Coll. Antropol. 39 (2015) Suppl. 1: 167–172
Original scientific paper

Activation Pattern of Lower Leg Muscles in Running on Asphalt, Gravel and Grass

Aleš Dolenec, Igor Štirn and Vojko Strojnik

University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

A B S T R A C T

Running is performed on different natural surfaces (outdoor) and artificial surfaces (indoor). Different surface characteristics cause modification of the lower leg muscle activation pattern to adopt ankle stiffness to these characteristics. So the purpose of our investigation was to study changes of lower leg muscles activation pattern in running on different natural running surfaces. Six male and two female runners participated. The participants ran at a freely chosen velocity in trials on asphalt while in trials on gravel, and grass surfaces they were attempting to reach similar velocities as in the trials on asphalt. Muscle activation of the peroneus brevis, tibialis anterior, soleus, and gastrocnemius medialis of the right leg was recorded. Running on asphalt increased average EMG amplitude of the m. tibialis anterior in the pre-activation phase and the m. gastrocnemius medialis in the entire contact phase compared to running on grass from 0.222±0.113 V to 0.276±0.136 V and from 0.214±0.084 V to 0.238±0.088 V, respectively. The average EMG of m. peroneus brevis in pre-activation phase increased from 0.156±0.026 V to 0.184±0.455 V in running on grass in comparison to running on gravel. Running on different surfaces is connected with different activation patterns of lower leg muscles. Running on asphalt requires stiff ankle joints, running on gravel requires greater stability in ankle joints, while running on grass is the least demanding on lower leg muscles.

Key words: *running, biomechanics, EMG, training load, natural surfaces*

Introduction

Running is performed on different surfaces, including meadows, forests, gravel roads, city streets and pavements, artificial, plastic surfaces in track and field stadiums, and parquet floors in gyms, etc. The surfaces differ in flatness, stiffness, elasticity, etc., which may result in specific responses of the neuro-muscular system for proper stiffness regulation[1]. Runners adjust their leg stiffness to accommodate changes in surface stiffness, allowing them to maintain similar running mechanics on different surfaces[2]. Stiffness regulation during the early contact phase of running is related to pre-activation[1], the short latency response of the stretch reflex[3], joint angle[4], and fatigue[5]. Not only agonist activation but a co-contraction of antagonist muscles enable the regulation of stiffness of agonist muscles[6].

The vast majority of runners are using heel-toe running techniques in running velocities to 5 m/s[7]. The role of the tibialis anterior muscle (TA) differs between heel-toe and toe running[8]. After the heel impact, the TA acts as an absorber in heel-toe technique, while the TA has no significant task in toe technique[8]. In heel-toe running, the pre-activation of TA serves to prepare the TA for the impact[8,9] to control foot eversion for absorption of the ground reaction force[10]. In toe running, the pre-activation phase of TA serves as an antagonist co-activation to the triceps surae. From the mid-stance to the toe-off, the forward propulsion takes place. The heel is rising, and the plantar flexors take the main control of the foot. Before the moment of toe-off, the plantar flexors and most of the other leg muscles switch off[11]. Running on uneven surfaces increases the possibility of foot inversion; consequently, ankle sprain can occur. The peroneus brevis and longus muscles are responsible for controlling the inversion[12].

Different surface characteristics are expected to modify the lower leg muscle activation pattern and leg kinematics to adapt ankle stiffness to these characteristics[4,13,14]. The role of the muscle activation pattern when running on different surfaces is mostly analyzed in laboratory conditions; there is a lack of data for running on outdoor surfaces. Therefore, the purpose of our investigation was to study the activation pattern of the lower leg muscles when running on different natural running sur-

Received for publication July 1, 2014

faces, in order to be able to suggest proper running surfaces according to the runner's condition and training session goal.

Materials and Methods

Participants

Six male and two female runners (age =25±2.2 years, height =177±6.8 cm, mass =75±12.1 kg) participated. At the time of the experiment, all the participants were active recreational runners and heel strikers. The participants used their own running shoes. No one had a history of ankle disorders within six months previous to the experiment. The experiments were in accordance with the guidelines of the Helsinki declaration and approved by National Ethics Commission. All participants gave written informed consent.

Measurement setup

The participants were fitted with EMG electrodes, acceleration sensors, and a miniature notebook computer (the weight of the equipment was 1.5 kg). Before the measurements, the participants made a few runs to accommodate themselves to the surface. The sequence of measurements was always the same since all the participants were used to run on all three surfaces (asphalt, gravel, and grass) used in this experiment. It was not expected any learning process to take part in separate trials. The first measurements were made on asphalt, then on gravel, and finally on grass. The participants ran at a freely chosen velocity in trials on asphalt, while in trials on the other two surfaces they were attempting to attain similar velocities as in the trials on asphalt. On each surface, the participants performed three correct runs (using the heel-toe technique) in which the velocity of running did not exceed ±5% of the average velocity of running on asphalt. The rest between the consecutive measurements was 3 to 5 minutes to avoid fatigue.

The running path consisted of 20 m of run up, 30 m of measuring area (constant running velocity), and a self-chosen stopping length. The measuring area was marked with a pair of photocells (Brower Timing, Utah, USA) at the beginning and at the end. The time was measured with precision of 1/100 s. The average running velocity was calculated from the time needed to cover 30 m distance. There were three different running surfaces for three different measuring conditions. The asphalt surface was the normal type of asphalt that is used for recreational sport areas. The grass surface was a flat regular lawn in a public park area, with a height of approximately 10 cm. A gravel road was used for the road condition. The road was made from sand and stones of different sizes. The biggest stones were 10 cm in diameter and 5 cm above the level ground. Distribution of the differently sized stones was random. There were some tree leaves on the road, so just a few stones were visible. The stiffness of the three different running conditions was not measured, but it can be concluded from the literature that asphalt is much harder surface than grass in the park[15].

Two lightweight biaxial acceleration sensors (±50g; Biovision, Weherheim, Germany), one on the each running shoe, were fixed to the rear part of the shoe soles with adhesive tape. Two high-speed cameras (300 fps; Casio Exilim High speed EX-F1; Tokyo, Japan) were used to monitor which part of the foot made first contact with the ground (rear, middle or front). One high-speed camera was positioned in the sagittal plane, 20 m from the running line and in the middle of the measuring interval. The other high-speed camera was positioned in the running line. The participant was tracked with a high-speed camera from the start to the end of the measuring interval.

A four-channel electromyography (EMG) system with a differential amplifier (Biovision, Weherheim, Germany) was used to record muscle activation. Bipolar Ag/AgCl surface electrodes 10 mm in diameter and with a 20 mm inter-electrode distance were put over the muscle bellies of the peroneus brevis (PB), tibialis anterior (TA), soleus (SO), and gastrocnemius medialis (GM) of the right leg. The EMG electrode positions for PB, TA, SO and GM were made according to the SENIAM recommendations [16]. The skin was shaved, lightly abraded with sandpaper, and cleaned with alcohol before application of the surface electrodes. All electrodes were tested for appropriate resistance (< 5 KΩ) and were confirmed through manual muscle testing for artifacts. Surface EMG electrodes, acceleration sensors, and associated wires and amplifiers were further secured using an elastic bandage to prevent cable tensioning and movement of the device during the experimental tasks.

Data processing

The EMG and acceleration data were transmitted to the UMPC miniature notebook computer (Viliv, Yukyung Technologies Corp., South Korea) where the analog data were sampled at 2000 Hz (16 bit resolution) and stored for analysis. DASYLab (version 11.0; Measurement Computing, Norton, MA, USA), was used. All data were analyzed using custom-made software.

Only steps with the heel-toe technique were used for further analysis. The contact time for each step was read from the acceleration signal of the right leg. The contact times of all analyzed steps in each running condition were averaged, and the standard deviation was calculated for a single runner. The accuracy of contact time achieved from acceleration signal was controlled by counting photos from the high-speed cameras during the foot's contact with the ground. An accuracy control was made for the two analyzed steps in each condition. The steps for control were chosen randomly from analyzed steps.

After acquisition, all EMG data were low-pass filtered (cut-off 10 Hz), and full-wave rectified. The EMG data were divided in to three phases for each step: pre-activation phase, reflex phase, and whole contact phase[17]. The pre-activation phase started 100 ms before the first foot contact and finished at the moment of that contact. The reflex mediated phase started 30 ms after the first contact and lasted for 90 ms. The average IEMG amplitude (aIEMG – the time of each phase was used to reset the integrator) was calculated for each phase, muscle, and step. Afterwards, averages for all steps were calculated and used for further statistics.

Statistics

A repeated-measures analysis of variance was performed within the participants over three surface conditions. Post hoc analyses using Bonferroni's honestly significant differences tests were performed to interpret effects. An effect size (r) was calculated according to Field[18]. The dependent variables were running velocity, right foot contact time, step frequency, aIEMG in pre-activation phase, reflex mediated phase and contact phase for PB, TA, SO, and GM. The α level was set at.05 for all comparisons. All data were analyzed with PASW Statistics (version 18; IBM, Armonk, NY, USA).

Results

Basic descriptive statistics of biomechanical parameters are presented in Table 1. The statistics reveal there were no significant differences in running velocity, contact time and stride frequency between different running conditions. For each muscle, the mean values and SDs of aIEMG in different phases are presented in Figures 1 to 4. Running on asphalt shows significantly higher aIEMG amplitude of TA in the pre-activation phase ($p<0.00$; $r=0.86$) (Figure 1) and GM in the entire contact phase ($p=0.03$; $r=0.78$) than running on grass (Figure 3). The aIEMG of PB in the pre-activation phase was significantly higher ($p=0.03$; $r=0.84$) while running on gravel than running on grass (Figure 4).

Discussion and Conclusion

In this paper, we have analyzed differences in the activation of the lower leg muscles while running on different natural running surfaces. Comparisons of running on asphalt, grass, and gravel showed that velocities, running frequencies, and contact times were not significantly different ($p>0.05$) among conditions. Similar running velocities among conditions were a basic prerequisite enabling studying differences in running techniques. Non-significant differences in running frequencies and contact times (basic kinematics) were also found by other investigators comparing running with shoes of different midsole hardnesses or running on surfaces with different stiffnesses[14] or who compare running shod and barefoot[19].

To maintain the same basic kinematics on different surfaces, one may expect that muscle activation should adapt to those surfaces. In this study, running on asphalt showed a 24% (0.276/0.222 V) higher TA aIEMG in the pre-activation phase than running on grass. Similar re-

TABLE 1
BASIC KINEMATIC PARAMETERS OF RUNNING ON DIFFERENT SURFACES

Variable	Asphalt		Road		Grass	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Velocity (m/s)	4.5	0.5	4.5	0.4	4.5	0.5
Contact time (ms)	222	25	220	24	225	31
Step frequency (Hz)	1.44	0.1	1.44	0.1	1.44	0.1

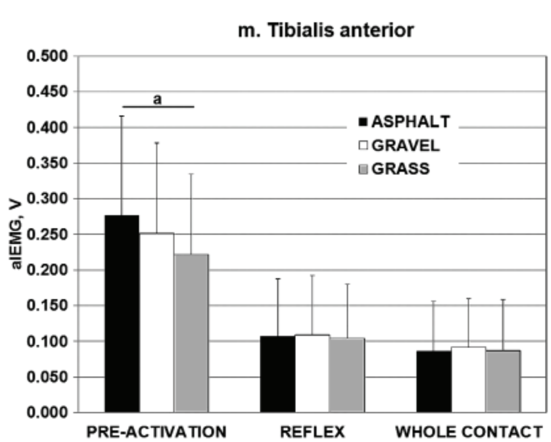

Fig. 1. aIEMG of m. tibialis anterior divided into different phases in running on three different surfaces. [a]p<0.05.

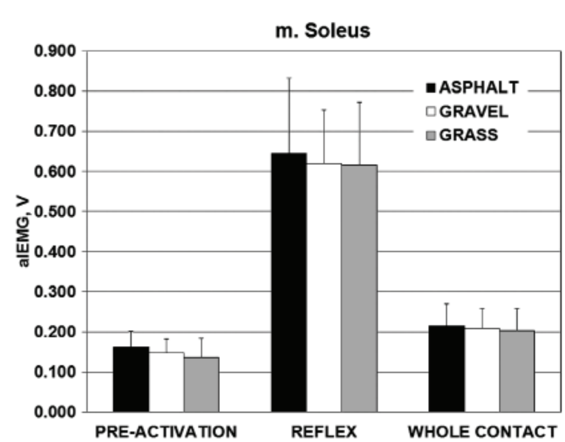

Fig. 2. aIEMG of m. soleus divided into different phases in running on three different surfaces.

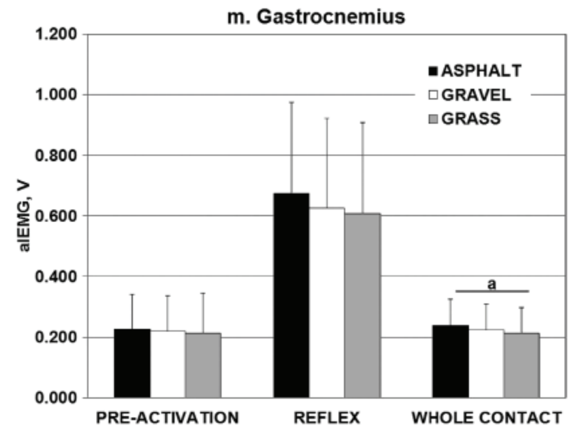

Fig. 3. aIEMG of m. gastrocnemius medialis divided into different phases in running on three different surfaces. [a]p<0.05.

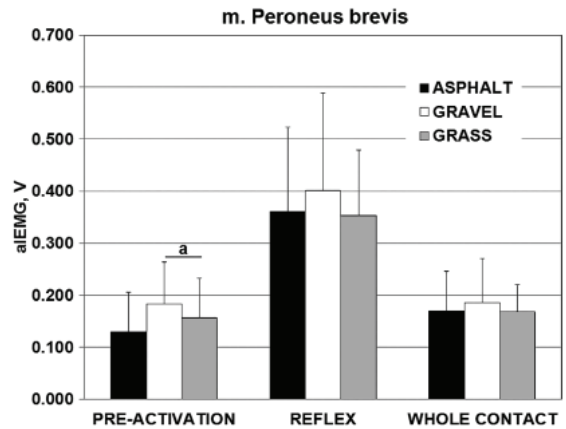

Fig. 4. aIEMG of m. peroneus brevis divided into different phases in running on three different surfaces. [a]p<0.05.

sults were obtained by Komibayashi and Muro[20]. Higher TA aIEMG in the pre-activation phase implied higher TA stiffness when running on asphalt, which is in accordance with the fact that stiffer surfaces cause higher impact forces than less stiff surfaces in running[21]. In heel-toe running, TA pre-activation is responsible for two actions: (I) with co-activation, it supports activation of plantar flexors enabling greater initial stiffness of plantar flexors at the first moment of the ground contact, and (II) it acts as an absorber and pronation corrector in the first thirty milliseconds after heel impact[8,22]. With the alteration of pre-activation of the ankle muscles and possible additional alteration of the leg kinematics, runners can properly adjust their stiffness to the surface stiffness as shown in running[23]. Lower muscle stiffness results in a less controlled laying of the foot on the surface and increased joint impact forces, as was previously shown in fatigued decline running[5]. To avoid poor control of the foot on the asphalt, the runners increased TA aIEMG in the pre-activation phase, which is a part of feed-forward control. Properly adjusted feed-forward control is important not only for effective movement but also for safe movement[24].

After the heel impact, the eversion of the foot takes place as a next mechanism of the ground reaction force absorption[10] and lasts until 45% of the contact phase[25]. Foot eversion is controlled by the eccentric action of TA and the tibialis posterior muscle, and the concentric action of PB and the peroneus longus muscle[26]. Because the only difference in observed muscle activation among surfaces was observed in TA pre-activation and not later, we suspected that its main role was mostly preparing initial TA stiffness to accommodate surface stiffness and less to prevent eversion[23].

PB showed higher aIEMG in the pre-activation phase in running on gravel as compared to running on grass ($p=0.03$; $r=0.84$). PB and the peroneus longus muscle are the main foot eversion muscles, and they counteract in case of unintended inversion of the foot[12]. In our experiment, the participants ran on a gravel road that was partially covered with tree leaves; therefore, the participants could not exactly see whether they were going to step on a flat or uneven surface although they had free trials before the measurement. They had to be prepared for any kind of ankle joint movement after heel touch-down. In this case, inversion of the foot is probably the most common and dangerous movement, since it can cause ankle sprain if the amplitude of inversion is too big[27]. We can conclude that the increased PB pre-activation in our study means that the participants were prepared at the moment of heel touch-down to react if necessary and to protect the ankle joint against excessive inversion.

In the reflex-controlled phase, PB aIEMG were 11% (0.401/0.361 V) and 14% (0.401/.353 V) higher on the gravel surface compared to asphalt and grass surfaces, respectively; however, the differences were not significant. This can be explained by the fact that not every step was made on same relief of gravel surface due to the random distribution of the stones in the gravel road. While the pre-activation is feed-forward controlled by the central nervous system and rather constant[1], the reflexes depend on feed-back control and, therefore, on the surface conditions that are less constant when running on uneven surfaces[13]. In our case, the uneven surface was best represented by the gravel road.

GA showed significantly higher aIEMG during the contact phase in running on asphalt in comparison to running on grass, while SO showed no difference between running conditions. GA showed a tendency of increased reflex activation in running on asphalt compared to running on grass. Since we found significant differences of GA aIEMG in the contact phase but not in the reflex-controlled phase, it is possible to speculate that systematic differences happened in the time interval of 120 ms after the heel impact and to the end of contact time. In our case, this time interval lasted for about 100 ms and corresponded to the propulsion phase. As a bi-articular muscle, GA transfers energy from proximal to the distal part of the body and further to the ground[28,29] which seems to be more effective on the hard and stable asphalt surface.

Based on the results of this experiment, some general prescriptions in choosing appropriate running surfaces for heel-toe runners can be given. Running on hard surfaces like asphalt is appropriate when there is no previous presence of lower leg muscle fatigue, and the runner would like to expose his/her lower leg muscles (especially TA) to high stress. Uneven surfaces like gravel and forest paths are useful when the runner would like to improve reactions to possible dangerous foot inversion. In running on uneven surfaces, the runner should be in a rested state and concentrate on appropriate ankle muscle stiffness, since ankle sprain can happen at any moment. Lower leg muscles, especially PB and probably the peroneus longus muscle are stressed the most. For tired runners, the »friendliest« and consequently the most advisable surface is grass in the park, which is more compliant than asphalt[15], and where runners experience the lowest impact forces acting on the body[21]. Runners should be aware that the »friendliest« surface probably has the smallest training effect on body concerning running biomechanics and kinematics, and the highest energy requirements as Davis and Mackinnon[30] showed for running on sand and grass. The runner should carefully choose the running surface according to his/her state and training session goal.

Limitation

An important limitation of our experiment was the absence of kinematic analysis of the body (ankle, knee, and hip angles) as some previous experiments showed that running on different surfaces can alter body position and leg movement[14,31]. Knowing more kinematic parameters, we could strengthen our conclusions that the running kinematic in our experiment was the same in all running conditions and, consequently, that the observed differences had an origin in different surface properties and not in altered running kinematics.

REFERENCES

1. MÜLLER R, GRIMMER S, BLICKHAN R, Hum Mov Sci, 29 (2010) 299. DOI: 10.1016/j.humov.2010.01.003. — 2. FERRIS DP, LOUIE M, FARLEY CT, Proc Biol Sci, 265 (1998) 989. — 3. CRONIN NJ, CARTY CP, BARRETT RS, PLoS ONE, 6 (2011). DOI: 10.1371/journal.pone.0023917. — 4. GOTTLIEB GL, AGARWAL GC, J Biomech, 11 (1978) 177. DOI: 10.1016/0021-9290(78)90010-6. — 5. MIZRAHI J, VERBITSKY O, ISAKOV E, Clin Biomech (Bristol, Avon), 16 (2001) 207. DOI: 10.1016/S0268-0033(00)00091-7. — 6. JINDRICH DL, FULL RJ, J Exp Biol, 205 (2002) 2803. — 7. KELLER TS, WEISBERGER AM, RAY JL, HASAN SS, SHIAVI RG, SPENGLER DM, Clin Biomech (Bristol, Avon), 11 (1996) 253. DOI: 10.1016/0268-0033(95)00068-2. — 8. OUNPUU S, Clin Sports Med, 13 (1994) 843. — 9. O'CONNOR KM, HAMILL J, Clin Biomech (Bristol, Avon), 19 (2004) 71. DOI: 10.1016/j.clinbiomech.2003.09.001. — 10. PERRY SD, LAFORTUNE MA, Clin Biomech (Bristol, Avon), 10 (1995) 253. DOI: 10.1016/0268-0033(95)00006-7. — 11. MANN RA, MORAN GT, DOUGHERTY SE Am J Sports Med, 14 (1986) 501. — 12. SANTILLI V, FRASCARELLI MA, PAOLONI M, FRASCARELLI F, CAMEROTA F, DE NATALE L, DE SANTIS F, Am J Sports Med, 33 (2005) 1183. DOI: 10.1177/0363546504274147. — 13. WAKELING JM, VON TSCHARNER V, NIGG BM, STERGIOU P, J Appl Physiol, 91 (2001) 1307. — 14. HARDIN EC, VAN DEN BOGERT AJ, HAMILL J, Med Sci Sports Exerc, 36 (2004) 838. — 15. KATKAT D, BULUT Y, DEMIR M, AKAR S, Biol Sport, 26 (2009) 285. — 16. HERMENS H, FRERIKS B, MARLETTI R, STEGEMAN D, BLOK J, RAU G, DISSELHORST-KLUG C, HAGG G, European Recommendations for Surface ElectroMyoGraphy. Vol 2 (Roessingh Research and Development, AH Enschede, 1999). — 17. DIETZ V, SCHMIDTBLEICHER D, NOTH J, J Neurophysiol, 42 (1979) 1212. — 18. FIELD A, Discovering Statistics Using SPSS. 2 ed. (Sage Publications Ltd, London, 2005). — 19. DE WIT B, DE CLERCQ D, AERTS P, J Biomech, 33 (2000) 269. DOI: 10.1016/S0021-9290(99)00192-X. — 20. KAMIBAYASHI K, MURO M, J Electromyogr Kinesiol, 16 (2006) 432. DOI: 10.1016/j.jelekin.2005.09.004. — 21. TESSUTTI V, TROMBINI-SOUZA F, RIBEIRO AP, NUNES AL, SACCO IDEC, J Sci Med Sport, 13 (2010) 151. DOI: 10.1016/j.jsams.2008.07.008. — 22. GERRITSEN KGM, VAN DEN BOGERT AJ, NIGG BM, J Biomech, 29 (1995) 661. DOI: 10.1016/0021-9290(94)00127-P. — 23. NIGG BM, LIU W, J Biomech, 32 (1999) 849. DOI: 10.1016/S0021-9290(99)00048-2. — 24. CAULFIELD B, GARRETT M, Clin Biomech (Bristol, Avon), 19 (2004) 617. DOI: 10.1016/j.clinbiomech.2004.03.001. — 25. POHL MB, MESSENGER N, BUCKLEY JG, Gait Posture, 25 (2007) 295. DOI: 10.1016/j.gaitpost.2006.04.012. — 26. MAHADEVAN V, WILLIAMS L, ANDERSON R, RENWICK P, STOLLER WD, The Interactive Foot & Ankle. (Primal Pictures, London, 2009). — 27. DOUGLAS I, Am Fam Physician, 74 (2006) 1714. — 28. PRILUTSKY BI, ZATSIORSKY VM, J Biomech, 27 (1994) 25. DOI: 10.1016/0021-9290(94)90029-9. — 29. SASAKI K, NEPTUNE RR, J Biomech, 39 (2006) 2005. DOI: 10.1016/j.jbiomech.2005.06.019. — 30. DAVIES SEH, MACKINNON SN, Ergonomics, 49 (2006) 651. DOI: 10.1080/00140130600558023. — 31. DIXON SJ, COLLOP AC, BATT ME, Med Sci Sports Exerc, 32 (2000) 1919.

A. Dolenec

University of Ljubljana, Faculty of Sport, Gortanova 22, 1000 Ljubljana, Slovenia
e-mail: ales.dolenec@fsp.uni-fi.si

OBRAZAC AKTIVACIJE POTKOLJENIČNIH MIŠIĆA PRILIKOM TRČANJA NA ASFALTU, ŠLJUNKU I TRAVI

SAŽETAK

Trčanje se obavlja na različitim prirodnim površinama (na otvorenom) i umjetnim površinama (na zatvorenom). Različite karakteristike površine uzrokuju izmjenu obrasca aktivacije donjih mišića nogu kako bi se postigla ukočenost gležanja ovisno o tim karakteristikama. Dakle, svrha našeg istraživanja bila je proučiti promjene obrasca aktivacije donjih mišića nogu prilikom trčanja na različitim prirodnim trkačim površinama. Sudjelovali su šest muških trkača i dvije ženske trkačice. Sudionici su trčali u vlastito izabranoj brzini u ispitivanjima na asfaltu, dok su u eksperimentima na šljunku i travi pokušavali doći do slične brzine kao u ispitivanjima na asfaltu. Mjerena je mišićna aktivacija peroneus brevis, tibialis anterior, soleus, and gastrocnemius medialis kod desne noge. Prilikom trčanja na asfaltu porasla je prosječna EMG amplitude m. tibialis anterior u fazi prije aktivacije i m. gastrocnemius medialis u cijeloj fazi kontakta u odnosu na trčanje na travi od 0.222±0.113 V za 0,276±0,136 V i od 0,214±0,084 V do 0,238±0,088 V. Prosječna EMG m. peroneus brevis u predaktivacijskoj fazi povećana je sa 0,156±0,026 V na 0,184±0,455 V prilikom trčanja na travi u odnosu na trčanje na šljunku. Trčanje na različitim površinama povezana je s različitim obrascima aktivacije donjih mišića nogu. Trčanje na asfaltu zahtijeva ukočene zglobove gležnja, dok na šljunku zahtijeva veću stabilnost u gležanju zglobova, a trčanje na travi je najmanje zahtjevno na donje mišiće nogu.