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ORIGINAL

LOWER LIMB MUSCLE ACTIVATION DURING RUNNING

ACTIVACIÓN MUSCULAR DE LA EXTREMIDAD INFERIOR DURANTE LA CARRERA

Hernández-Stender, C.L.¹; Molina-Rueda, F.²; Alguacil-Diego, I.M.³

¹ PhD Student. Department of Physiotherapy, Occupational Therapy, Rehabilitation and Physical Medicine. Health Sciences Faculty. Rey Juan Carlos University (Spain)
cl.hernandezstender@gmail.com

² Assistant Professor. Department of Physiotherapy, Occupational Therapy, Rehabilitation and Physical Medicine. Health Sciences Faculty. Rey Juan Carlos University (Spain)
francisco.molina@urjc.es

³ Associate Professor. Department of Physiotherapy, Occupational Therapy, Rehabilitation and Physical Medicine. Health Sciences Faculty. Rey Juan Carlos University (Spain)
isabel.alguacil@urjc.es

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ABSTRACT

The objective of the present study was to verify the differences in the lower limb muscle activation patterns between the different running modalities (sprinters, middle distance runners and long distance runners) during outdoor running, observing certain muscle and spatiotemporal activation parameters in the initial contact and toe off phases. Results suggest significant differences in the muscular activity of the Biceps Femoris in the initial contact phase between middle distance runners and long distance runners ($p = 0.02$), and in certain spatiotemporal variables. These results show differences in the lower limb muscle activation patterns and in certain spatiotemporal parameters during outdoor running.

KEY WORDS: Running, Lower extremity, Electromyography.

RESUMEN

El objetivo del presente estudio es comprobar las diferencias en los patrones de activación muscular de la extremidad inferior entre las distintas modalidades de carrera (velocidad, medio fondo y fondo) al aire libre, observando determinados parámetros de activación muscular y espacio-temporales en las fases de contacto inicial y despegue. Se obtuvo como resultados diferencias significativas en la actividad muscular del Bíceps Femoral, en la fase de contacto inicial entre mediofondistas y fondistas ($p=0,02$), y en determinadas variables espaciotemporales. Los resultados muestran la existencia de diferencias en los patrones de activación muscular de la extremidad inferior y en ciertos parámetros espaciotemporales durante la carrera al aire libre.

PALABRAS CLAVE: Correr, Extremidad inferior, Electromiografía.

INTRODUCTION

In recent years, running has become one of the most commonly practiced sports. According to the last survey of sporting habits in Spain (1), 30.4% of the Spanish population practices running as a sport regularly. However, the sport of running also produces a high number of injuries, 8.6% of all recreational sport injuries (2) and 5% of all professional sport injuries(3) are caused by running. Knowledge regarding the characteristics of running, as well as the work performed by each muscle while running, is essential for preventing, evaluating, and treating running-related injuries.

Previous research has studied muscle activity during running, however, most of these studies were performed in movement analysis laboratories, thus removing the athlete from his natural environment and limiting both running speed and muscle activity (4–6). To the best of our knowledge, only two previous studies have examined muscle activity in athletes during indoor racing, thus approaching realistic conditions, however these studies included small sample

sizes (7, 8). No previous studies were found in the literature that include representative samples of runners, specialized in different running modalities, running at a realistic speed under training or competitive conditions (7, 9, 10). Such a study is needed to investigate possible differences in muscle activity patterns caused by variations in speed and running technique.

Therefore, we investigated the muscle activity and spatiotemporal parameters of runners of different running modalities (sprinters, middle-distance, and long-distance athletes) while they were running outdoors.

OBJECTIVES

The main objective of this research is to investigate differences in the patterns of lower limb (LL) muscle activity during outdoor running that occur due to changes in running speed, by studying variations in the average degree of LL muscle activity in runners who specialize in either sprinting, middle-distance, or long-distance running.

MATERIAL AND METHODS

SUBJECTS

Thirty runners (sprinters, middle-distance, and long-distance runners) with a mean age of 23.6 years voluntarily participated in this observational study. The participants were chosen by consecutive non-probability sampling from athletic teams in Spain. Participants were divided into three groups according to their running modality: sprinters, middle-distance, and long-distance runners. Each group included 5 men and 5 women. The following inclusion criteria were used for enrolling participants in the study:

- Age between 18 and 35 years; the upper limit was chosen based on evidence that muscle performance declines between the ages of 35 and 40 years (11).
- No current pain occurring while running
- Actively in competition season during the study
- High level of physical activity according to the “*International Physical Activity Questionnaire*” (IPAQ) (12)

The following were considered as exclusion criteria:

- Musculoskeletal injury suffered in either LL within the past year
- History of surgery
- Coexistence of neuromuscular pathology

ETHICAL ASPECTS

This study has been reviewed and approved by the Ethics Committee of Investigation of Rey Juan Carlos University under the number 0911201713417.

All participants were previously informed about the procedure and signed the respective informed agreement.

INSTRUMENTS

The participants' running cycles were recorded at 30 frames per sec using a high-speed Casio Exilim ZR1000[®] camera. The camera was placed 15 m from the track, perpendicular to the sagittal plane of the runner, at a height of 1 m above the ground on its tripod. Kinovea video analysis software 0.8.15[®] was used to analyze the 2D video. A Biometrics[®] DataLOG MWX8 portable surface electromyography system was used to record muscle activity; this system has a plantar pressure sensor that determines the exact moment of initial contact and toe off.

PROCEDURE

Participants were requested to wear competition shoes without spikes (lighter, less cushioned and commonly used for competition), as well as competition-style shorts that enabled visualization of the relevant bone eminences for placement of the electrodes.

In addition, the following recommendations were made to each participant: sleep for at least 8 hours the night before the recording; do not drink alcohol the day before data collection; eat their usual breakfast at their usual time; and shave both LL to ensure adequate electrode adherence.

Measurements were recorded on a regular running track. Each runner completed the procedure and measurements in a single session. Demographic data, as well as additional data relevant to the study, were collected from each runner, including sex, age, weight, height, years of experience as an athlete, and weekly volume of running (in kilometers). The "Harris test of lateral dominance", specifically the section dedicated to determining the dominant LL, was used to determine which LL to use as a reference during observation (13). The IPAQ was used to corroborate physical activity level (12).

Prior to electrode placement, the reference LL was cleaned with alcohol. A pre-gelled rectangular reference electrode was placed on the sacrum. Twelve pre-gelled Ag/AgCl electrodes were placed on the principal muscles using an inter-electrode distance of 20 mm, according to the recommendations of the European guide of "Surface Electromyography for the Non-Invasive Assessment of Muscles" (SENIAM) (14, 15).

Each participant then performed a common warm-up routine followed by five 100 m runs at their respective competition pace; a 5 min rest period was taken between each 100 m interval. All tests were performed on synthetic outdoor tracks approved by the National Athletics Federation.

OUTCOME MEASURES

Muscle activity (expressed as a percentage) was recorded in the gluteus medius, gluteus maximus, biceps femoris, rectus femoris, tibialis anterior, and medial gastrocnemius during both initial contact and toe off. The following spatiotemporal parameters were also recorded: stride length, stride time, and maximum speed.

ANALYSIS OF DATA

For data acquisition, a 100 m stretch was selected from a 400 m outdoor running track. According to an analysis of the 100 m run (16), athletes initially use explosive force to propel themselves from stationary to maximum acceleration. Then, from 30 to 40 m, the “balance” phase begins, which reflects the elastic force that depends on the muscle tendon stiffness. Finally, a decrease in speed occurs over the last 20 to 30 m (16). Therefore, to avoid influences from the acceleration and deceleration phases and standardize our measurements, the recording was performed between the 50 and 70 m marks of our 100 m stretch.

FILTERING OF THE SURFACE EMG SIGNAL

Using Biometrics Ltd[®] software, the following filters were applied in order to transform the variable alternate values into a stable graph: a high-pass corner frequency of 20 Hz, a low-pass corner frequency of 400 Hz, Rectify and Root Mean Square.

To normalize the obtained electromyograms, the Maximum Peak of each muscle activity was taken to be 100% activity (17).

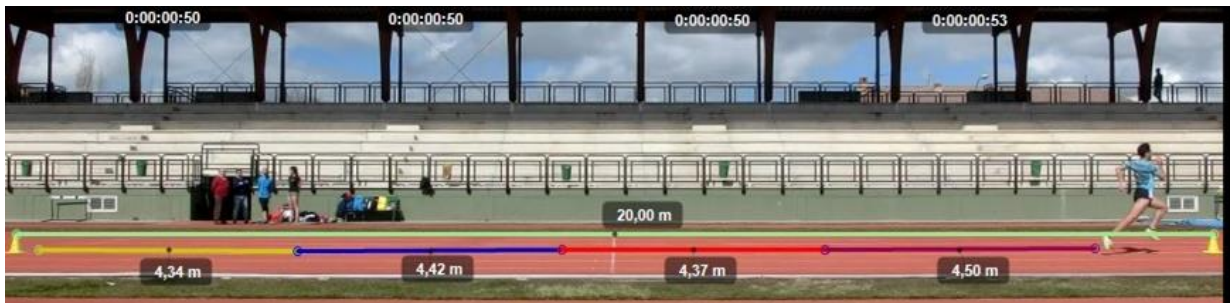
IMAGE PROCESSING

Stride length: using the “line” tool, a line was drawn between the lateral malleolus markers of two consecutive strides during the initial point of contact. The “contrast measure” option was then, which indicates to the program the actual measurement between the 50 m and 70 m lines on the track and returns the measure corresponding to the line we have drawn (Figure 1).

Stride time: using the “clock” tool, the stopwatch was started at the moment of initial contact and stopped at the pre-swing (Figure 1).

Speed: using the formula $v = e / t$, where “v” represents speed, “e” stride length, and “t” stride time.

Figure 1. Image processing.



STATISTICAL ANALYSIS

SPSS software version 22 was used for statistical analysis. Comparisons of the measured variables were performed between groups consisting of sprinters, middle-distance, and long-distance runners by using the means of the results of each participant. All variables followed a normal distribution; therefore the Student's t-test for independent samples was used for analysis. The α level was set at $p < 0.05$.

RESULTS

Demographic and other interesting data are shown in Table 1.

Table 1. Demographic data.

Group	Age (years)	Weight (kg)	Height (metres)	Experience (years)	Km/Week (km)	Dominance Right/Left
Sprint	22.5 (4.95)	62.6 (10.4)	1.71 (0.09)	11 (5.7)	18 (6.3)	90% / 10%
Middle Distance	22.8 (5.27)	62.3 (8.1)	1.71 (0.1)	12 (4.6)	52.5 (21.2)	90% / 10%
Long Distance	25.5 (4.5)	61.2 (11.1)	1.69 (0.09)	9 (4.9)	71 (30)	80% / 20%

Results expressed as mean and standard deviation.

The results of this study demonstrate a significant difference in the muscle activity of the biceps femoris during initial contact between the groups of middle-distance and long-distance runners ($p = 0.02$) (Table 2). No additional significant differences in muscle activity were observed between groups in this sample, however, the differences in percentage of proximal and distal muscle activity between each group are notable (Figure 2).

Table 2. Intergroup contrast of muscle activity.

Muscle	% muscle activity		Comparison between groups					
	Initial contact Mean (SD)	Toe off Mean (SD)	M. Dif Initial contact	CI 95% Initial contact	p-value Initial contact	M.Dif Toe off	CI 95% Toe off	p-value Toe off
Gluteus Medius	a) 48.6(15.14) b) 48 (13.47) c) 56.2(12.02)	a) 11.6(9.1) b) 8.6(6.4) c) 13(6.67)	1) 0.6 2) -7.6 3) -8.2	1) (-12.8 a 14.1) 2) (-20.4 a 5.2) 3) (-20.2 a 3.8)	1) .92 2) .23 3) .16	1) 3 2) -1.4 3) -4.4	1) (-4.4 a 10.4) 2) (-8.9 a 6.1) 3) (-10.5 a 1.7)	1) .41 2) .7 3) .15
Gluteus Maximus	a) 30.9(16.36) b) 42.7(19.37) c) 32.9(8.12)	a) 12.9(8.49) b) 12.6(13.24) c) 10.10(8.39)	1) -11.8 2) 5.7 3) 9.8	1) (-28.6 a 5) 2) (-14.1 a 10.1) 3) (-4.1 a 23.7)	1) .16 2) .73 3) .16	1) 0.3 2) 2.8 3) 0.2	1) (-10.2 a 10.8) 2) (-5.1 a 10.7) 3) (-11.3 a 11.7)	1) .95 2) .47 3) .49
Biceps Femoris	a) 40.2(8.72) b) 53.1(18.19) c) 32.8(17.31)	a) 19.8(11.26) b) 20.8(15.76) c) 18.7(23.3)	1) -12.9 2) 7.4 3) 20.3	1) (-26.3 a 0.5) 2) (-5.5 a 10.3) 3) (3.6 a 36.9)	1) .06 2) .2 3) .02*	1) -1 2) 1.1 3) 2.1	1) (-13.9 a 11.9) 2) (-16.1 a 18.3) 3) (-16.6 a 20.9)	1) .87 2) .89 3) .81
Rectus Femoris	a) 22.9(11.97) b) 33.9(13.79) c) 31(9.56)	a) 22.5(14.18) b) 20(12.47) c) 18.9(12.07)	1) -10.9 2) -8 3) 2.9	1) (-23.1 a 1.2) 2) (-18.2 a 2.2) 3) (-8.3 a 14.1)	1) .08 2) .11 3) .59	1) 2.5 2) 3.6 3) 1.1	1) (-10.1 a 15.1) 2) (-8.7 a 15.9) 3) (-10.4 a 12.6)	1) .68 2) .55 3) .84
Tibialis Anterior	a) 42.1(21.36) b) 31.1(16.98) c) 31.3(8.7)	a) 25.8(19.7) b) 23.9(22.81) c) 197(13.49)	1) 11 2) 10.8 3) -0.2	1) (-7.1 a 29.1) 2) (-4.5 a 26.1) 3) (-12.8 a 12.5)	1) .28 2) .15 3) .97	1) 1.9 2) 6.1 3) 4.2	1) (-18.1 a 21.9) 2) (-9.7 a 21.9) 3) (-13.4 a 21.8)	1) .7 2) .7 3) .7
Medial Gastrocnemius	a) 54.3(19.33) b) 58.7(17.7) c) 49(22.97)	a) 21.7(11.73) b) 15.7(12.36) c) 15.5(12.21)	1) -4.4 2) 5.3 3) 9.7	1) (-21.8 a 13) 2) (-14.6 a 25.2) 3) (-9.5 a 28.9)	1) .6 2) .6 3) .3	1) 6 2) 6.2 3) 0.2	1) (-5.3 a 17.3) 2) (-5.05 a 17.4) 3) (-11.3 a 11.7)	1) .28 2) .26 3) .97

Mean (SD): Mean (Standard Deviation). **M. Dif.:** Mean difference. **CI:** Confidence Interval 95%
a) Sprint; **b)** Middle Distance; **c)** Long Distance. **1)** Sprint vs. Middle Distance; **2)** Sprint vs. Long Distance; **3)** Middle Distance vs. Long Distance. *p<.05. Parametric test: ANOVA One way test.

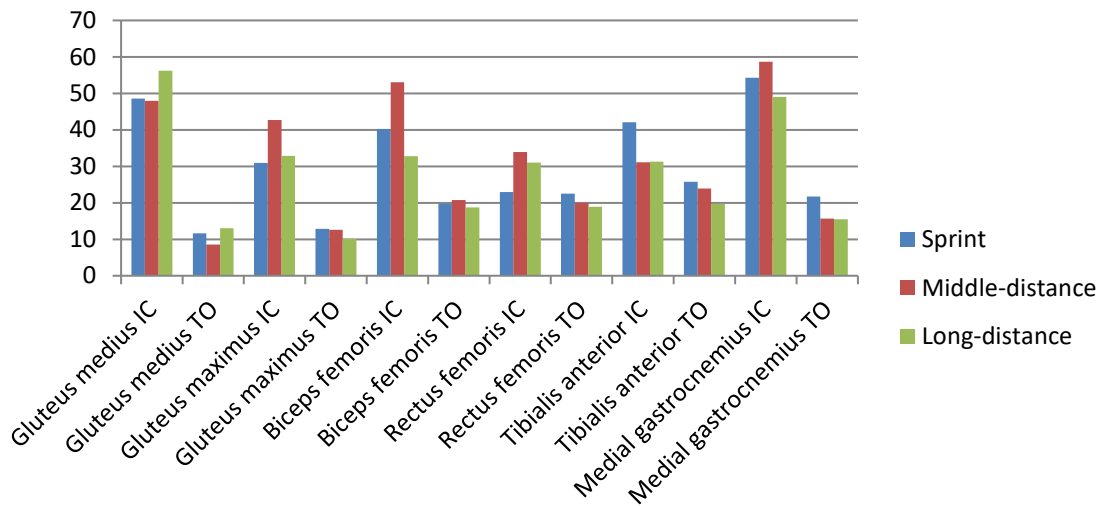
Regarding spatiotemporal variables, significant differences in: stride length were observed between middle-distance and long-distance runners (p< 0.01) and between sprinters and long-distance runners (p= 0.02); stride time between middle-distance and long-distance runners (p= 0.01) and between sprinters and long-distance runners (p< 0.01); and maximum speed between middle-distance and long-distance runners (p< 0.01) and between sprinters and long-distance runners (p< 0.01) (Table 3).

Table 3. Contrast of spatiotemporal parameters.

Parameters	Mean (SD)	Comparison between groups		
		M. Dif	CI 95%	p-value
Stride length (m)	a) 4.15(0.41) b) 4.23(0.33) c) 3.62 (0.53)	1) -.7 2) .53 3) .06	1) (-0.4 a 0.3) 2) (0.08 a 0.9) 3) (0.1 a 1)	1) .67 2) .022* 3) .007*
Stride time (s)	a) 0.48(0.034) b) 0.51(0.04) c) 0.57(0.05)	1) -.02 2) -.08 3) -.06	1) (-0.06 a 0.08) 2) (-0.1 a -0.04) 3) (-0.1 a 0.01)	1) .133 2) .001* 3) .014*
Maximum speed (m/s)	a) 8.12(0.63) b) 7.69(1.01) c) 6.03 (0.74)	1) .4 2) 2 3) 1.6	1) (-0.3 a 1) 2) (1.4 a 2.7) 3) (0.8 a 2.5)	1) .28 2) <.001* 3) .001*

Mean (SD): Mean (Standard Deviation). **m:** meters; **s:** seconds; **m/s:** meters/seconds **M. Dif.:** Mean difference. **CI:** Confidence Interval 95%. **a)**Sprint; **b)**Middle-distance; **c)**Long-distance.
1) Sprint vs. Middle Distance; **2)** Sprint vs. Long Distance; **3)** Middle Distance vs. Long Distance. *p<.05. Parametric test: ANOVA One way test.

Figure 2. Mean percentage of muscle activity.



IC: Initial contact; TO: Toe off

DISCUSSION

According to our results, biceps femoris muscle activity during the initial contact phase was significantly different between the middle-distance and long-distance runners. Middle-distance runners and sprinters demonstrated the highest levels of muscle activity, in addition to significant differences in the spatiotemporal parameters of stride length, stride time and maximum speed between the three modalities.

Regarding spatiotemporal parameters, previous research has demonstrated significant differences in stride length, stride time, and speed between running modalities. A sprinter presents a stride similar to, however faster than, a middle-distance runner, while a middle-distance runner presents a longer and faster stride than a long-distance runner. Therefore, the technique and characteristics of each runner differ according to their running modality (18–22)

According to the International Association of Athletics Federation, “speed” disciplines include races from 60 to 400 m, “middle-distance” from 800 to 3000 m, and “long-distance” 5000 m to the marathon.

Broadly speaking, sprinters are distinguished by their high proportion of fast muscle fibres (23) and an initial contact at the metatarsal, which creates a shorter support time and requires a greater vertical force of reaction compared to other running modalities (24, 25). The need to generate high forces in a short time highlights the importance of the force-speed relationship and the elastic force in muscles such as gastrocnemius (26). The higher the speed, the more the contraction of gastrocnemius is reduced, the tendon assumes much of the required length change, and a lower energy consumption and improved running economy are achieved (27).

In general, middle-distance runners have biomechanics similar to sprinters. Middle-distance runners contact the surface with the metatarsal, similar to sprinters, and require both high strength generation and high endurance. The endurance capacity takes precedence in 3000 m runners, while anaerobic work provides more influence in 800 and 1500 m runners (28). Middle-distance runners require both fast and slow muscle fibres (24).

The distinguishing characteristics of a long-distance runner are great aerobic capacity and a large percentage of slow muscle fibres (24, 29). Long-distance runners contact from the heel to the forefoot, thus providing a longer support time (24). Compared to sprinters and middle-distance runners, long-distance runners generate smaller vertical force reactions, thus causing greater impact on the LL that must be absorbed by the surrounding muscles, bones, and tendons (22).

The form of initial contact and support during running depends on the speed of the runner: below a speed of 7 m/s contact occurs from heel to forefoot, while above 7 m/s contact occurs at the forefoot (24), with the absorption phase being lower at higher speeds (19). There is a “preactivation” in the musculature of the LL at initial contact (19, 24). Consequently, the role of certain muscles and tendons of the LL change depending on the speed of the runner.

Regarding muscle activity, to the best of our knowledge no prior study has compared the different modalities of athlete in a natural environment, which could affect the results. The scientific literature includes research conducted using treadmills, on which adaptations in running biomechanics have been observed (4–6), and in movement analysis laboratories that contain tracks of distances comparatively short for athletes, thus preventing the ability to observe the reflex elastic force phase (16).

Our results show a significant difference in the muscular activation of the biceps femoris during initial contact between the middle-distance and long-distance runners. Sprinters and middle-distance runners demonstrated the highest level of muscular activity, which could be explained by increased LL deceleration function of the hamstrings during the end of flight phase and initial contact due to greater speeds (30).

However, observing the proximal and distal muscle activity graphic, the percentages of activation are remarkable. Currently, it is thought that higher speeds require greater muscle activation and greater reaction forces due to the short support time and increased need for stabilization (7). However, contrary to previous studies (30), the highest gluteus medius muscle activity levels in our study were seen in the long-distance runners (the slowest runners), both at initial contact and toe off. Meanwhile, sprinters and middle-distance runners had comparatively lower activity levels in the gluteus medius. Other authors have argued that the force of gluteal muscle contraction decreases as step rate increases in such a way that a 10% increase in step rate generates a 10% decrease in the peak force of each gluteal muscle (31) Considering the role gluteus medius plays in absorbing impact forces during running and in

decreasing acceleration of the centre of mass (32, 33), it is possible that absorption mechanics differ between running modalities, and the contributions by certain muscles to propulsion and acceleration depend on LL motor pattern changes related to running speed.

In a study of the kinematics and kinetics of individuals walking and running at different speeds, Novacheck (18) showed that hip flexion increases with speed, thus the knee joint absorbs the impact of contact at low speeds and participates in propulsion during sprinting, while the plantar flexor muscles are responsible for the absorption of impact and propulsion mostly at higher speeds. Other authors have shown that, at speeds above 7 m/s, the triceps surae functions to generate the vertical reaction forces during support; in other words, as speed increases, the role of this muscle shifts to support rather than progression (8). These studies suggest that muscle intervention, both distal and proximal, varies according to running performance, which implies different levels of muscle activity and load, in line with our results.

These results could explain why some injuries occur more frequently in certain running modalities (34). Usually, hamstring overstrain injury is related to maximum speed running. This injury occurs when the hamstrings exceed the mechanical limits of the muscle tissue as a consequence of repetitive negative work and fluctuations in neuromuscular control (30). In long-distance runners, increased internal rotation of the knee during the support phase is associated with iliotibial band syndrome, while high impact and a high plantar pressure peak is related to Achilles tendon injury (22). Additionally, the high mileages runners face during training and competition may lead to a state of prolonged fatigue, associated with reduced maximum forces and overuse injury (35). Similarly, in long-distance runners, the onset of fatigue increases the support time and step length, which reduces the normal stiffness or tension of the LL (36) and could lead to poor LL control, both proximally and distally. No specific injuries have been associated with middle-distance runners; this group seems to be the least common modality.

Individual running biomechanics are determined by running modality and speed. Previous research has failed to consider this factor despite the fact that each modality of running involves, in each phase of running, different levels of muscle activity and different running technique. The differences in technique of each modality can be expected to produce different patterns of muscle activity. In addition, treadmills, despite being a useful research tool, have been questioned over concerns regarding differences in running biomechanics compared to outdoor running, mainly reduced muscle activity peaks during initial contact and increased peaks during the swing phase and preparation for contact (5).

In light of the results obtained here, it is essential to include speed and running modality as variables when studying running and the rehabilitation of running-related injuries.

LIMITATIONS

The present study shows the following limitations. First, the small sample size does not allow the results to be generalized; it would be interesting to continue the research with a larger sample. Second, the measurements were made on seven different tracks, which were located at different altitudes, and also during different seasons of the year. Therefore, possible variations in the material of each track that may have effected its density and hardness, which thus may have influenced a runners' response, must be considered. Third, wind speed, wind orientation, and humidity conditions were not taken into account during the measurements. Fourth, the measurements were recorded during competitive periods for the athletes, and all participants used their own shoes without spikes. Not using the same model of shoe for each athlete may have caused a bias in the results, although it could be minimized by to carry out the test in conditions of maximum comfort. Finally, using video analysis software such as Kinovea could lead to a margin of error not covered in the research.

CONCLUSIONS

The results of this study confirm the existence of differences in LL muscle activity patterns and spatiotemporal parameters during outdoor running that correspond with the speed of movement and running modality.

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