar flexor generating the force in the late stance (3,8). Meanwhile, it was reported that the elasticity of the Achilles tendon did not play any specific role during push-off since it does not differ between elite sprinters and untrained people (9,10). Therefore, the contribution of the ankle joint during the start action of midfoot sprinting is important due to the function of the biarticular gastrocnemius muscle and the soleus muscles that are producing the greater peak of ankle joint moment and power and consequently the greater block and toe-off velocity (11).

Hence, the active range of motion (ROM) of the ankle joint is important for positioning the foot in midfoot contact and the flying phase (8,9). It has been stated that a total of 40° of active ROM in the sagittal plane is needed during a midfoot sprint, from 10° of dorsiflexion to 30° of plantar flexion in a midfoot running cycle (3,8,10). From this point of view, muscle strength and joint ROM are essential features during the positioning of the foot in midfoot strike and during the force activation in toe-off. Although females are more flexible than males, as O'Brien et al. stated, the sex difference may not affect the viscoelastic properties of the tendon during force activation (12). However, it was stated that the isokinetic strength at slow (30°/s, 60°/s) and medium (120°/s, 140°/s) velocities of agonist and antagonist ankle joint muscles may cause the main differences in the sprint running times of healthy athletes of both sexes (8,13,14). Additionally, the imbalance that arises between the right and left sides due to dominancy or leg preference may also result in an asymmetry of strength and flexibility of the lower extremities and may possibly affect the athlete's performance and increase the risk of injury (15,16). Ziyagil reported the importance of right-handedness, explaining that right-handed subjects had better sprinting speeds and multiple-sprint performances (17). Thus, the relations among the physiological, anatomical, and anthropometrical differences between men and women athletes on both sides resulting in different performance levels in sprint running may be other considerations to focus on (10,17-21). This may provide practical information regarding the performance of injured athletes for testing the dynamic strength of the ankle-foot complex and for decision-making about their return to competition during their rehabilitation process (14,22,23). It may also be informative for coaches while they are planning strength-training programs for the athletes to improve their performances. Therefore, the purpose of this study was to observe the relationship between the isokinetic strength and ankle joint range and the running time in Turkish male and female national sprinters of both sexes.

Methods

Subjects

The investigation was conducted on 11 elite sprinters (5 females [F] & 6 males [M]) with a mean age of 21.3 ± 3.4 years (range: 18-27 years). Their mean body weight (BW) was 57.0 ± 4.9 kg (F) and 71.5 ± 6.6 kg (M), their mean height was 167.8 ± 5.2 cm (F) and 175.6 ± 5.4 cm (M), and their mean body mass index (BMI) was 20.2 ± 1.1 kg/m^2 (F) and 23.1 ± 1.1 kg/m^2 (M). They had no history of recent injury to their lower extremities. All were national sprinters as hurdlers at distances of 100 m (n = 4), 400 m (n = 3), 100-200 m (n = 2), and 110 m (n = 2) for periods of 1-9 years. Except for one male, all were right-handed. They all gave written consent of their own free will to participate in the test protocols of the study, which were approved by the Ethics Committee of Marmara University. The following were the inclusion criteria for the study: being licensed athletes for at least 3 years, being on the national team at least once or being eligible for inclusion, and being in the top 3 rankings according to Turkish national classification. The scarcity of the athletes eligible for these criteria was the main limitation of the study.

Equipment

A Cybex 6000 was used to assess the dorsiflexor, plantar flexor, evertor, and invertor strength (peak torque, peak torque / BW, total work, average power) of the athletes. Position calibration was performed at the beginning of each test on both sides at slow (30°/s) and medium (120°/s) velocities (13,23,24).

An electronic goniometer (Lafayette Guymon Electronic Goniometry) was used to measure the ankle joint ROM of both ankles.

The NewTest Photocell System 2000 (NewTest OY) was used to measure the duration of the 100-m sprint run of the athletes. BMI (kg/m^2) was calculated according to the formula of weight / height^2 for each athlete.

Assessment

The athletes were informed about the isokinetic test procedures and they were asked to perform the test with their maximal effort. Thus, encouragement and feedback were given during the test.

Before the tests began, the athletes warmed up with a 10-min free run on a treadmill. They were then asked to perform a warm-up exercise of 10 submaximal repetitions at 90°/s in order to adapt to the movement and the equipment. For testing the dorsiflexion and the plantar flexion, the subjects lay prone with hip and knee joints at full extension; for ankle eversion and inversion, they lay supine with the knee flexed to 90° and the ankle placed in neutral position (90°). The ankle joint axis was aligned with the axis of the dynamometer and it was stabilized tightly against the trochlea tali, keeping in mind that there might be a clear shift between the ankle joint axis and the axis of rotation of the dynamometer (25,26). The reference angle corresponded to the ankle's neutral position (90°). Tight Velcro bands were used from the distal of the calves and pelvis for the stabilization of the leg. The other leg was strapped with a Velcro band to avoid compensatory movements.

During the testing procedure, the athletes were asked to do dorsiflexion and plantar flexion, and then to do the eversion and inversion movements of the ankle joints with an angular velocity of 30°/s for 3 maximal repetitions and of 120°/s for 5 maximal repetitions (23,27). The test was applied to both legs respectively and a short resting period (20 s) was given after each angular velocity movement (13,23).

The dorsiflexion, plantar flexion, and inversion and eversion movements (28,29) were monitored by the same investigator (BE). For the sprint assessment, the photocell couples, which were placed at the beginning and end of the 100-m lane, were positioned at the level of the center of gravity of each athlete, which was calculated as 59% of their overall height (4).

Statistical analyses

Descriptive statistics of the means, standard deviations (SDs), and ranges were determined for each athlete. The Pearson product-moment correlation test was performed to understand the relation between the sprint running time and the data achieved via isokinetic assessment and ROM testing of the ankle and the subtalar joints. The Mann-Whitney U test was used to understand the effects of sex, weight (<64 kg vs. ≥65 kg), height (<169 cm vs. ≥170 cm), and BMI (<20 vs. ≥21) on the data from the isokinetic assessment and ROM tests. The Wilcoxon signed rank test was used to compare all test data (isokinetic assessment and ROM tests of the ankle and the subtalar joints) of male and female athletes for their right and left sides. The results were considered significant at the level of $P < 0.05$.

Results

The average 100-m sprint running times of the athletes were measured for female athletes as 12.21 ± 0 s and for males as 10.80 ± 0.28 s ($P < 0.01$) (Table 1). In this context, the running speed was 8.19 m/s for female sprinters and 9.26 m/s for male sprinters.

Table 1. The sex differences in the running times of the sprinters (100 m).

	Sex	X ± SD	u	z	Significance
Running time (s)	F (n = 5)	12.21 ± 0.44	0.000	–2.745	**0.006****
	M (n = 6)	10.80 ± 0.28			

**P < 0.001.

According to the results of the isokinetic assessment of ankle and subtalar joints, a significant negative correlation was observed in females between the 100-m sprint time and the average power of the right dorsiflexors (25.02 ± 5.20 W) (r = –0.975; P < 0.001) and in males between the 100-m sprint time and the power of the right invertors (39.22 ± 12.21 W) (r = –0.866; P < 0.05) at 120°/s. Additionally, the average powers of the right (13.12 ± 5.62 W) (r = –0.820; P < 0.05) and left (13.65 ± 5.58 W) (r = –0.860; P < 0.05) evertors of the male athletes at 30°/s were significantly negatively correlated with sprint running time (Table 2). The peak torque, peak torque / BW, and the total work of the dorsiflexor, plantar flexor, evertor, and inventor muscles on both sides and at both velocities were not found to be in correlation with the sprint running time of the male and female athletes. We did not find any significant differences between the isokinetic data of the right and left sides in both groups, except the difference between the peak torque of invertors of female sprinters in favor of the right side (z = –2.023; P < 0.05) at a velocity of 120°/s (Table 3).

According to the mean values of the ROM, the plantars and dorsiflexors of the nondominant side and the invertors and evertors of the dominant side were significant in both sexes (P < 0.05) (Table 4).

Table 2. The relationship between the average power values of the ankle muscles at 30°/s and 120°/s and the running time (12.21 ± 0.44 s [F], 10.80 ± 0.28 s [M]) of the sprinters at 100 m (n = 5 F, n = 6 M) in both sexes.

	Sides	Average power (W) 30°/s X ± SD	r	Average power (W) 120°/s X ± SD	r
Dorsiflexors	R†	9.8 ± 1.2 F	–0.583	25.0 ± 5.2 F	–0.975**a
		14.6 ± 3.5 M	–0.078	32.5 ± 13.0 M	–0.365
	L†	10.2 ± 2.3 F	–0.677	28.3 ± 3.8 F	–0.836
		14.6 ± 3.5 M	–0.050	42.9 ± 18.7 M	–0.051
Plantar flexors	R	18.3 ± 6.8 F	–0.144	45.9 ± 20.2 F	–0.627
		37.9 ± 6.8 M	–0.064	50.7 ± 24.8 M	0.310
	L	18.5 ± 4.6 F	–0.274	44.0 ± 7.2 F	–0.825
		38.0 ± 10.5 M	–0.082	70.8 ± 19.3 M	–0.122
Invertors	R	5.8 ± 0.7 F	0.509	17.6 ± 2.7 F	–0.042
		14.7 ± 3.6 M	–0736	39.2 ±12.2 M	–0.866*b
	L	5.3 ± 2.0 F	–0.507	14.6 ± 2.2 F	–0.675
		18.2 ± 11.6 M	0.227	38.8 ± 13.9 M	–0.657
Evertors	R	7.20 ± 0.9 F	0.027	18.1 ± 2.1 F	–0.156
		13.12 ± 5.6 M	–0.820*c	30.5 ±12.3 M	–0.767
	L	6.64 ± 1.2 F	–0.469	17.0 ± 2.3 F	–0.171
		13.65 ± 5.5 M	–0.860*d	33.0 ± 12.2 M	–0.625

* P < 0.05, ** P < 0.001; significance: a) 0.005, b) 0.026, c) 0.046, d) 0.028.
† R: right; L: left.

Table 3. Comparison of isokinetic strength between right and left ankle invertors in female sprinters at 120°/s.

	Peak torque (120°/s) X ± SD Right	Left	Difference	z	Significance
Invertors	20.02 ± 3.65	16.20 ± 3.36	3.82 ± 0.29	–2.023	0.043*

* P < 0.05.

Table 4. Comparison of ranges of motion in ankle joints according to sex.

ROM	Sex	X ± SD Right	X ± SD Left	Difference	z	Significance
Dorsiflexion	F (n = 5)	14.00 ± 2.00	63.20 ± 16.33	49.20 ± 14.33	–2.023	0.043*
	M (n = 6)	12.17 ± 3.71	48.17 ± 11.83	36.00 ± 8.12	–2.207	0.027*
Plantar flexion	F (n = 5)	14.80 ± 2.95	62.50 ± 17.07	47.70 ± 14.12	–2.032	0.042*
	M (n = 6)	14.50 ± 2.34	51.33 ± 6.21	36.83 ± 2.34	–2.214	0.027*
Inversion	F (n = 5)	23.80 ± 2.77	13.40 ± 2.07	–10.40 ± 0.70	–2.023	0.043*
	M (n = 6)	24.33 ± 3.93	11.00 ± 2.36	–13.33 ± 1.57	–2.201	0.028*
Eversion	F (n = 5)	22.80 ± 3.56	14.20 ± 1.92	–8.60 ± 1.64	–2.023	0.043*
	M (n = 6)	25.17 ± 3.76	10.50 ± 1.76	–14.67 ± 2.00	–2.207	0.027*

* P < 0.05.

With regard to the relationship between the sprint running time and the ROM of the athletes, only the plantar flexion range was significantly correlated in male athletes (14.50° ± 2.3°) (P < 0.05).

Discussion

In this study, we found a significant relation between the average power and the sprint running times of the athletes. According to the findings, the average power of right dorsiflexors of female sprinters at a velocity of 120°/s was related with the sprint time (P < 0.001). This may be partly due to the higher right-hand dominance of our subjects. The results of a study by Kale et al. support these outcomes, suggesting that the difference in isokinetic strength criteria and sprint velocity variables of Turkish elite sprinters were found significant between the dominant and nondominant legs (30). Additionally, this difference in our study may also be due to the counter forces created by the eccentrically contracted dorsiflexors against the plantar flexors contracting concentrically to produce forward propelling forces at toe-off (2). Our results are also supported by the study of Nasser et al., reporting that the ankle dorsiflexion peak torque at 5.24 rad/s in the 10-m sprint may be the predictor of a 40-m sprint performance (r = 0.855). On the other hand, they also reported a positive relation between ankle plantar flexion at 1.05 rad/s and 40-m sprint performance. Thus, they reached the conclusion that stronger plantar flexors may slow the 40-m sprint (7). Dowson et al. pointed out the positive relationship between the peak torque values of the plantar flexors at slow (1.05 rad/s) and fast velocities and the sprint time of the athletes in distances of 0-15 m and 30-35 m (31). This may be due to the kinesiological hierarchy between the muscles to which the plantar flexors and the Achilles tendon are responsible to transfer the forces falling from the proximal joints forwardly toward the toes as a result of the provided stiffness and the cocontraction of the musculoskeletal structures around the ankle joint (2,5,6). In the present study, although the right plantar flexors of the female sprinters were stronger than the dorsiflexors of the same side, no significant relation was found between the plantar flexors' peak torque and the times for the 100-m sprint run. This finding supports the results of Nasser et al. They stated that hip extensors, knee flexors, and the plantar flexors are responsible for the forward propelling force of sprinting, and the plantar flexors are primarily responsible for transmitting the forces to the standing foot (7). Meanwhile, Bezodis et al. reported the positive work of the plantar flexors in the late stance of maximum sprint velocity (normalized value = 0.053 ± 0.010), mainly due to the activation of the soleus muscle (3). Thus, the propulsive impulse, just before the takeoff, depends on the shorter moment arm of the plantar flexors, which transfer the forces mainly toward the toes (32). Additionally, the eccentrically contracting dorsiflexors generated the maximal force (13,23,32) to increase the forceful concentric contraction of the plantar flexors at takeoff (6,33). Hence, the significant negative correlation that we found in this study between the average power of dorsiflexors and the sprint running time of female athletes may support the idea that the dorsiflexors of the dominant side are responsible in females for generating forces to increase the effectiveness of the plantar flexor muscles that are responsible for the takeoff.

Mann and Herman reached the conclusion that athletes running at the speed of 2.7 m/s presented no activation in their triceps surae muscles (34). Since the athletes in this study had higher speeds (8.19 m/s for females and 9.26 m/s for males), this may reveal the cause of the insignificancy among the peak torque of the plantar flexors for the 100-m sprint run.

Other data achieved in this study were the significant negative relations of the the 100-m sprint running time with the average power of right invertor muscles of the male athletes at medium velocity (120°/s) and the evertors of both sides at slow velocity ($P < 0.05$). This relation points toward the importance of the invertor muscles of the sprinters having midfoot strike to decrease the duration of foot contact with the ground (5) and to position the foot mainly under the control of eccentrically contracting evertors on both sides just before the takeoff (3,4). Although we found a significant relation between the sprint running time and the average power of the right invertors (120°/s) and the evertors of both sides (30°/s) of male sprinters, there was no correlation between the achieved data for the right and left ankles in each group. Hence, the characteristics of ankle muscle groups at higher velocities, as Nadeau et al. suggested, may also be evaluated to bring out more comparative understandings regarding their effectiveness during sprint runs (35).

Significance between both sides was found only in the peak torque of the invertor muscles among female sprinters at medium frequency (120°/s) in favor of the right side. Since the average power of dorsiflexors on the same side and at the same frequency was also significant, it may be concluded that the dominant dorsiflexors and the invertors of the female sprinters produce more power than their nondominant sides. This imbalance may be considered important by track and field coaches within their strength-training strategies as well as by physiotherapists during their exercise programs.

As we expected, male sprinters were faster than female sprinters. According to the comparative analysis of the data for both sides in male and female sprinters, we found a significant relation between the dorsiflexion, plantar flexion, inversion, and eversion ROMs in favor of wider joint ranges. However, only the plantar flexion ranges of male athletes were significant for their sprint performances. Thus, we may assume that the wider plantar flexion range may positively affect the sprint performance in male athletes. Therefore, we may suggest that simple joint range assessment can be made by physiotherapists (14,29) for cost-effective prospective information for coaches and trainers regarding the performance of male sprinters.

We can conclude that the strength of the dominant side's dorsiflexors in female sprinters and the strength of the dominant invertors and the evertors of both sides in male sprinters are important for 100-m sprint performance. Additionally, the wider plantar flexion range of the male sprinters may provide better sprint performance. In fact, since all sprinters except one male were right-handed, these biomechanical outcomes may point toward the importance of the strength training of the nondominant side of sprinters of both sexes. Thus, the strength of the nondominant dorsiflexors of female athletes and the nondominant invertors of male athletes could be improved to decrease the strength asymmetry between the right and left ankle for enhancing sprint performance. This may be considered as practical information for coaches to improve the performance of their athletes and not to disregard the strength of the nondominant side during training programs, as well as for the physiotherapists to understand the physical conditions of injured athletes in relation to their sprint performance.

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References

1. Belli A, Kyolainen H, Komi PV. Moment and power of lower limb joints in running. Int J Sports Med 2002; 23: 136-41.
2. Cronin JB, Hensen KT. Strength and power predictors of sports speed. J Strength Cond Res 2005; 19: 349-57.
3. Bezodis IN, Kervin DG, Salo AI. Lower-limb mechanics during the support phase of maximum-velocity sprint running. Med Sci Sports 2008; 40: 707-15.
4. Adrian MJ, Cooper JM. Biomechanics of human movement. Madison (WI): WCB Brown & Benchmark; 1995. p.295-314.
5. Biewener AA, Farley CT, Roberts TJ, Temaner M. Muscle mechanical advantage of human walking and running: implications for energy cost. J App Physiol 2004; 97: 2266-74.
6. Williams KR. The dynamics of running. In: Zatsiorsky V, editor Biomechanics in sport performance enhancement and injury prevention. Oxford: Blackwell Science; 2000. p.161-83.
7. Nasser TW, Latin RW, Berg K, Prentice E. Physiological determinants of 40-meter sprint performance in young athletes. J Strength Cond Res 1996; 10: 263-7.
8. Jacobs R, Bobbert MF, van Ingen Schenau GJ. Mechanical output from individual muscles during explosive leg extensions: the role of biarticular muscles. J Biomech 1996; 29: 513-23.
9. Kubo K, Tabata T, Ikebukuro T, Igrashi K, Yata H, Tsunoda N. Effects of mechanical properties of muscles and tendon performance in long distance runners. Eur J Appl Physiol 2010; 110: 507-14.
10. Stafilidis S, Arampatzis A. Muscle-tendon unit mechanical and morphological properties and sprint performance. J Sport Sci 2007; 25: 1035-46.
11. Mero A, Kuitunen S, Harland M, Kyröläinen H, Komi PV. Effects of muscle-tendon lengths on joint moment and power during sprint starts. J Sport Sci 2006; 24: 165-73.
12. O'Brien TD, Reeves ND, Baltzopoulos V, Jones DA, Maganaris CN. Mechanical properties of the patellar tendon in adults and children children. J Biomech 2010; 43: 1190-5.
13. Mahieu NN, Witvrouw E, Stevens, V, Van Tiggelen D, Roget P. Intrinsic risk factors for the development of Achilles tendon overuse injury. Am J Sports Med 2006; 34: 226-35.
14. Gatt A, Chockalingam N. Clinical assessment of ankle joint dorsiflexion: a review of measurement techniques. J Am Pod Med Assoc 2011; 101: 59-69.
15. Rahnama N, Lees A & Bambaecichi E. A comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. Ergonomics 2005; 48: 1568-75.
16. Newton RU, Gerber A, Nimphius S, Shim KJ, Doan BK, Robertson M et al. Determination of functional strength imbalance of the lower extremities. J Strength Con Res 2006; 20: 971-7.
17. Ziyagil MA. Handedness and footedness: relations to differences in sprinting speed and multiple sprints performance in prepubertal boys. Percept Motor Skill 2011; 112: 440-50.
18. Perez-Gomez J, Rodriguez GV, Ara I, Oldemillas H, Chavarren J, Gonzáles Henriquez JJ et al. Role of muscle mass on sprint performance: gender differences? Eur J Appl Physiol 2008; 102: 685-94.
19. Cheuvront SN, Carter R, DeRuisseau KC, Moffatt RJ. Running performance differences between men and women. An update. Sports Med 2005; 35: 1017-24.
20. Ransdell LB, Wells CL. Sex differences in athletic performance. Women Sport Phys Activ J 1999; 8: 55.
21. Abha K, Shalini G. The relationship of ankle and subtalar joint range of motion with balance scores in females. Indian J Physio Occu Ther 2007; 1: 35-40.
22. Cipriani DJ. Physiological principles of resistance training and rehabilitation. In: Zachazewski JE, Magee DJ, Quillen WS, editors. Athletic injuries and rehabilitation. Philadelphia (PA): W.B. Saunders Company; 1996. p.206-28.
23. Jacoby SM. Isokinetics in rehabilitation. In: Prentice WE, Voight MI, editors. Techniques in musculoskeletal rehabilitation. New York: McGraw-Hill; 2001. p.153-66.
24. Chan KM, Maffuli N. Principles and practice of isokinetics in sports medicine and rehabilitation. Hong Kong: Williams & Wilkins; 1996. p.2-62.
25. Arampatzis A, Morey-Klapsing G, Karamanidis K, De Monte G, Stafilidis S, Bruggemann GP. Differences between measured and resultant joint moments during isometric contractions at the ankle joint. J Biomech 2005; 38: 855-92.
26. Arampatzis A, Stafilidis S, De Monte G, Karamanidis K, Morey-Klasping G, Bruggeman G. Strain and elongation of the human gastrocnemius tendon and aponeurosis during maximal plantar flexing effort. J Biomech 2005; 38: 833-41.
27. Yıldız Y, Şekir U, Hazneci B, Örs F, Saka T, Aydın T. Reliability of a functional test battery evaluating functionality, proprioception and strength of the ankle joint. Turk J Med Sci 2009; 39: 115-23.
28. Menadue C, Raymond J, Kilbreath SL, Refshauge KM, Adams R. Reliability of two goniometric methods of measuring active inversion and eversion range of motion at the ankle. BMC Musculoskel Disord 2006; 7: 60.
29. Kendall FP, McCreary EK, Provance PG, Rodger MM, Romani WA. Muscle testing and function with posture and pain. Philadelphia (PA): W.B. Saunders Company; 2005. p.359-464.
30. Kale M, Açıkada A, Yılmaz İ. Relationships between isokinetic criteria and sprint velocity variables in the competition phase of sprinters. Hacettepe J Sport Sci 2008, 19: 125-38.
31. Dowson MN, Nevill ME, Lakomy HK, Nevill AM, Hazeldine RJ. Modeling the relationship between isokinetic muscle strength and sprint running performance. J Sports Sci 1998; 16: 257-65.
32. Lee SSM, Piazza SJ. Built for speed: musculoskeletal structure and sprinting ability. J Exp Biol 2009; 212: 3700-7.
33. Monohan JP, Hartley R, Hall C, Smith S. The ankle and foot. In: Hall CM, Brody LT, editors. Therapeutic exercise: moving towards function. Philadelphia (PA): Lippincott Williams & Wilkins; 2005. p.524-54.
34. Mann R, Herman J. Kinematic analysis of Olympic sprint performance. Men's 200 meters. In: Biomechanics research at the Olympic Games: 1984-1994. Philadelphia (PA): Human Kinetics; 1994. p.56-67.
35. Nadeau S, Gravel D, Arsenault AB, Goyette M. Preloading and range of motion effect on plantar flexors muscle performance. J Biomech 2005; 38: 1491-500.