J Int Acad Phys Ther Res 2020; 11(4): 2221~2228
ISSN 2092-8475
www.japtr.org
https://doi.org/10.20540/JIAPTR.2020.11.4.2221

Effect of Walking with Combat Boots on the Muscle Tone and Stiffness of Lower Extremity

Background: Shoes cover the feet and ankle joints and come into contact with the ground directly during walking, and the shape of shoes is related to the muscle tone of the lower extremity muscles. However, no study has been conducted on the muscle tone of the lower extremity after wearing combat boots.
Objectives: To compare and analyze the effects of walking in combat boots and in athletic shoes on muscle tone and stiffness, to identifying the effect of the characteristics of shoes on the muscle tone.
Design: Randomized controlled trial.
Methods: Thirty subjects were randomly divided into a combat boots group and an athletic shoes group, and interventions were implemented. Both groups walked for 30 minutes on a treadmill at 4.2 km/h. MyotonPRO was used to measure the muscle tone and stiffness of the lower extremity. The measuring sites were set to five muscles on both legs.
Results: In the combat boots group, muscle tone and stiffness of the medial gastrocnemius on the dominant side, the muscle tone and stiffness of rectus femoris, and the muscle stiffness of hamstring on the non-dominant side significantly decreased after walking. In the athletic shoes group, there was no significant change in the muscle tone and stiffness.
Conclusion: The results of this study can be used to inform the wearing combat boots while walking on a treadmill reduces the muscle tone and stiffness of the lower extremity compared to athletic shoes. It indicates that the restriction of joint movement occurring when wearing combat boots influences reducing muscle tone and stiffness.

Keywords: *Combat boots; Athletic shoes; Walking; Muscle tone; Muscle stiffness*

Joongsan Wang, PT, PhD[a], Sieun Park, PT, PhD[b], Jeongja Kim, PT, PhD[a]

[a]Department of Physical Therapy, Howon University, Gunsan, Republic of Korea
[b]Department of Physical Therapy, Woosong University, Deajeon, Republic of Korea

Received : 17 September 2020
Revised : 26 October 2020
Accepted : 03 November 2020

Address for correspondence
Jeongja Kim, PT, PhD
Department of Physical Therapy, Howon University, Gunsan, Republic of Korea
Tel: *** - **** - ****
E-mail: kotpt@hanmail.net

INTRODUCTION

Combat boots are shoes specially made for soldiers and were developed for the purpose of absorbing shock, protecting the feet from direct trauma, and providing stability for the ankle joints, and their performance is constantly being improved.[1] Recent trends in studies for the ergonomic improvement of combat boots have generally centered around the feet and the lifespan of the boots, including impact absorption ability, the posture correction effect of wearing functional insoles, and the accelerated aging of rubber for combat boots.[2-4] Since among major activities related to damage to soldiers, body movements are the most frequent cause of damage (with 35% of injuries being attributed to running and 20% attributed to walking and marching), it can be considered that previous studies have focused on the functionality of combat boots in order to address such problems.[5]

If the scope of studies, which has thus far been the foot area affected by the wearing of combat boots, is expanded to other body parts, the fact that the shape of the shoes is an important factor that affects body functions, including the functions of the joints and muscles of the lower extremity, should be considered.[6]

Previous study reported that along with soldiers' high-intensity training programs and military equipment, the effects of shoes acted as a main cause of damage to the musculoskeletal system of the leg.[7] The experience of ankle sprain before enlistment acts as a potential risk factor that increases the rate of leg damage by 13% after enlistment.[8] The most common musculoskeletal injuries in soldiers are muscle strain, sprain, overuse, and knee conditions, and the rate of injuries related to leg training is shown to be 37%.[8] On reviewing the rates of injuries by single body part, it can be seen that the injury rate of ankle joints was the highest at 13%; followed by that of the knee joint at 13%; that of the pelvis, hip, or femur areas at 13%; and that of the lower back at 7.5%.[5]

All the muscles and fasciae in the regions ranging from the feet to the lower back have complex relationships in the role of physical mechanical compensation and functional performance through mutual functional connections.[9,10] Considering the fact that shoes are an important factor that affects the mechanics of lower extremity injuries of soldiers, diverse studies are needed to improve the anthropometric functions of combat boots.[7] Although fourth-generation new combat boots have been developed and distributed recently, the development of combat boots considering environmental and seasonal factors has been proposed.[11] In going beyond the existing studies related to combat boots regarding the shock absorption ability limited to the feet region and the accelerated aging of the insole and rubber, quantitative analysis of the effects of combat boots on major joints and muscles will have positive effects on improving the function of combat boots as well as on preventing injuries and enhancing combat power.[2-4]

The muscle tone and stiffness of the lower extremity muscles are affected by the deformity of body alignment, knee joint damage, and paralysis related to nervous system damage.[12-14] Muscle tone refers to the internal stiffness induced by the elasticity of the contractile apparatus and the intrinsic elasticity of muscle tendons and connective tissues in relation to physical properties, and abnormal muscle tone causes body damage.[15,16] However, since muscle tone and stiffness are often evaluated subjectively in clinical practice, objective evaluation is necessary to measure muscle tone in order to monitor the effectiveness of medical treatment or therapeutics.[17]

The MyotonPRO equipment used to measure muscle tone is non-invasive equipment that enables the identification of mechanical properties such as muscle tone and stiffness simultaneously by inducing muscle vibration after applying brief mechanical stimulation using a probe.[17] This equipment is considered to produce a reliable measure of the mechanical properties of muscle and tendon tissues and provides quantitative measurements of soft tissues.[18]

Therefore, based on the necessity of such studies, this study was intended to quantitatively compare and analyze the effects of walking after wearing combat boots and athletic shoes on the muscle tone and stiffness of lower extremity muscles in healthy adult men in their twenties, with a view to discovering the effects of the properties of individual shoes on the muscle tone and stiffness of the lower extremity muscles. In addition, the study data as such are intended to provide basic data for the development of improved combat boots.

SUBJECTS AND METHODS

Subjects

This study selected 30 healthy men in their twenties who were enrolled in Howon University in Jeollabuk-do, South Korea. From among those who wanted to participate in the study, candidates were selected who had not received any medical diagnosis or treatment in relation to musculoskeletal diseases within the last six months, were active for participation in the study, and had signed the agreement for participation in the study. Those who had any cardiovascular disorder, vestibular system disorder, respiratory system disorder, and so on were excluded from the study. In addition, in this study, in order to minimize the possible effects of foot deformity on the study results, those who had flat feet were excluded from the study through the navicular drop test. In the navicular drop test, after having the subject sit on a chair in a posture with 90° knee flexion, the researcher correctly aligned the subject's ankle joints, made the skin mark on the most protruding point of the navicular tubercle, and measured the vertical height of the skin mark from the ground. Thereafter, the vertical height of the skin mark was measured again when the subject was in a standing position with the load of his/her own weight without support, and in cases where the height changed by more than 10 mm, the subject was diagnosed with flat feet,[19] and excluded from the study. All studies were conducted with the approval of the Bioethics Committee of Howon University (HWU-202002-001-02).

Interventions

In this study, 30 subjects were randomly divided into a combat boots group of 15 subjects and an athletic shoes group of 15 subjects. The combat boots group wore combat boots (South Korean fourth-generation new combat boots, Treksta, South Korea), and the athletic shoes group wore personal athletic shoes (Figure 1). Both groups walked for 30 minutes at 4.2 km/h on the treadmill. The walking speed of the treadmill was set according to the average walking speed of Korean men (1.175 m/s). There was no rest time during exercise, and there was no change in treadmill slope.

Figure 1. Compat boot (South Korean fourth-generation new combat boots, Treksta, South Korea)

Measurement of muscle tone and muscle stiffness

In this study, Myoton®PRO (Myoton AS, Estonia) was used to measure the muscle tone and stiffness of the muscles of both legs of the subject. MyotonPRO is equipment of which the high reliability has been verified through previous studies,[17] and has recently been used in several human body studies relating to musculoskeletal diseases[18] and nervous system diseases.[14,18] The muscle tone include its tension state, characterized by frequency (Hz). Muscle stiffness include mechanical property (N/m), indicating muscle ability to resist of external force.[17] The muscles to be measured were set to five muscles, including rectus femoris (RF), tibialis anterior (TA), hamstring (Ham), lateral head of gastrocnemius (LGCM), and medial head of gastrocnemius (MGCM), in both lower extremities. As for the postures for measurement of individual muscles, the RF muscle and TA muscle were measured in a supine position, and the Ham, LGCM, and MGCM muscles were measured in a prone position. As for the measurement method, a marking point was drawn with a non-toxic pen on the highest point of the muscle belly of each muscle to be measured, so that the same points could be measured before and after the study. The researcher measured each marked point while maintaining the measuring equipment in the vertical state and used the average value of two measurements for the study results.[12] All measurements were carried out by one physical therapist for accurate palpation and measurement of individual muscles. The measurements were performed before and after treadmill walking.

Data and Statistical Analysis

Statistical analysis was conducted using a statistical processing program (SPSS 23.0/PC, USA). The normal distribution of the study group was analyzed by conducting a Kolmogorov-Smirnov test. Paired t-tests were used to compare the muscle tone and muscle stiffness of the lower extremity muscles before and after treadmill walking within the study groups, and independent t-tests were used for comparison between the study groups. All statistical significance levels in this study were set to α=.05 for analysis.

RESULTS

Characteristics of subjects

As for the general characteristics of the study subjects, in the case of the combat boots group, the mean

Table 1. General characteristic of subjects

	Combat boots group (n=15)	Athletic shoes group (n=15)	*P*
Age (years)	22.47 ± 1.92	21.13 ± 1.68	.053
Weight(kg)	23.83 ± 10.25	31.22 ± 14.55	.540
Height (cm)	175.13 ± 3.98	173.19 ± 5.84	.295
Dominant side of lower extremity	Right (15) / Left (0)	Right (14) / Left (1)	

Mean±SD, $^*P$<.05

age was 22.47±1.92 years, weight was 75.27±6.73 kg, and height was 175.13±3.98 cm. And, in the athletic shoes group, the mean age was 21.13±1.68 years, weight was 72.93±12.93 kg, and height was 173.19±5.84 cm. General characteristics of the subjects between both groups were not significantly different (Table 1).

In the combat boots group, the muscle tone and stiffness of the MGCM muscle on the dominant side decreased significantly after intervention (treadmill walking), and the muscle tone and stiffness of the RF muscle and the muscle stiffness of the Ham muscle on the non-dominant side also decreased significantly after intervention. On the other hand, in the athletic shoes group, there was no significant change in the muscle tone and stiffness of all muscles between before and after intervention. In comparison between the combat boots group and the athletic shoes group, the muscle tone and stiffness of the Ham and MGCM muscles on the dominant side and those of the RF muscle on the non-dominant side in the combat boot group significantly decreased compared to those in the athletic shoes group (Table 2).

Table 2. Muscle tone and stiffness of each muscle

Variables			Group	Pre-test	Post-test	t	*P*	t	*P*
Rectus femoris	DO Side	MT (Hz)	Combat boots	15.65 ± 1.06	15.70 ± 1.13	-.263	.797	-.836	.410
			Athletic shoes	15.32 ± 1.02	15.72 ± 1.87	-1.019	.326		
		MS (N/m)	Combat boots	281.90 ± 26.15	279.77 ± 25.12	.675	.511	-1.116	.274
			Athletic shoes	265.50 ± 27.38	274.93 ± 50.49	-.956	.355		
	non-DO Side	MT (Hz)	Combat boots	15.56 ± 1.45	14.97 ± 1.07	3.400	.004**	-3.319	.003**
			Athletic shoes	15.24 ± 1.06	15.35 ± 1.22	-.909	.379		
		MS (N/m)	Combat boots	277.57 ± 34.98	266.73 ± 30.92	4.810	.000**	-3.276	.003**
			Athletic shoes	268.40 ± 32.35	267.50 ± 32.26	.443	.664		
Tibialis anterior	DO Side	M (Hz)	Combat boots	21.54 ± 2.55	21.14 ± 2.22	1.386	.188	.234	.816
			Athletic shoes	20.49 ± 1.22	19.96 ± 2.07	1.202	.249		
		MS (N/m)	Combat boots	479.23 ± 85.84	455.33 ± 72.72	1.915	.076	-.587	.562
			Athletic shoes	431.43 ± 52.79	417.23 ± 70.24	1.311	.211		
	non-DO Side	MT (Hz)	Combat boots	21.68 ± 2.19	21.31 ± 2.47	1.283	.220	-1.424	.166
			Athletic shoes	20.73 ± 1.79	20.93 ± 1.61	-.729	.478		
		MS (N/m)	Combat boots	465.33 ± 67.74	458.17 ± 83.53	.606	.554	-.706	.486
			Athletic shoes	440.13 ± 65.64	444.30 ± 58.22	-.384	.707		
Hamstring	DO Side	MT (Hz)	Combat boots	15.36 ± 1.47	14.95 ± 1.52	1.244	.234	-2.107	.044*
			Athletic shoes	14.75 ± 1.31	15.31 ± 1.78	-1.744	.103		
		MS (N/m)	Combat boots	277.17 ± 37.97	266.27 ± 40.71	1.355	.197	-2.237	.033*
			Athletic shoes	256.43 ± 39.20	270.70 ± 46.02	-1.814	.091		
	non-DO Side	MT (Hz)	Combat boots	15.00 ± 1.31	14.59 ± 1.11	1.918	.076	-.670	.508
			Athletic shoes	15.18 ± 1.37	14.94 ± 1.16	1.734	.105		
		MS (N/m)	Combat boots	266.30 ± 35.29	253.00 ± 32.95	2.493	.026*	-1.963	.060
			Athletic shoes	263.10 ± 37.73	262.87 ± 35.91	.059	.954		
	DO Side	MT (Hz)	Combat boots	17.64 ± 1.90	18.00 ± 1.84	-1.910	.077	-.378	.708
			Athletic shoes	17.27 ± 1.53	17.73 ± 1.64	-2.193	.046		

Table 2. Muscle tone and stiffness of each muscle

Variables			Group	Pre–test	Post–test	t	P	t	P
LGCM	DO Side	MS (N/m)	Combat boots	321.63 ± 50.36	328.93 ± 46.49	−1.493	.158	−.163	.872
			Athletic shoes	307.43 ± 40.39	315.87 ± 40.48	−1.704	.110		
	non–DO Side	MT (Hz)	Combat boots	17.66 ± 1.61	17.56 ± 1.50	.669	.515	−1.262	.217
			Athletic shoes	17.26 ± 2.00	17.49 ± 1.88	−1.071	.302		
		MS (N/m)	Combat boots	319.63 ± 33.74	321.73 ± 39.94	−.468	.647	−1.059	.298
			Athletic shoes	311.93 ± 54.34	322.17 ± 48.67	−1.642	.123		
MGCM	DO Side	M (Hz)	Combat boots	16.91 ± 1.06	16.32 ± .87	3.927	.002**	−3.323	.002**
			Athletic shoes	16.58 ± 1.48	16.82 ± 1.70	−1.210	.246		
		MS (N/m)	Combat boots	291.47 ± 19.99	280.00 ± 16.77	4.050	.001**	−3.585	.001**
			Athletic shoes	280.30 ± 33.80	284.83 ± 35.88	−1.314	.210		
	non–DO Side	MT (Hz)	Combat boots	16.52 ± 1.05	16.52 ± 1.02	0.000	1.000	−.188	.852
			Athletic shoes	16.53 ± 1.59	16.58 ± 1.49	−.303	.767		
		MS (N/m)	Combat boots	284.60 ± 20.61	283.77 ± 19.48	.214	.834	−.885	.384
			Athletic shoes	280.63 ± 34.39	284.40 ± 31.20	−1.095	.292		

Mean±SD, *P<.05, **P<.01, MT: Muscle tone, MS: Muscle stiffness, DO: Dominant
LGCM: Lateral head of gastrocnemius, MGCM: Medial head of gastrocnemius

DISCUSSION

Shoes cover the foot and ankle joints and come into direct contact with the ground during walking. Therefore, the shapes of shoes affect the muscle tone of the lower extremity muscles. In this study, when the subjects walked on a treadmill for 30 minutes at a speed of 4.2 km while wearing athletic shoes and combat boots, respectively, no significant difference in the muscle tone and stiffness appeared between before and after walking in the athletic shoes group. A previous study reported that when subjects walked at the same speed as in this study, there was no significant change in the muscle tone or stiffness of the TA, peroneus longus, and MGCM muscles on both sides;[20] findings identical to the results of this study. On the other hand, in the combat boots groups of this study, muscle tone and stiffness were significantly lower in the RF, Ham, and MGCM muscles after walking. In the case of boots, a smoother boot shaft and lower vamp stiffness increase the movements of the ankle joints, gait velocity, and step length.[21] In the case of the combat boots applied in this study, the movement of the ankle joint is limited because the boot shaft is firm and the vamp stiffness is high. It has been reported that taping or ankle braces, which are frequently applied to limit the movement of the ankle joint, reduce the efficiency of the ankle joint, but have a positive effect on maintaining balance by providing somatosensory feedback.[22–24] Therefore, it is thought that since the combat boots applied in this study have hard boot shafts and high vamp stiffness, it played the role of an orthosis for the ankle joint, thereby reducing the mobility of the ankle joint while improving stability. Since the combat boots improve the stability of the ankle joint when compared to other shoes, it is judged that the reduction in mobility as such affected the decreasing of the muscle tone. On the other hand, in the case of athletic shoes, it is considered that since the boot shaft is below the ankle and the vamp stiffness is softer than combat boots, the movement of the ankle joint is not limited and, therefore, no change in the muscle tone and stiffness was caused.

As for the muscle tone and stiffness of each muscle, no significant difference appeared in the TA muscle and LGCM muscle of combat boots group and athletic shoes group. The contraction of the TA muscle functionally acts on the ankle dorsiflexion and inversion to prevent foot drop in the swing phase during walking and acts on heel strike in the stance phase. Since the boot shaft was high in the case of the combat boots used in this study, the ankle dorsiflexion and inversion movements were limited during walking so that the muscle tone and muscle stiffness of the TA muscles on both sides decreased after walking, but no significant difference appeared. On the other hand, the muscle tone and muscle stiffness of the LGCM muscle of both the combat boots group and athletic shoes group increased after walking, but no significant difference appeared. The reason for the increase of LGCM's muscle tone and muscle stiffness, although not significant, is considered that initial values of LGCM muscle tone and stiffness are lower than the muscle tone and stiffness of TA muscle.

The muscle tone and stiffness of the Ham and MGCM muscles on the dominant side significantly decreased in the combat boots group compared to the athletic shoes group. Whereas, the muscle tone and stiffness of the RF muscle on the dominant side showed no significant different in the between groups. It considered that muscle tone and stiffness of MGCM muscle decreased significantly after walking compared to before walking in combats groups. The Ham muscle is located behind the leg, connected to the MGCM muscle, which is affected by decreased MGCM's muscle tone and stiffness. However, RF muscle is located at the front of the leg, so it is considered that it was not affected by MGCM's muscle tone and stiffness. In the case of combat boots, it is considered that since the boot shaft was high, which relatively restricts the movement of plantar flexion and dorsiflexion of the ankle joint but relatively increases the stability of the ankle joints, the muscle tone of the MGCM muscle significantly decreased after walking. In general, ankle-foot orthosis (AFO), which provides stability to the ankle joints, plays the role of lowering muscle tone and is applied to subjects with high muscle tension due to stroke or cerebral palsy utilizing the foregoing apparatus.[25] The combat boots used in this study also restrict the movements of the ankle joints, similarly to AFO, and the restriction of movements as such is considered to have affected the lowering of the muscle tone of the muscles. Another previous study reported that in the case of combat boots, the values of the angle at heel strike, relative range of motion, and peak dorsiflexion of the ankle joints in the sagittal plane when running were significantly lower compared to running shoes.[26] This means that when walking in combat boots, the movement of the ankle joints in the sagittal plane decreases and the muscle activity of the gastrocnemius muscle, which is mainly involved in plantar flexion in the sagittal plane, decreases. This is considered to be the reason why the muscle tone and muscle stiffness of the MGCM muscle on the dominant side decreased in the results of this study. In the case of the Ham muscle, the muscle tone and muscle stiffness significantly decreased on the dominant side in the combat boots group compared to the athletic shoes group. This suggests that the muscle tones of the two muscles decreased together because the fasciae of the Ham and MGCM muscles had continuity.[9] These results indicate that the characteristics of the shoes termed combat boots affect the muscle tone and stiffness of not only the muscles of the ankle joint but also the muscles of the knee joint.

The limitations of this study include the fact that the qualitative and quantitative differences in walking were not compared. When walking wearing combat boots, the number of steps and the angle of the lower limb joints may be changed to compensate for the restriction of the movements of the ankle joints. Therefore, in future studies, a spatiotemporal analysis of walking after wearing combat boots should also be conducted. In addition, another limitation of this study is that the muscle tone and stiffness of the lower extremity muscles during running and marching related to military training were not checked. However, it may not be appropriate to control major variables, such as an increase in weight due to the wearing of military gear or military weapons or changes in the slope of the ground during a march, and check the physiological changes of the lower extremity muscles according to the characteristics of combat boots. Our follow-up study is planned to study the increase or decrease in the muscle tone and muscle stiffness of the lower extremity muscles during the march of soldiers, focusing on the main results derived from this study. In addition, since the subjects' walking was performed on a treadmill in this study, it should be considered that the muscle tone may differ from that of walking on the general ground. However, until now, studies that have investigated muscle tone when walking wearing combat boots or athletic shoes are limited, and the results of this study will be significant in that they can be used as basic data on wearing combat boots.

From the results of this study, it could be seen that wearing combat boots while walking on a treadmill for 30 minutes further reduced muscle tone and stiffness of the lower extremity muscles compared to athletic shoes. Such study results indicated that the restriction of joint movements occurring when wearing combat boots has an effect on decreasing muscle tone.

CONCLUSION

Combat boots relatively limit the movement of the ankle joint compared to athletic shoes, and this characteristic has an effect on decreasing the muscle tone of the lower extremity muscles. Based on the results of this study, if the effects on the muscle tone and stiffness of the lower extremity muscles are taken into account when developing combat boots and the results are used for product development, the products can be utilized more diversely not only by soldiers but also by subjects with high muscle tone or hypermobility of the ankle joint and other similar conditions.

ACKNOWLEGEMENT

Funding of this paper was provided by Howon University.

REFERENCES

1. Paisis P, Hanley B, Havenetidis K, et al. Cypriot and Greek Army Military boot cushioning: ground reaction forces and subjective responses. *Military medicine*. 2013;178(4):e493–e497.
2. Park SB, Lee KD, Kim DW, et al. Plantar pressure measurement of Korean new combat boots with improved comfort. *JKSPE*. 2015;5:548–549.
3. Yoon WJ, Song DH, Shin GS. Evaluation of posture-correcting shoe inserts for military boots. *J Ergonomics Soci Korea*. 2019;5:43–43.
4. Yu GS, Lee NR, Yeo YH, et al. Accelerated life prediction of the rubber for combat boots. *Korea Academy Industrial Cooperation Society*. 2015;16(12):8637–8642.
5. Roy TC, Songer T, Ye F, et al. Physical Training Risk Factors for Musculoskeletal Injury in Female Soldiers. *Mil Med*. 2014;179(12):1432–1438.
6. Kerrigan DC, Franz JR, Keenan GS, et al. The effect of running shoes on lower extremity joint torques. *Pm&r*. 2009;1(12):1058–1063.
7. Andersen KA, Grimshaw PN, Kelso RM, Bentley DJ. Musculoskeletal lower limb injury risk in army populations. *Sports Med Open*. 2016;2:22.
8. Jones BH, Cowan DN, Tomlinson JP, et al. Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc*. 1993;25(2):197-203.
9. Myers TW. *Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists*. 3rd. Churchill Livingstone; 2013.
10. Wang JS. Therapeutic effects of massage and electrotherapy on muscle tone, stiffness and muscle contraction following gastrocnemius muscle fatigue. *J Phys Ther Sci*. 2017;29(1):144–147.
11. Sim JH, Namkung SP, Park SH. A study on the diagnosis of combat boots supply necessity depending on military operation environment. *J Convergence Cult Technol*. 2018;4(1):237–240.
12. Um KM, Park SE, Wang JS. An analysis on the muscle tone of lower limb muscles on flexible flat foot. *J Phys Ther Sci*. 2015;27(10):3089–3092.
13. Wang JS, An HJ, Kim YY. Effect of joint mobilization on improvement of knee pain, isokinetic strength, muscle tone, muscle stiffness in an elite volleyball player with knee injury. *J Korea Acad Industr Coop Soc*. 2016;17(7):326–333.
14. Chuang LL, Wu CY, Lin KC, et al. Reliability, validity, and responsiveness of myotonometric measurement of muscle tone, elasticity, and stiffness in patients with stroke. *Arch Phys Med Rehabil*. 2012;93(3):532–540.
15. Pisano F, Miscio G, Colombo R, et al. Quantitative evaluation of normal muscle tone. *J Neurol Sci*. 1996;135(2):168–172.
16. Butler RJ, Crowell HP, Davis IM. Lower extremity stiffness: implications for performance and injury. *Clin Biomech*. 2003;8(6):511–517.
17. Agyapong-Badu S, Aird L, Bailey L, et al. Interrater reliability of muscle tone, stiffness and elasticity measurements of rectus femoris and biceps brachii in healthy young and older males. *Work Papers Health Sci*. 2013;4:1–11.
18. Morgan GE, Martin R, Williams L, et al. Objective assessment of stiffness in Achilles tendinopathy: a novel approach using the MyotonPRO. *BMJ open sport & exercise medicine*. 2018;4(1):e000446.

19. Cote KP, Brunet ME, Gansneder BM, et al. Effects of pronated and supinated foot postures on static and dynamic postural stability. *J Athl Train*. 2005;40(1):41.
20. Wang JS. The influence of walking on the crural muscle tone and stiffness in pronated foot. *IAPTR*. 2018;9(4):1596-1601.
21. Cikajlo I, Matjačić Z. The influence of boot stiff-ness on gait kinematics and kinetics during stance phase. *Ergonomics*. 2007;50(12):2171-2182.
22. Cordova ML, Ingersoll CD, LeBlanc MJ. Influence of ankle support on joint range of motion before and after exercise: a meta-analysis. *J Orthop Sports Phys*. 2000;30(4):170-177.
23. Emin E, Bulent U. Proprioception and ankle injuries in soccer. *Clin Sports Med*. 2008;27:195-217.
24. Kim KH, Cho JH. The effects of ankle taping on ankle angular velocity, ground reaction force and postural stability during jump landing on athlete with functional ankle instability. *KJSB*. 2009;19(3):519-528.
25. Kobayashi T, Leung AK, Hutchins SW. Design and effect of ankle-foot orthoses proposed to influence muscle tone: a review. *J Prosthet Orthot*, 2011;23(2):52-57.
26. Sinclair J, Taylor PJ. Influence of new military athletic footwear on the kinetics and kinematics of running in relation to army boots. *J Strength Cond Res*. 2014;28(10):2900-2908.