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Original Article

Effect of isotonic and isokinetic exercise on muscle activity and balance of the ankle joint

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Abstract. [Purpose] This study was performed to examine how the balance of lower limbs and the muscle activities of the tibialis anterior (TA), the medial gastrocnemius (GCM), and the peroneus longus (PL) are influenced by isotonic and isokinetic exercise of the ankle joint. [Subjects] The subjects of this study were healthy adults (n=20), and they were divided into two groups (isotonic=10, isokinetic=10). [Methods] Isotonic group performed 3 sets of 10 contractions at 50% of MVIC and Isokinetic group performed 3 sets of 60°/sec. Muscle activity was measured by EMG and balance was measured by one-leg standing test. [Results] For muscle activity, a main effect of group was found in the non-dominant TA, and the dominant TA, GCM and PL. For balance, a main effect of time was found in both groups for the sway area measured support was provided by the non-dominant side. [Conclusion] In terms of muscle activity, the two groups showed a significant difference, and the isokinetic group showed higher muscle activities. In terms of balance, there was a significant difference between the pre-test and the post-test. The results of this study may help in the selection of exercises for physical therapy, because they show that muscle activity and balance vary according to the type of exercise.
Key words: Isotonic, Isokinetic, Balance

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INTRODUCTION

The ankle joints play an important role in gait. The structure of foot is adapted for locomotion and the alignment of the foot and ankle plays an important role in standing and gait[1)], and supporting weight during gait[2)]. The proper functioning of the ankle joint is necessary for daily life, recreation and sports activities[3)], and it is important in ambulation and functional gait in terms of its mechanical properties[4)]. The strength of the muscles around the ankle is related injuries from sports activities[3)], and this strength is essential for the prevention of falls[5)]. The passive torque gained through the tension of muscular tissue and the stiffness of the tissues adjacent to joints like ligaments or tendons is required for the development of an appropriate strategy for the ankle joint. The central nervous system, which controls the spontaneous physical response to the external events, and stretches and contracts the muscles, generates the active torque. The active torque that is gained through the central nervous system is also required for the development of an appropriate strategy for the ankle joint[6)]. Postural control involves an adequate stepping strategy and the appropriate use of the muscles attached to the hips and ankles[7)]. The primary functions of the ankle joints are the provision of balance adjustment in response to postural disturbance, absorption of shock during gait, and movement of the lower extremity[8)].

The maintenance of balance is a complex prcess, and it is influenced by a range of several sensorimotor functions, including muscular strength, proprioception, and the visual and vestibular sensory systems[9)]. The central nervous system uses ascending motor pathways that receive information from the feet to control the position of the body and coordinate posture in relation to the surrounding environment[10)]. The ankle joint has the function of balance control, responding to the ground reaction force, it contracts muscles such as the gastrocnemius, the soleus and the tibialis anterior[6)]. The plantar flexor and dorsiflexor play a central role in maintaining balance during single-limb support and bilateral-limb support, and the gastrocnemius and soleus play a significant role in postural correction[11)]. Muscular strength and muscle activation are required for balance, to keep the center of gravity within the base of support[12)].

In one study, subjects performed short-term isometric and isotonic exercise, and isometric exercise increased muscular strength significantly at the low speed of 60°/sec, while isotonic exercise did the same at the higher speeds of 120°/sec and 180°/sec[13)]. Another study analyzed how the function and muscular strength of the lower limbs are influenced by isotonic and isokinetic exercise in a closed kinetic chain type exercise for 6 weeks, and reported that muscular strength, muscle power and muscle endurance of the knee joint extensors and flexors did not show any statistically significant differences[14)]. Also, a study of a muscle strengthening program, including isometric and isotonic contractions and stretching

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exercises, performed by elderly women for a period of 12 weeks, reported that increased muscular strength improved their balance[15]. Another study analyzed the isokinetic torque and the absolute peak torque of the invertor and evertor muscles of females with functional ankle instability who performed eccentric contraction and concentric contraction at the respective speeds of 60°/sec and 120°/sec. Deficits in eccentric invertor strength contributed to symptoms of functional ankle instability, and it was noted that eccentric contraction decrease of the invertor had a significant impact on the results[16]. Another study analyzed the equilibrium and EMG (electromyography) activity of a sports player using a single-limb stance on four different unstable surfaces and reported that the EMG activities of the peroneus longus, extensor digitorum longus, and tibialis anterior muscle were greater on a small wood board than on to hemi-cylindrical and large plastic wood boards[17].

The calf muscle-tendon unit of the ankle plays an important role in basic human movement activities[18], such as balance control while standing[19], and the enhancement of the effectiveness of walking[20]. In spite of the fact that the ankle joint is of such importance, most studies have performed exercises on the knee joint muscle rather than on the ankle joint and analyzed the variables of muscular function such as muscle strength and muscle power. Therefore, this study examined the effects of isotonic and isokinetic exercise performed by the essential muscles of the ankle joint, which play an important role in balance and gait. The purpose was to investigate how the muscle activity and balance were affected by isotonic and isokinetic exercise. In addition, the effects of isotonic and isokinetic exercise on the tibialis anterior, which is responsible for dorsiflexion, and on the peroneus longus and gastrocnemius, which are responsible for ankle plantarflexion were investigated.

SUBJECTS AND METHODS

Twenty students (10 men, 10 women; 18 right dominant, 2 left dominant) attending Namseoul University in Cheonan-si, Republic of Korea, volunteered for this study. They were clearly informed of the purpose and experimental procedures before providing their written consent. None of the subjects had impairments of the musculoskeletal or neurological systems, and none had a history of athletics or had received any training for muscle strengthening within the past 6 months[21]. Two types of exercises were performed and 10 subjects each were randomly assigned to the isotonic and isokinetic exercise groups.

A body composition analyzer (Inbody720. Biospace O. Ltd, Seoul, Korea) was used to measure subjects' physical characteristics. A Functional Rehab System (PRIMUS RS, BTE Tech., Hanover, USA) was used to asses maximal voluntary isometric contraction and to perform isotonic and isokinetic exercise. A Free EMG system (Free EMG, BTS Inc., Milan, Italy) was used to measure muscle activity. A computerized balance platform (HUR BT4, BURLABS, Tampere, Finland) was used to measure balance ability.

Prior to the commencement of this experiment, the subjects were informed of the contents of the experiment and were allowed to participate in the experiment only after submitting their written consent. The subjects were placed in either the isotonic exercise group or the isokinetic exercise group with 10 individuals in each group. The subjects were ordered to kick a ball on the ground, and the side they used to kick the ball was considered to be their dominant side[22]. Surface electrodes were then attached to the bilateral tibialis anterior, the peroneus longus and the medial gastrocnemius of each participant. The subjects were seated on a dynamometer with their hip joint and knee joints fixed in the mid-positon with a brace belt. The rotation axis of the equipment was then adjusted to match the line that links the medial malleolus, and the foot was fixed for the isokinetic exercise[23]. No movement was possible, and the exercise was performed on the non-dominant side[24]. Balance was measured immediately after completion of the exercise protocol[11]. All exercises and measurements were performed with the subjects barefoot to prevent any potential confusion being caused by different shoe types or heel heights[18].

For surface electromyography, electrodes were attached to the muscle at maximum static contraction to prevent any technical difficulties from influencing the experiment[25]. The skin was abraded with sandpaper and shaved, then cleaned with an alcohol-soaked cotton swab, to reduce the electrical impedance of the skin to less than 5 kΩ. Active electrodes (Carbon electrode, 3M, USA) were placed 2 cm apart, in parallel with the muscle fibers, on the tibialis anterior, the peroneus longus and the medial gastrocnemius[26]. During the electromyography measurements, the electromyography signals were recorded at a sampling rate of 1 kHz, bandpass-filtered between 20 and 500 Hz. The root mean square value was calculated from the raw EMG data[27]. The EMG data of balance measures was processed after excluding the first and last 5 seconds. The subjects performed a series of 5 submaximal contractions as a warm-up to familiarize themselves with the dynamometer[28]. They rested for 5 minutes after warming up to prevent the fatigue effect[29]. The highest peak torque of 3 maximum voluntary isometric contractions (MVICs) was used in this study[30].

In the isotonic group, the level of resistance was set at 50% of MVIC[31]. The exercise was performed at a self-paced speed for 1 set[32]. The istonic group performed dorsiflexion and plantar flexion 10 times for 3 sets and had a 1-minute rest between sets to prevent fatigue[13]. In the isokinetic group, the angular velocity of 60°/sec that is generally used for muscle strengthening exercises for healthy adults and athletes was chosen from among the angular velocities of 60°/sec, 180°/sec and 300°/sec, which are appropriate for isokinetics[33]. In the isotonic group, the ankle was placed in the neutral position[34], and subjects performed dorsiflexion and plantarflexion in a non-painful range of motion 10 times for 3 sets, for a total of 30 times[35], and had a 1-minute rest between sets to prevent fatigue[24]. Calibration was conducted before starting the measurements[25]. To measure balance, the one-leg standing test with eyes open was performed on a computerized balance platform[35]. During the trials, the subjects had to stand barefoot on one leg for 30 seconds with their eyes open[36], while the other leg was held off the surface with a knee flexion of 30 degrees along the anterior-posterior axis of the foot plate[35], and with both arms in a relaxed state at the sides. For visual information, the subjects were

Table 1. Subject characteristics

Group	N	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
		M±SD	M±SD	M±SD	M±SD
Isotonic	10	20.3±1.7	170.2±9.9	70.0±14.6	23.9±2.6
Isokinetic	10	20.2±1.8	165.5±9.9	65.8±20.2	23.6±4.8

M±SD: means±standard deviation, BMI: body mass index

Table 2. Comparison of muscle electromyography between pre- and post-test (mV)

Variable	Group	Pre-test	Post-test
		M±SD	M±SD
Non-dominant tibialis anterior*	isotonic	0.35±0.30	0.33±0.14
(support by non-dominant side)	isokinetic	1.47±1.52	1.18±0.83
Dominant tibialis anterior*	isotonic	0.16±0.13	0.42±0.64
(support by non-dominant side)	isokinetic	0.62±0.59	0.71±0.52
Dominant gastrocnemius*	isotonic	0.57±0.59	1.37±2.14
(support by dominant side)	isokinetic	2.35±1.62	2.42±2.25
Dominant peroneus longus*	isotonic	0.62±0.58	1.01±0.83
(supported by dominant side)	isokinetic	1.40±0.90	1.87±1.23

*Significant difference, p<0.05

Table 3. Comparison of balance between pre- and post-test (mm^2)

Variable	Group	Pre-test	Post-test
		M±SD	M±SD
Sway area	isotonic	435.0±139.1	615.1±244.1*
(support by non-dominant side)	isokinetic	389.3±215.6	515.6±277.7*

* Significant difference, p<0.05

asked to stand in as stable a position as possible, watching a point on a monitor that was 65 cm in front of them during experimental testing[37]. For visual information directions, a reverse countdown was started from 4 before beginning the measurements, and "stop" was said after the measurements had been taken. Calm and stable surroundings were provided for all procedures[38]. The measurements were taken twice, and the mean value of the two measurements was calculated.

The physical characteristics are reported as mean±SD. The dependent variables were tested for normality using the Kolmogorov-Smirnov test, and for homogeneity of variance using Levene's test. MANOVA (multivariate analysis of variance) was used to examine the significance of differences in balance and compare EMG and the balance of the tibialis anterior, the peroneus longus and the medial gastrocnemius between the groups (isotonic and isokinetic exercise) and time (pre-exercise and post-exercise). Statistical analyses were performed using SPSS for Windows v.18.0. The statistical significance level was chosen as α=0.05. This study was approved by the Institutional Review Board of Namseoul University (Cheonan, Korea, NSU-140528-1).

RESULTS

Twenty healthy adults took part in this study, and their physical characteristics are presented in Table 1. The results of the comparison of muscle electromyography between pre-test and post-test by group are shown in Table 2. Statistical analysis revealed that both the isotonic exercise and isokinetic exercise groups showed neither an interaction effect between group and time as, nor a main effect of time. A main effect of group was found in the non-dominant tibialis anterior, the dominant tibialis anterior, the dominant gastrocnemius and the dominant peroneus longus (p<0.05). The changes in balance between pre-test and post-test by group are shown in Table 3. Statistical analysis revealed that both the isotonic exercise and isokinetic exercise groups showed neither an interaction effect between group and time, nor a main effect of group. A main effect of time was statistically significant for the sway area when support was provided by the non-dominant side in both groups (p<0.05).

DISCUSSION

Maintaining balance in an upright stance is an essential factor of daily life[39]. Loss of balance is caused by the center of foot pressure leaving the limits of stability of the base of support[38]. The sensory process of balance is interaction among the somatic senses, which include proprioception, visual sense, and stereotactic input from the vestibular system[40]. The lower limb activity sequence is an important factor for the neuromuscular function of the ankle joint[41], and the sway is related to the postural variable, which provides important information about stability and postural control. Fatigue increases the sway[36] and analyzing the sway is essential for understanding of the postural control mechanisms and the treatment of patients with balance dysfunction[42]. In this study, healthy adults performed isotonic and isokinetic exercise for the ankle joint, and how the respective exercises influenced muscle activity and balance was investigated. When muscle activity was compared between pre-test and post-test by group, both the dominant tibialis anterior and the non-dominant tibialis anterior presented significant differences when support was provided by the non-dominant side, and the dominant gastrocnemius muscle and the dominant peroneus longus presented significant differences when support was provided by the dominant side.

Razaeimanech and Farsani[43] reported that performance of isotonic exercise for the lower limb for 6 weeks increased EMG and improved the muscle strength of volleyball players. Onambele et al.[38] reported that in both elderly and young adults, EMG of the tibialis anterior was higher than that of the gastrocnemius when their eyes were closed. They also reported that the tibialis anterior EMG of the elderly was higher than that of the gastrocnemius, but the gastrocnemius EMG of the young adults was higher than the tibialis anterior EMG their eyes were open. In this study, the dominant tibialis anterior showed a significant increase when support was provided by the non-dominant side, and the dominant gastrocnemius muscle and dominant peroneus longus showed a significant increase when support was provided by the dominant side. Thus, our present study's results are similar to those of previous studies. Kennedy et al.[44] studied neuromuscular fatigue caused by isometric contraction of the plantar flexor and dorsiflexor, and reported that central fatigue could be determined by comparing the level of voluntary activation of the dorsiflexor and plantar flexor between pre-fatigue and post-fatigue. However, the two muscle groups had different characteristics of fatigue mechanism and recovery, and because the mechanisms of the two muscle groups were not similar, they might not be influenced by the same method. They also reported that it took 7 minutes for the plantar flexor to recover from fatigue, while it took only 1 minute for the dorsiflexor. In addition, the possibility of compensation between muscles was higher in the plantar flexor than in the dorsiflexor, which is mainly composed of the tibialis anterior, contrary to that of the plantar flexor, which is composed of synergistic muscle. So we conjecture the reason why both sides (regardless of dominant or non-dominant side) of the tibialis anterior had a better recovery speed than the plantar flexor (as indicated by the significant difference in this study) is due to compensation among muscles. Berger et al.[45] reported that the EMG of the exercised tibialis anterior decreased in their study of the bilateral effects of unilateral lower limb muscle fatigue on EMG. They reported that the fatigued muscle activity was related to passive tension increase, and to resist increasing the stretch of the fatigued muscle, the decrease of the exercised tibialis anterior EMG might restrict tension and increase the risk of injury to the fatigued triceps surae. Thus, the reason why the non-dominant tibialis anterior showed a significant difference when support was provided by the non-dominant side, in this study, can be attributed to the fact that the muscle tension was influenced by the fatigue of the non-dominant tibialis anterior.

In this study, the dominant gastrocnemius muscle and the dominant peroneus longus showed significant differences when support was provided by the dominant side. South and George[46] studied the effect of fatigue of the peroneus muscle on proprioception and reported that fatigue of the peroneus muscle did not affect ankle position sense after inducing muscle fatigue using an isokinetic dynamometer. McLoda et al.[47] concluded that muscles around the ankle other than the peroneal muscle are able to compensate for fatigue of the peroneal muscle as they are less fatigued than the peroneal muscle and can process the sensory information. They also reported that only 5 out of 12 muscles passing through the ankle, are restricted by the ankle joint. Giulio et al.[48] suggested that the tibialis anterior is not always the best muscle for preventing postural sway, and that the triceps surae is not always an agonist of ankle muscles. They also suggested that these roles are dynamic and can change according to the location of the center of gravity relative to the ankle joint. Paillard et al.[49] studied the impairment of postural control in the contralateral (non-exercised) lower limb after stimulation and voluntary contraction of the ipsilateral (exercised) lower limb. They observed a cross-over fatigue effect after the sensory stimulus, and suggested that voluntary contraction might impair postural control, since the sway area showed a significant difference after fatigue of the lower limbs had been induced by voluntary contraction and electrical stimulus. It is also known that the effect of one leg balance training can be transferred to the untrained contralateral side by the cross-education effect[50]. Accordingly, we consider the dominant gastrocnemius and peroneus longus showed a significant difference in the current study due to the fact that fatigue induced by exercise being transferred to the dominant tibialis anterior by the cross-over fatigue effect, and the non-exercised muscle transmitting the sensory information, because the location of the center of gravity changed during the one leg stance.

In this study, the sway area showed a significant difference between pre-test and post-test by group when support was provided by the non-dominant side. Boyas et al.[11] studied postural control impairment after muscle fatigue induced by isokinetic exercise of the ankle joint in healthy adults. They reported that the sway area during the one-leg stance with eyes open was greater when the plantar flexor and ankle dorsiflexor were exercised simultaneously than when the two muscles were exercised separately[11]. Yaggie and McGregor[51] conducted a study in which they examined the balance maintenance and postural limits after inducing muscle fatigue by isokinetic exercise of the ankle joint at 60°/sec in healthy and young adults. They reported that fatigue of the ankle plantar flexor and ankle dorsiflexor significantly affected the sway and the range of posture control. Bisson et al.[52] studied the acute effects of fatigue on the plantar flexor and reported that postural sway increased as fatigue increased, especially during the one-leg stance. Boyas et al.[36] studied postural changes related to postural control impairment due to fatigue of the plantar flexor during the one-leg stance and reported that the sway area was greater during the post-fatigue period than during the pre-fatigue period, showing that fatigue of the plantar flexor is directly connected to changes in the postural sway. The results of our present study show that fatigue of the lower limb, induced by isotonic or isokinetic exercise, significantly affected the mechanism of postural control and the sway area. Hence, we consider the results of our present study are similar to those of previous studies in that the sway area showed a significant difference between pre- and post-fatigue.

In conclusion, this study was conducted to examine how the balance of the lower limbs and the muscle activities of the tibialis anterior, the medial gastrocnemius and the peroneus longus are influenced by isotonic and isokinetic exercise of the ankle joint. The subjects of this study were healthy adults in their 20s, and the following results were obtained. (1) The changes in muscle activities between pre- and post-test in both the isotonic and isokinetic exercise groups did not show an the interaction effect between group and time, and a main effect of time was not shown by either of the groups. A main effect was shown by in the non-dominant tibialis anterior, the dominant tibialis anterior, the dominant gastrocnemius muscle and the dominant peroneus longus. (2) The changes in balance between pre-test and post-test in both exercise groups did not show an the interaction effect between group and time, and a main effect was not shown by either of the groups. A main effect of time was shown by both the isotonic and isokinetic exercise groups for the sway area when support was provided by the non-dominant side. The two exercise groups showed significant differences in muscle activities, and the group performing isokinetic exercise showed higher muscle activities. In terms of balance, there was no difference between the groups, but there was a significant difference between the pre-test and the post-test results.

The results of this study may help in the selection of exercises for physical therapy, because they demonstrate that muscle activity and balance vary according to the type of exercise.

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REFERENCES

1) Lee JE, Park GH, Lee YS, et al.: A comparison of muscle activities in the lower extremity between flat and normal feet during one-leg standing. J Phys Ther Sci, 2013, 25: 1059–1061. [Medline] [CrossRef]
2) Kim MK, Lee YS: Kinematic analysis of the lower extremities of subjects with flat feet at different gait speeds. J Phys Ther Sci, 2013, 25: 531–533. [Medline] [CrossRef]
3) Ozyemisci-Taskiran O, Özdoğan V, Sepici V, et al.: Test-retest and inter-rater reliability of isokinetic ankle dorsiflexor and plantar flexor strength measurement in healthy adults. Turk J Phys Med Rehabil, 2013, 59: 32–35.
4) Gao F, Ren Y, Roth EJ, et al.: Effects of repeated ankle stretching on calf muscle-tendon and ankle biomechanical properties in stroke survivors. Clin Biomech (Bristol, Avon), 2011, 26: 516–522. [Medline] [CrossRef]
5) Kang MK, Nam BR, Lee YS, et al.: Relationship between the application of TENS to the lower limbs and balance of healthy subjects. J Phys Ther Sci, 2013, 25: 1079–1081. [Medline] [CrossRef]
6) Yuk GC: The acute effects of 15 minutes plantarflexor static stretch in quite stance. J Korean Soc Phys Med, 2012, 7: 191–197. [CrossRef]
7) Soda N, Ueki T: Electromyography study of forward-stepping motion. J Phys Ther Sci, 2013, 25: 615–617. [Medline] [CrossRef]
8) Park YH, Kim YM, Lee BH: An ankle proprioceptive control program improves balance, gait ability of chronic stroke patients. J Phys Ther Sci, 2013, 25: 1321–1324. [Medline] [CrossRef]
9) Son SM, Kang KW, Lee NK, et al.: Influence of isokinetic strength training of unilateral ankle on ipsilateral one-legged standing balance of adults. J Phys Ther Sci, 2013, 25: 1313–1315. [Medline] [CrossRef]
10) Christovão TC, Neto HP, Grecco LA, et al.: Effect of different insoles on postural balance: a systematic review. J Phys Ther Sci, 2013, 25: 1353–1356. [Medline] [CrossRef]
11) Boyas S, Remaud A, Bisson EJ, et al.: Impairment in postural control is greater when ankle plantarflexors and dorsiflexors are fatigued simultaneously than when fatigued separately. Gait Posture, 2011, 34: 254–259. [Medline] [CrossRef]
12) Lewis NL, Brismée JM, James CR, et al.: The effect of stretching on muscle responses and postural sway responses during computerized dynamic posturography in women and men. Arch Phys Med Rehabil, 2009, 90: 454–462. [Medline] [CrossRef]
13) Shin SY, Jung YH, Lee KH, et al.: Muscle strength following short term isometric and isotonic exercise. J Korean Acad Phys Ther, 1999, 6: 167–171.
14) Han SW, Paek YW, Kim SS: The effect of functional performance and muscular strength in the quadriceps and hamstring between isotonic and isokinetic exercise in closed kinetic chain type. J Coaching Development, 2010, 12: 161–170.
15) Cho SK, Lee JP, Oh JK, et al.: The effect of 12 weeks strengthening and stretching combined exercise for balancing ability in elderly women. J Korean Phys Educ Assoc Girls Women, 2006, 20: 53–64.
16) Munn J, Beard DJ, Refshauge KM, et al.: Eccentric muscle strength in functional ankle instability. Med Sci Sports Exerc, 2003, 35: 245–250. [Medline] [CrossRef]
17) Cimadoro G, Paizis C, Alberti G, et al.: Effects of different unstable supports on EMG activity and balance. Neurosci Lett, 2013, 548: 228–232. [Medline] [CrossRef]
18) Gajdosik RL, Vander Linden DW, McNair PJ, et al.: Effects of an eight-week stretching program on the passive-elastic properties and function of the calf muscles of older women. Clin Biomech (Bristol, Avon), 2005, 20: 973–983. [Medline] [CrossRef]
19) Mecagni C, Smith JP, Roberts KE, et al.: Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlational study. Phys Ther, 2000, 80: 1004–1011. [Medline]
20) Salsich GB, Mueller MJ: Effect of plantar flexor muscle stiffness on selected gait characteristics. Gait Posture, 2000, 11: 207–216. [Medline] [CrossRef]
21) Yoon DS, Kim TH, Cynn HS, et al.: The effects of the angle of ankle joints and direction of isometric contraction on fatigue in the contralateral muscle. Korean Res Soc Phys Ther, 2005, 12: 46–55.
22) Cramer JT, Beck TW, Housh TJ, et al.: Acute effects of static stretching on characteristics of the isokinetic angle —torque relationship, surface electromyography, and mechanomyography. J Sports Sci, 2007, 25: 687–698. [Medline] [CrossRef]
23) Jun AY, Hwang BG, Cho SH, et al.: Recovery of muscle power following early weight-bearing and ankle exercise after surgical repair of acute achilles tendon rupture. J Korean Ortho Assoc, 2012, 47: 111–118. [CrossRef]
24) Szeto G, Strauss GR, Domenico GD, et al.: The effect of training intensity on voluntary isometric strength improvement. Aust J Physiother, 1989, 35: 210–217. [Medline] [CrossRef]
25) Byun YH, Lee HH, Han SH: Surface EMG analysis of quadriceps muscle during isokinetic exercise in patients with patellofemoral pain. J Coaching Development, 2007, 9: 157–164.
26) Murley GS, Bird AR: The effect of three levels of foot orthotic wedging on the surface electromyographic activity of selected lower limb muscles during gait. Clin Biomech (Bristol, Avon), 2006, 21: 1074–1080. [Medline] [CrossRef]
27) Park HJ, Sim SM, Choi JD, et al.: The effects of isometric lower limb contraction on the activation of contralateral trunk muscles in healthy young adults in supine position. Phys Ther Korea, 2012, 19: 11–19. [CrossRef]
28) DeStaso J, Kaminski TW, Perrin DH: Relationship between drop vertical jump heights and isokinetic measures utilizing the stretch-shortening cycle. Isokinet Exerc Sci, 1997, 6: 175–179.
29) Brughelli M, Mendiguchia J, Nosaka K, et al.: Effects of eccentric exercise on optimum length of the knee flexors and extensors during the preseason in professional soccer players. Phys Ther Sport, 2010, 11: 50–55. [Medline] [CrossRef]
30) Bisson EJ, Remaud A, Boyas S, et al.: Effects of fatiguing isometric and

isokinetic ankle exercises on postural control while standing on firm and compliant surfaces. J Neuroeng Rehabil, 2012, 9: 39. [Medline] [CrossRef]
31) Webber SC, Porter MM: Reliability of ankle isometric, isotonic, and isokinetic strength and power testing in older women. Phys Ther, 2010, 90: 1165–1175. [Medline] [CrossRef]
32) Fang Y, Siemionow V, Sahgal V, et al.: Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. Brain Res, 2004, 1023: 200–212. [Medline] [CrossRef]
33) Bang HS, Kim JS: The effects of angular velocity on muscle strength of biceps brachii. J Korean Soc Phys Med, 2009, 4: 157–164.
34) Hwang IS, Abraham LD: Quantitative EMG analysis to investigate synergistic coactivation of ankle and knee muscles during isokinetic ankle movement. Part 1: time amplitude analysis. J Electromyogr Kinesiol, 2001, 11: 319–325. [Medline] [CrossRef]
35) Muehlbauer T, Roth R, Mueller S, et al.: Intra and intersession reliability of balance measures during one-leg standing in young adults. J Strength Cond Res, 2011, 25: 2228–2234. [Medline] [CrossRef]
36) Boyas S, Hajj M, Bilodeau M: Influence of ankle plantarflexor fatigue on postural sway, lower limb articular angles, and postural strategies during unipedal quiet standing. Gait Posture, 2013, 37: 547–551. [Medline] [CrossRef]
37) Lee AJ, Lin WH: Twelve-week biomechanical ankle platform system training on postural stability and ankle proprioception in subjects with unilateral functional ankle instability. Clin Biomech (Bristol, Avon), 2008, 23: 1065–1072. [Medline] [CrossRef]
38) Onambélé GL, Narici MV, Rejc E, et al.: Contribution of calf muscle-tendon properties to single-leg stance ability in the absence of visual feedback in relation to ageing. Gait Posture, 2007, 26: 343–348. [Medline] [CrossRef]
39) Bisson EJ, McEwen D, Lajoie Y, et al.: Effects of ankle and hip muscle fatigue on postural sway and attentional demands during unipedal stance. Gait Posture, 2011, 33: 83–87. [Medline] [CrossRef]
40) Lee YM, Jang C, Bak IH, et al.: Effects of computer-assisted cognitive rehabilitation training on the cognition and static balance of the elderly. J Phys Ther Sci, 2013, 25: 1475–1477. [Medline] [CrossRef]
41) Papadopoulos ES, Nikolopoulos CS, Athanasopoulos S: The effect of different skin-ankle brace application pressures with and without shoes on single-limb balance, electromyographic activation onset and peroneal reaction time of lower limb muscles. Foot Edinb, 2008, 18: 228–236. [Medline] [CrossRef]
42) Karlsson A, Persson T: The ankle strategy for postural control—a comparison between a model-based and a marker-based method. Comput Methods Programs Biomed, 1997, 52: 165–173. [Medline] [CrossRef]
43) Rezaeimanesh D, Farsani PA: The effect of a 6 week isotonic training period on lower body muscle EMG changes in volleyball players. Procedia Soc Behav Sci, 2011, 30: 2129–2133. [CrossRef]
44) Kennedy A, Hug F, Bilodeau M, et al.: Neuromuscular fatigue induced by alternating isometric contractions of the ankle plantar and dorsiflexors. J Electromyogr Kinesiol, 2011, 21: 471–477. [Medline] [CrossRef]
45) Berger LL, Regueme SC, Forestier N: Unilateral lower limb muscle fatigue induces bilateral effects on undisturbed stance and muscle EMG activities. J Electromyogr Kinesiol, 2010, 20: 947–952. [Medline] [CrossRef]
46) South M, George KP: The effect of peroneal muscle fatigue on ankle joint position sense. Phys Ther Sport, 2007, 8: 82–87. [CrossRef]
47) McLoda TA, Stanek JM, Hansen AJ, et al.: A task failure has no effect on the electromechanical delay of the peroneus longus. Electromyogr Clin Neurophysiol, 2009, 49: 109–115. [Medline]
48) Di Giulio I, Maganaris CN, Baltzopoulos V, et al.: The proprioceptive and agonist roles of gastrocnemius, soleus and tibialis anterior muscles in maintaining human upright posture. J Physiol, 2009, 587: 2399–2416. [Medline] [CrossRef]
49) Paillard T, Chaubet V, Maitre J, et al.: Disturbance of contralateral unipedal postural control after stimulated and voluntary contractions of the ipsilateral limb. Neurosci Res, 2010, 68: 301–306. [Medline] [CrossRef]
50) Carroll TJ, Herbert RD, Munn J, et al.: Contralateral effects of unilateral strength training: evidence and possible mechanisms. J Appl Physiol 1985, 2006, 101: 1514–1522. [Medline] [CrossRef]
51) Yaggie JA, McGregor SJ: Effects of isokinetic ankle fatigue on the maintenance of balance and postural limits. Arch Phys Med Rehabil, 2002, 83: 224–228. [Medline] [CrossRef]
52) Bisson EJ, Chopra S, Azzi E, et al.: Acute effects of fatigue of the plantarflexor muscles on different postural tasks. Gait Posture, 2010, 32: 482–486. [Medline] [CrossRef]