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Electromyography activity of triceps surae and tibialis anterior muscles related to various sports shoes

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ABSTRACT

Triceps surae (TS) and tibialis anterior (TA) activation patterns have not yet been studied under different types of sport shoes. We hypothesized that sports shoes may reduce the activity patterns of these muscles in relation to barefoot condition. Thus, our main aim was to evaluate the activity patterns of TS and TA muscles in healthy people during all gait phases using five types of sport shoes with respect to barefoot condition. A total sample of thirty healthy participants, mean age 36.20 ± 8.50, was recruited in a podiatry laboratory following an observational research design. During walking and running, electromyography signals were recorded from TS and TA muscles using surface electrodes in the following experimental situations: 1.) barefoot, 2.) minimalist, 3.) pronated control, 4.) air chamber, 5.) ethyl-vinyl-acetate and 6.) boost. The TS and TA showed significant reductions ($P < 0.05$) in the peak amplitude of different sport shoes types with respect to the barefoot condition in different phases of the gait cycle during walking and running. Nevertheless, the boost sport shoe produced statistically significant increases in the peak amplitude of the gastrocnemius medialis muscle in comparison with the barefoot condition in the midstance phase of the gait cycle during running ($P = 0.047$). In addition, the pronation control and air chamber sport shoes produced statistically significant increases in the peak amplitude of the TA muscle with respect to the barefoot condition in the contact phase of the gait cycle ($P = 0.021$; $P = 0.013$), respectively, during running. Despite TS and TA muscles activity patterns seem to be reduced using different sport shoes types with respect to the barefoot condition in different phases of the gait cycle during walking and running, some sport shoes may increase this muscular activity in specific phases of the gait cycle during running.

1. Introduction

Triceps surae (TS) and tibialis anterior (TA) are antagonist muscles at foot and ankle that play an important role for the support, balance postural and dynamic stability for walking in the people (Honeine et al., 2018). In addition, the condition of both muscles may alter the physical integrity in the activities on the daily living (Calmels and Minaire, 2018). Their disorders can be related with loss of quality of life (Allami et al., 2017), significant functional disability (Kazemi et al., 2017), and risk of falls (Moreland et al., 2004).

Currently, the high prevalence rate of TS and TA disorders ranged between 33% and 75% and may usually affect to persons with contracture of the soleus and gastrocnemius muscles (Abdulmassih et al., 2013a), thickened tendon (Mengiardi et al., 2005), swelling and redness (Grunwald and Silberman, 1959), ankle and foot pain (Maskill et al., 2010). These problems present a multifactorial etiology that suggest incomplete muscular evolution (DiGiovanni and Langer, 2007), incorrect sitting and sleeping posture (Abdulmassih et al., 2013b), diabetic mellitus (Lavery et al., 2002), neurological disorders (Gracies, 2005), local steroid infiltrations (Ford and DeBender, 1979),

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mechanical stress (Scheller et al., 1980), and footwear type (Taunton et al., 2003). Although these disorders remain unclear, they may be the cause or secondary factors included in this complex system. Nevertheless, none prior study has evaluated the surface electromyography (EMG) activity patterns of the TS and TA musculature using varied types of sport shoes. This tool is usually utilized to recorded muscle activity patterns in neurological patients (Lamontagne et al., 2000).

To date, activation patterns of the TS and TA muscles have not yet been studied under different types of sport shoes. We hypothesized that sports shoes may reduce the activity patterns of these muscles in relation to barefoot condition. Thus, our main aim was to evaluate the activity patterns of TS and TA muscles in healthy people during all gait phases using five types of sport shoes with respect to barefoot condition.

2. Materials and methods

2.1. Design and sample

A total of thirty healthy volunteers were recruited in a podiatry laboratory of the King Juan Carlos University, located in the Campus of Alcorcón (Madrid, Spain) during six months (June-December 2017). An observational research protocol was carried out following the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) criteria and checklist (von Elm, Oct et al., 2007). In addition, a consecutive nonprobability sampling method was used. The inclusion criteria for participants in the study were that they had to 1) be at between eighteen at forty-five years of age, 2) have neutral feet (from 0 to 5 scores according to the Foot Posture Index [FPI]) and 3) have signed a consent form for the study. If the participants were not at least eighteen years old, had neutral feet, an autoimmune disease, history of surgery or limb injury, neurological disease or declined to the rules and agreements of the study they did not participate (Roca-Dols et al., 2018).

2.2. Procedure

A single trained researcher recorded baseline measurements, the first step included an interviewed about disease and clinical characteristics related with the following factors, such as: 1) health condition, 2) demographic variables (age and sex), 3) chronic conditions (mental diseases, cardiovascular alterations, rheumatoid arthritis, diabetes mellitus type 1 and 2, metabolic syndrome, obesity, neurological problems, musculoskeletal alterations, vascular illness) and 4) daily physical activity.

Regarding the next step in the process, patients removed their footwear and socks, and after a podiatrist assessed height and weight with the subject in barefoot condition. In addition, the body mass index (BMI) was calculated from the height (m) and weight (kg^2), applying the Quetelet's equation as BMI = weight / height^2 (Garrow and Webster, 1985).

Then, the podiatric physician examined and wrote down the biomechanical foot problems using the technique described by Redmon et al. related to the Foot Posture Index (FPI) (Redmond et al., 2006). This method comprised a non-invasive scale for evaluating the five grades scores of foot posture related to: 1) highly supinated foot posture (from −12 to −5 scores), 2) supinated foot posture (from −4 to −1 scores), 3) neutral foot posture (from 0 to 5 scores), 4) pronated foot posture (from 6 to 9 scores), or 5) highly pronated foot posture (from 10 to 12 scores). It is a validated tool with a suitable reliability as a checkup instrument in order to evaluate foot posture (Evans et al., 2018; Keenan et al., 1991).

Afterwards, each volunteer remained in a laid-back position and the podiatrist placed the electrodes in the center of a grid mark coinciding with the center of the anatomical structures, such as the TS (right-left lower limbs) and TA (right-left lower limbs). The surface EMG electrodes (SX230 model) were utilized to register the signal of the EMG activity patterns (Biometrics Ltd, United Kingdom) using the protocol described by the European for surface EMG in order to establish a non-invasive technique which is used for assessment of muscles related with the following areas: 1) Neurology, 2) Rehabilitation, 3) Orthopedics, 4) Ergonomics, and 5) Sports Sciences (Hermens et al., 2018).

Finally, the EMG measurements were recorded at 2 different velocity rates for walking (at 5.17 km/h) and running (at 9 km/h). All participants walked steadily for a period of three minutes in the electric motorized treadmill at velocity rate of 5.17 km/h (Cunningham et al., 2010) under the following conditions: 1.) barefoot, 2.) minimalist, 3.) pronated control, 4.) air chamber, 5.) ethyl-vinyl-acetate and 6.) boost. All the muscular activity patterns were registered for all conditions during thirty seconds, with five minutes recovery between tests where all volunteers remained seated (Fleming et al., 2015a). The identical protocol was used for walking in the electric motorized treadmill but at velocity rate of the 9 km/h (Shih et al., 2013).

2.3. Ethical considerations

The observational research protocol (ethical approval code: 1001201701317) was reviewed in accordance with the board Research and Ethics Committee, King Juan Carlos University, Madrid, Spain. Each volunteer signed the consent inform form to take part in the present research. Besides, ethical and human rules in all experimentation followed the Declaration of Helsinki and other institutions.

2.4. Statistical analysis

A detailed statistical analysis was carried out following the methodology of a prior published study (Roca-Dols et al., 2018). A normality distribution analysis was carried out by the Shapiro Wilks test, considering a normal distribution when $P > 0.05$. Demographic characteristics such as age, height, weight and BMI were described. Considering the description of quantitative data, mean and standard deviation (SD) were applied to the data set. Considering the description of categorical data, frequency and percentage were used.

Regarding the normality of the variables, the paired Student *t*-test was applied for parametric data and the related samples Wilcoxon test was used for non-parametric data in order to analyse the differences between the follow-up measurements.

Considering the parametric data, the Student *t*-tests for independent samples were utilized to determine if between-groups comparison showed statistically significant differences. Regarding non-parametric data, the Mann-Whitney *U* test was applied to analyse if between-groups comparison showed statistically significant differences.

Data were analyzed by means of the IBM SPSS Statistics software (SPSS, v19, Inc, Chicago, Illinois). Statistically significant differences were considered at $P < 0.05$ with a 95% confidence interval (CI).

3. Results

3.1. Runners' descriptive data

The sample comprised 30 male runners whose means ± SD of age, height, weight, BMI, shoe size, and neutral FPI scores were presented in Table 1.

3.2. Sport shoes descriptive data

The features of the sport shoes types were described in Table 2. The sport shoes types used in this study were pronation control, air chamber, minimalist, ethyl-vinyl-acetate and boost.

Table 1
Anthropometric characteristics of the runners.

	N	Age (years)	Height (cm)	Weight (kg)	Shoe size (EC)	BMI (Kg/m^2)	FPI
Mean ± SD (95% CI)	30	36.20 ± 8.50 (33.16–39.24)	177.2 ± 4.25 (175.68–178.62)	72.10 ± 6.39 (69.81–74.39)	43.43 ± 0.82 (43.14–43.73)	23.03 ± 1.73 (22.41–23.66)	2.5 ± 0.9 (2.18–2.82)

Abbreviations: BMI, body mass index; CI, confidence interval; EC, European countries; FPI, Foot Posture Index; SD, standard deviation.

3.3. EMG maximum amplitude registry during walking

The phases of the gait cycle were divided into pre-activation phase (PAP) before the contact phase (last 50 ms of the swing phase), contact phase (CP), midstance phase (MSP), and propulsion phase (PPSP) for walking study at a speed of 5.17 km/h (Shih et al., 2013). In addition, EMG maximum amplitude registry from different muscle groups such as gastrocnemius medialis, gastrocnemius lateralis, soleus and TA was described and discussed.

3.3.1. Gastrocnemius medialis

Considering the Table 3 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius muscle at walking speed of 5.17 km/h, the minimalist sport shoes showed statistically significant decreases in the amplitude peak with respect to barefoot condition in the pre-activation ($P = 0.022$) and contact phases ($P = 0.042$). The ethyl-vinyl-acetate sport shoes showed statistically significant decreases in the amplitude peak with respect to barefoot condition in the midstance phase ($P = 0.039$).

3.3.2. Gastrocnemius lateralis

According to the Table 4 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius lateralis muscle at walking speed of 5.17 km/h, the minimalist sport shoe showed a statistically significant decrease in the peak amplitude with respect to the barefoot condition in the contact phase of the gait cycle ($P = 0.030$). In addition, the pronation control sport shoe demonstrated a statistically significant reduction in the peak amplitude with regards to the barefoot condition in the pre-activation ($P = 0.017$), midstance ($P = 0.012$) and propulsion ($P = 0.003$) phases of the gait cycle. Furthermore, the air chamber sport shoe evidenced a statistically significant reduction in the peak amplitude with respect to the barefoot condition in the pre-activation ($P = 0.002$), contact ($P = 0.011$) and propulsion ($P = 0.002$) phases of the gait cycle. Moreover, the ethyl-vinyl-acetate sport shoe showed a statistically significant reduction in the peak amplitude with regards to the barefoot condition in the pre-activation ($P = 0.005$), midstance ($P = 0.037$) and propulsion ($P = 0.009$) phases of the gait cycle. Finally, the boost sport shoe exhibited a statistically significant reduction in the peak amplitude with respect to the barefoot condition in the pre-activation ($P = 0.002$), contact ($P = 0.024$) and propulsion ($P = 0.013$) phases of the gait cycle.

3.3.3. Soleus

Described in Table 5, about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the soleus muscle at walking speed of 5.17 km/h, the minimalist and boost sport shoes showed statistically significant decreases in the peak amplitude in comparison with the barefoot condition in the pre-activation phase of the gait cycle ($P = 0.033$; $P = 0.049$), respectively. The pronation control and ethyl-vinyl-acetate sport shoes produced statistically significant reductions in the peak amplitude with respect to the barefoot condition in the propulsion phase of the gait cycle ($P = 0.013$; $P = 0.015$), respectively.

3.3.4. Tibialis anterior

Regarding the Table 6 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the tibialis anterior muscle at walking speed of 5.17 km/h, all sport shoes types (minimalist, pronation control, air chamber, ethyl-vinyl-acetate and boost) generated statistically significant decreases in the peak amplitude in comparison with the barefoot condition in the midstance phase of the gait cycle ($P = 0.005$; $P < 0.001$; $P = 0.013$; $P < 0.001$; $P = 0.001$), respectively. The pronation control and ethyl-vinyl-acetate sport shoes produced statistically significant reductions in

Table 2
Technical features of the sport shoes types.

Technical characteristics	Minimalist sport shoe* (EVO PURE M PBT YELLOW MESH©)	Ethyl-vinyl-acetate (EVA)** ASICS-GEL-SPEEDSTAR-6 ©) sport shoe	Pronation control sport shoe*** (NIKE AIR ZOOM STRUCTURE 19©)	Air chamber sport shoe**** (NIKE MAX LUNAR1 WR©)	Boost Sport shoe (*****) (ADIDAS Questar Boost ©)
Out Sole material	Rubber	Rubber	Carbon rubber under heel, blown rubber under forefoot	Rubber	Rubber
Mid-sole material	Rubber	Ethyl-vinyl-acetate	Triple density foam	Ethyl-vinyl-acetate	Boost TPU
Impact absorption system	Non-existent	Rearfoot GEL® Cushioning	Air chamber under forefoot	Air chamber	Boost TPU
Control system	None	None	Postero-medial	None	None
Heel-to-toe drop* (mm)	0	9	9	13	11
Weight (gr)	172	250	286	340	320

• Heel-to-toe drop (38) is the height difference between the forward and rear parts of the inside of the running shoe according to each type of sport shoe.
(******) Boost TPU, thermoplastic polyurethane link: https://www.runnea.com/zapatillas-running/adidas/questar-boost/1634/.
* **Minimalist EVO PURE M PBT YELLOW MESH©) sport shoe link**; http://vi.vipr.ebaydesc.com/ws/eBayISAPI.dll?ViewItemDescV4&item= 292483310516&t = 0&tid= 10&category= 95672&seller=virtualexchanges&excSoj= 1&excTrk= 1&lsite= 0&ittenable=false&domain=ebay.com&descgauge= 1&cspheader= 1&oneClk= 1&secureDesc= 0.
** Ethyl-vinyl-acetate (EVA) ASICS-GEL-SPEEDSTAR-6 ©) sport shoe https://strengthrunning.com/2012/08/asics-speedstar-6-review/.
*** **Pronation control sport** NIKE AIR ZOOM STRUCTURE 19sport shoe link, https://www.solereview.com/nike-air-zoom-structure-19-review/.
**** **Air chamber sport NIKE MAX LUNAR1 WR©)** https://www.sneakerhead.com/nike-air-max-lunar-1-wr-654470003.html.

the peak amplitude with respect to the barefoot condition in the propulsion phase of the gait cycle ($P = 0.007$; $P = 0.011$), respectively.

3.4. EMG maximum amplitude registry during running

The phases of the gait cycle were divided into PAP before the contact phase (last 50 ms of the swing phase), CP, MSP, and PPSP for running study at a speed of 9 km/h. In addition, EMG maximum amplitude registry from different muscle groups such as gastrocnemius medialis, gastrocnemius lateralis, soleus and TA was described and discussed.

3.4.1. Gastrocnemius medialis

Regarding the Table 7 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius medialis at running speed of 9 km/h, the minimalist sport shoe produced statistically significant reductions in the peak amplitude in comparison with the barefoot condition in the propulsion phase of the gait cycle ($P = 0.004$). The pronation control and air chamber sport shoes generated statistically significant reductions in the peak amplitude with respect to the barefoot condition in the pre-activation ($P = 0.004$; $P = 0.017$) and propulsion ($P = 0.016$; $P = 0.026$) phase of the gait cycle, respectively. The boost sport shoe produced statistically significant increases in the peak amplitude in comparison with the barefoot condition in the midstance phase of the gait cycle ($P = 0.047$).

3.4.2. Gastrocnemius lateralis

Considering the Table 8 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius lateralis muscle at running speed of 9 km/h, all sport shoes types (minimalist, pronation control, air chamber, ethyl-vinyl-acetate and boost) generated statistically significant decreases in the peak amplitude in comparison with the barefoot condition in the propulsion phase of the gait cycle ($P < 0.001$; $P < 0.001$; $P < 0.001$; $P = 0.002$; $P = 0.003$), respectively. The pronation control, air chamber, ethyl-vinyl-acetate and boost sport shoes produced statistically significant reductions in the peak amplitude with respect to the barefoot condition in the pre-activation phase ($P = 0.001$; $P = 0.001$; $P = 0.003$; $P < 0.001$) and midstance ($P = 0.003$; $P = 0.009$; $P = 0.001$; $P = 0.016$) phases of the gait cycle, respectively. The pronation control and air chamber sport shoes produced statistically significant reductions in the peak amplitude with respect to the barefoot condition in the contact phase of the gait cycle ($P = 0.009$; $P = 0.027$), respectively.

3.4.3. Soleus

Regarding the Table 9 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the soleus muscle at running speed of 9 km/h, the minimalist sport shoe showed statistically significant decreases in the peak amplitude in comparison with the barefoot condition in the propulsion phase of the gait cycle ($P = 0.009$). The pronation control and ethyl-vinyl-acetate sport shoes produced statistically significant reductions in the peak amplitude with respect to the barefoot condition in the pre-activation phase ($P = 0.012$; $P = 0.004$) and propulsion ($P = 0.010$; $P = 0.004$) phases of the gait cycle, respectively.

3.4.4. Tibialis anterior

Regarding the Table 10 about the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the tibialis anterior muscle at running speed of 9 km/h, the minimalist sport shoe showed statistically significant increases in the peak amplitude in comparison with the barefoot condition in the pre-activation phase of the gait cycle ($P = 0.009$). The pronation control and air chamber sport shoes produced statistically significant increases in the peak amplitude with respect to the barefoot condition in the contact phase of the gait cycle ($P = 0.021$; $P = 0.013$), respectively.

4. Discussion

The current research may be stated as the first research to support novel evidence about the EMG muscle activity patterns of the triceps surae and tibialis anterior muscles considering different sport shoes types (minimalist, pronation control, air chamber, ethyl-vinyl-acetate and boost) in the different gait cycle phases during walking and running. According to our main hypothesis, the electromyography activity patters of the TS and TA muscles seem to be decreased wearing different types of sport shoes with respect to the barefoot condition in different phases of the gait cycle during walking and running. Nevertheless, boost sport shoes for the gastrocnemius medialis, as well as pronation control and air chamber sport shoes for the TA may increase their muscular activity peak amplitudes in specific phases of the gait cycle during running.

Table 3
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius muscle at walking speed of 5.17 km/h.

EMG parameter	Variable of gait	Type of shoe				
		Mean ± SD (mV) 95% CI				
Peak amplitude (mV)		**Barefoot**	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	23.80 ± 17.73 17.18–30.42	20.62 ± 16.68 11.39–26.85	18.41 ± 19.10 11.28–25.54	19.44 ± 19.97 11.98–26.89	19.25 ± 19.51 11.96–26.54
	Contact Phase (CP)	29.80 ± 20.11 22.29–37.31	26.03 ± 18.71 19.04–33.01	29.39 ± 22.75 20.89–37.89	29.20 ± 24.17 20.17–38.23	30.33 ± 21.48 22.31–38.36
	Midstance Phase (MSP)	57.33 ± 17.67 50.73–63.93	57.86 ± 15.32 52.14–63.59	54.16 ± 20.94 46.34–61.98	67.04 ± 31.91 55.13–78.96	52.57 ± 19.19 45.40–59.73
	Propulsion Phase (PPSP)	69.47 ± 18.07 62.72–76.22	70.03 ± 21.69 61.92–78.13	62.54 ± 28.34 51.95–73.12	62.04 ± 29.15 51.15–72.93	65.64 ± 28.21 55.11–76.17

EMG parameter	Type of shoe	*P* value				
	Mean ± SD (mV) 95% CI					
Peak amplitude (mV)	**Boost**	Mini. vs bare.	Pron. vs bare.	Air. vs bare.	EVA vs bare.	Boost vs bare.
	19.41 ± 20.61 11.71–27.10	0.022	0.102	0.152	0.137	0.140
	31.74 ± 25.03 22.39–41.09	0.042	0.919	0.907	0.893	0.669
	61.09 ± 27.31 50.89–71.29	0.810	0.256	0.055	0.039	0.297
	69.72 ± 29.43 58.72–80.71	0.872	0.139	0.087	0.394	0.953

Abbreviations: CI, confidence interval; EMG, electromyography; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 4
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius lateralis muscle at walking speed of 5.17 km/h.

EMG parameter	Variable of gait	Type of shoe Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	24.31 ± 18.59 17.37–31.26	20.56 ± 16.91 14.25–26.88	19.56 ± 18.68 12.58–26.54	13.81 ± 15.77 7.91–19.69	15.03 ± 17.17 8.62–21.44
	Contact Phase (CP)	26.42 ± 21.71 18.31–34.53	21.41 ± 18.75 14.41–28.42	19.65 ± 19.91 12.21–27.08	16.25 ± 17.76 9.62–22.89	20.51 ± 23.01 11.91–29.10
	Midstance Phase (MSP)	47.72 ± 27.86 37.31–58.12	44.97 ± 23.89 36.05–53.90	31.29 ± 26.71 21.31–41.26	40.95 ± 33.66 28.37–53.52	34.04 ± 27.91 23.61–44.46
	Propulsion Phase (PPSP)	69.28 ± 32.66 57.09–81.48	68.65 ± 34.80 55.66–81.65	43.19 ± 27.80 32.81–53.57	42.19 ± 27.65 31.86–52.51	46.24 ± 28.21 35.71–56.78

EMG parameter	Type of shoe Mean ± SD (mV) 95% CI	*P* value				
Peak amplitude (mV)	**Boost**	Mini. vs bare.	Pron. vs bare.	Air. vs bare	EVA vs bare.	Boost vs bare.
	13.71 ± 15.75 7.82–19.59	0.143	0.017	0.002	0.005	0.002
	17.22 ± 17.11 10.83–23.61	0.030	0.067	0.011	0.129	0.024
	35.96 ± 28.20 25.43–46.46	0.479	0.012	0.349	0.037	0.079
	47.59 ± 30.01 36.38–58.80	0.860	0.003	0.002	0.009	0.013

Abbreviations: CI, confidence interval; EMG, electromyography; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 5
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the soleus muscle at walking speed of 5.17 km/h.

EMG parameter	Variable of gait	Type of shoe Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	15.88 ± 16.38 9.76–22.01	13.86 ± 15.96 7.91–19.82	13.47 ± 16.53 7.30–19.64	11.05 ± 8.11 8.01–14.08	12.61 ± 10.41 8.71–16.49
	Contact Phase (CP)	22.58 ± 19.41 15.33–29.83	23.81 ± 27.87 13.41–34.22	26.93 ± 25.53 17.39–36.46	26.64 ± 32.97 14.33–38.95	27.69 ± 29.68 16.61–38.78
	Midstance Phase (MSP)	58.87 ± 17.49 52.33–65.40	59.96 ± 20.79 52.19–67.72	56.28 ± 25.72 46.67–65.68	80.02 ± 124.34 33.59–126.45	53.63 ± 23.41 44.89–62.37
	Propulsion Phase (PPSP)	76.21 ± 18.58 69.27–83.15	72.73 ± 20.91 64.92–80.54	63.63 ± 24.53 54.46–72.79	65.04 ± 68.57 39.44–90.65	64.26 ± 24.18 55.22–73.29

EMG parameter	Type of shoe Mean ± SD (mV) 95% CI	*P* value				
Peak amplitude (mV)	**Boost**	Mini. vs bare.	Pron. vs bare.	Air. vs bare	EVA vs bare.	Boost vs bare.
	13.60 ± 16.35 7.49–19.71	0.033	0.119	0.45	0.228	0.049
	26.49 ± 32.99 14.17–38.81	0.706	0.243	0.447	0.344	0.372
	73.84 ± 104.25 34.91–112.77	0.741	0.511	0.345	0.232	0.417
	80.20 ± 94.84 44.78–115.62	0.335	0.013	0.334	0.015	0.804

Abbreviations: CI, confidence interval; EMG, electromyography; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 6
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the tibialis anterior muscle at walking speed of 5.17 km/h.

EMG parameter	Variable of gait	Type of shoe Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	39.58 ± 18.43 32.69–46.46	41.84 ± 18.36 34.99–48.71	36.95 ± 17.02 30.60–43.31	38.49 ± 18.03 31.76–45.22	38.68 ± 18.59 31.74–45.62
	Contact Phase (CP)	42.18 ± 20.33 34.59–49.78	43.94 ± 19.15 36.78–51.09	38.91 ± 17.35 32.43–45.39	44.03 ± 20.57 36.34–51.71	42.25 ± 21.42 34.25–50.25
	Midstance Phase (MSP)	27.91 ± 22.04 19.68–36.14	21.51 ± 21.14 13.61–29.39	17.83 ± 20.31 10.25–25.42	22.36 ± 20.66 14.64–30.07	19.27 ± 20.54 11.59–26.94
	Propulsion Phase (PPSP)	25.96 ± 19.91 18.52–33.39	22.64 ± 19.26 15.45–29.84	20.28 ± 19.89 12.85–27.72	26.21 ± 22.18 17.92–34.49	21.74 ± 19.93 14.29–29.18

EMG parameter	Type of shoe Mean ± SD (mV) 95% CI	*P* value				
Peak amplitude (mV)	**Boost**	Mini. vs bare.	Pron. vs bare.	Air. vs bare	EVA vs bare.	Boost vs bare.
	38.77 ± 17.56 32.21–45.33	0.217	0.199	0.608	0.717	0.681
	40.35 ± 18.21 33.54 − 47.15	0.402	0.230	0.460	0.984	0.345
	20.60 ± 20.53 12.93–28.27	0.005	0.000	0.013	0.000	0.001
	22.72 ± 20.40 15.11–30.34	0.150	0.007	0.914	0.011	0.126

Abbreviations: CI, confidence interval; EMG, electromyography; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 7
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius medialis at running speed of 9 km/h.

EMG parameter	Variable of gait	Type of shoe				
		Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	37.89 ± 17.31 31.42–44.35	35.02 ± 17.93 28.32–41.72	27.11 ± 20.48 16.46–34.76	30.07 ± 22.36 21.72–38.42	30.82 ± 22.43 22.44–39.20
	Contact Phase (CP)	44.03 ± 16.47 37.88–50.19	43.49 ± 20.44 35.85–51.12	41.84 ± 24.74 32.60–51.08	45.32 ± 24.37 36.22–54.42	46.48 ± 24.79 37.22–55.74
	Midstance Phase (MSP)	77.55 ± 21.67 69.46–85.64	81.86 ± 19.29 74.65–89.06	80.01 ± 25.02 70.66–89.34	84.24 ± 28.39 73.64–94.85	79.84 ± 28.76 69.09–90.58
	Propulsion Phase (PPSP)	77.46 ± 19.39 70.22–84.71	70.83 ± 20.31 63.25–78.41	66.42 ± 27.41 56.18–76.66	68.36 ± 28.37 57.76–78.95	72.72 ± 24.37 63.62–81.82

EMG parameter	Type of shoe	*P* value				
	Mean ± SD (mV) 95% CI					
	Boost	Mini. vs bare.	Pron. vs bare.	Air vs bare.	EVA vs bare.	Boost vs bare.
Peak amplitude (mV)	34.43 ± 37.52 20.42–48.44	0.77	0.004	0.017	0.056	0.556
	47.40 ± 30.87 32.88–61.91	0.799	0.573	0.702	0.572	0.609
	88.54 ± 35.19 75.39–101.68	0.146	0.496	0.099	0.501	0.047
	79.69 ± 31.78 67.83–91.16	0.004	0.016	0.026	0.145	0.594

Abbreviations: CI, confidence interval; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 8
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the gastrocnemius lateralis muscle at running speed of 9 km/h.

EMG parameter	Variable of gait	Type of shoe				
		Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	40.45 ± 31.65 28.63–52.27	32.45 ± 18.17 25.65–39.24	21.94 ± 18.44 15.05–28.83	23.62 ± 18.44 16.74–30.51	24.89 ± 18.80 17.87–31.91
	Contact Phase (CP)	47.48 ± 20.85 39.70–55.27	48.91 ± 24.45 39.77–58.04	37.71 ± 25.09 22.34–41.08	31.94 ± 23.83 23.04–40.85	34.98 ± 28.94 24.17–45.79
	Midstance Phase (MSP)	88.02 ± 41.99 72.34–103.71	85.79 ± 35.21 72.64–98.94	57.81 ± 40.01 42.86–72.75	61.44 ± 48.06 43.50–79.49	56.39 ± 39.74 41.55–71.22
	Propulsion Phase (PPSP)	88.78 ± 55.04 68.23–109.23	72.86 ± 47.42 55.15–90.57	46.31 ± 34.32 33.49–59.12	47.69 ± 34.74 34.72–60.66	51.65 ± 35.44 38.41–64.88

EMG parameter	Type of shoe	*P* value				
	Mean ± SD (mV) 95% CI					
	Boost	Mini. vs bare.	Pron. vs bare.	Air vs bare.	EVA vs bare.	Boost vs bare.
Peak amplitude (mV)	21.72 ± 18.51 14.81–28.63	0.70	0.001	0.001	0.003	0.000
	32.65 ± 25.38 23.17–42.13	0.595	0.009	0.027	0.093	0.145
	62.55 ± 49.01 44.24–80.85	0.631	0.003	0.009	0.001	0.016
	53.16 ± 38.09 38.94–67.39	0.000	0.000	0.000	0.002	0.003

Abbreviations: CI, confidence interval; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 9

Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the soleus muscle at running speed of 9 km/h.

EMG parameter	Variable of gait	Type of shoe Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	34.96 ± 22.47 26.57–43.36	33.82 ± 23.11 25.19–42.45	27.72 ± 17.88 21.04–34.39	32.73 ± 40.15 17.73–47.73	25.32 ± 14.87 19.77–30.87
	Contact Phase (CP)	49.34 ± 30.81 37.84–60.85	51.52 ± 33.02 39.19–63.85	45.25 ± 28.91 34.46–56.05	55.35 ± 63.34 31.70–79.01	46.81 ± 32.47 34.67–58.93
	Midstance Phase (MSP)	94.21 ± 35.64 80.89–107.51	99.01 ± 29.55 87.98–110.05	91.18 ± 30.92 79.63–102.62	110.21 ± 117.-49 66.33–154.08	87.78 ± 29.91 76.62–98.95
	Propulsion Phase (PPSP)	91.21 ± 24.21 82.16–100.24	81.13 ± 24.83 71.86–90.41	75.77 ± 27.27 65.58–85.95	86.78 ± 70.35 60.51–113.05	80.00 ± 25.12 70.62–89.38

EMG parameter	Type of shoe Mean ± SD (mV) 95% CI	*P* value				
	Boost	Mini. vs bare.	Pron. vs bare.	Air vs bare.	EVA vs bare.	Boost vs bare.
Peak amplitude (mV)	30.54 ± 29.53 19.51–41.56	0.559	0.012	0.755	0.004	0.364
	51.59 ± 55.02 31.04–72.13	0.468	0.262	0.480	0.502	0.742
	112.71 ± 111.-51 71.06–154.34	0.202	0.502	0.350	0.179	0.252
	100.71 ± 94.24 65.51–135.90	0.009	0.010	0.704	0.004	0.552

Abbreviations: CI, confidence interval; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

Table 10
Results of the maximum muscular activity and the time of the phases of the gait with the different sports shoes used in the tibialis anterior muscle at running speed of 9 km/h.

EMG parameter	Variable of gait	Type of shoe				
		Mean ± SD (mV) 95% CI				
		Barefoot	**Minimalist**	**Pronated control**	**Air chamber**	**EVA**
Peak amplitude (mV)	Pre-activation phase (PAP) before the contact phase. Last 50 ms of the swing phase	37.20 ± 18.21 30.40–44.01	46.77 ± 20.24 39.21–54.32	39.87 ± 20.78 32.11–47.63	44.15 ± 21.74 36.03–52.27	41.61 ± 20.13 34.08–49.12
	Contact Phase (CP)	25.23 ± 16.13 19.21–31.25	30.14 ± 19.88 22.72–37.57	34.63 ± 23.57 25.83–43.43	35.39 ± 25.15 26.01–44.78	32.31 ± 24.72 23.08–41.55
	Midstance Phase (MSP)	24.82 ± 16.55 18.64–31.01	28.07 ± 32.21 16.04–40.10	28.72 ± 27.21 18.56–38.88	26.93 ± 24.57 17.75–36.11	28.80 ± 29.44 17.81–39.79
	Propulsion Phase (PPSP)	24.38 ± 17.26 17.93–30.82	22.95 ± 21.39 14.96–30.94	21.25 ± 21.89 13.08–29.43	27.91 ± 24.55 18.73–37.06	23.66 ± 22.35 15.31–32.01

EMG parameter	Type of shoe Mean ± SD (mV) 95% CI	*P* value				
	Boost	Mini. vs bare.	Pron. vs bare.	Air vs bare.	EVA vs bare.	Boost vs bare.
Peak amplitude (mV)	42.92 ± 18.66 35.96–49.89	0.009	0.470	0.099	0.216	0.077
	30.48 ± 19.21 23.31 − 37.65	0.135	0.021	0.013	0.115	0.101
	26.57 ± 24.26 17.51–35.63	0.463	0.374	0.534	0.419	0.618
	27.40 ± 23.15 18.75–36.04	0.595	0.331	0.352	0.811	0.421

Abbreviations: CI, confidence interval; EVA, ethyl-vinyl-acetate; mV, millivolts; SD, standard deviation.

4.1. Gastrocnemius medialis muscle activity during walking

Our results regarding the gastrocnemius medialis muscle activity during walking disagree with Scott et al. (2012), who showed a statistically significant increase for the gastrocnemius medialis muscle EMG pattern activity with the use of pronation control sport shoes with respect to barefoot condition during the contact and propulsion phases of the gait cycle. This fact may be due to our pronation control sport shoes presented a heel height of 27.5 mm, while the used pronation control sport shoes the study of Scott et al. (2012) presented a heel height of 20 mm. Nevertheless, our study results are in accordance with Murley and Bird (2006), who found that the gastrocnemius medialis muscle activity did not present statistically significant differences with medial wedge foot orthoses, with similar results to the pronation control sport shoes effects of our study.

4.2. Gastrocnemius medialis muscle activity during running

Our gastrocnemius muscle activity results during walking showed similar results to Fleming et al. (2015b) and Divert et al. (2005), who reported that that the gastrocnemius medialis muscle activity in the pre-activation phase of the gait cycle was higher in barefoot condition with respect to wearing shoes. In line with our research, Rao et al. (2015) observed that the gastrocnemius muscle activity was increased during running with the use of minimalist and boost sport shoes with respect to barefoot condition.

4.3. Gastrocnemius lateralis muscle activity during walking

To the authors' knowledge, no previous studies have been completed that have studied the soleus muscle group under these types of conditions (air chamber, minimalist, pronation control, ethyl-vinyl-acetate and boost sport shoes with regards to the barefoot condition during walking). Nevertheless, we believe that the cushioning and pronation control mechanism of the sport shoes may be the key elements to reduce the neuromotor activity of this muscle during the gait cycle phases. This rationale could explain the mechanisms in order to clarify our findings about the reductions in the peak amplitude during different phases of the gait cycle during the walking EMG analysis. Further studies are necessary regarding this matter.

4.4. Gastrocnemius lateralis muscle activity during running

The results of the gastrocnemius lateralis muscle activity during running of the present study are in line with Fleming et al. (2015b) and Divert et al. (2005), who reported a medial gastrocnemius muscle decrease activity wearing shoes with respect to the barefoot condition. Nevertheless, the findings reported by Rao et al. (2015) during the contact and propulsion phases of the gait did not match with our results, due to the lateral gastrocnemius muscle activity increased with the use of minimalist and boost sport shoes with respect to barefoot condition. In addition, there were not statistically significant differences between the use of all sport shoes types, according to Rao et al. (2015).

4.5. Soleus muscle activity during walking

To the authors´ knowledge, there were not previous studies which showed the soleus muscle activity in similar conditions. In addition, further research should be developed regarding the soleus neuromotor activity of this muscle during the gait cycle phases.

4.6. Soleus muscle activity during running

According to Divert et al. (2005), the soleus muscle presented a significant reduction of its muscle activity during running in the pre-activation phase of the gate cycle wearing shoes with respect to barefoot condition in line with our findings regarding the pronation control and ethyl-vinyl-acetate sport shoes with respect to the barefoot condition. According to Rao et al. (2015), there were not statistically significant differences in the soleus muscle activity during contact or propulsion phases of the gait cycle between barefoot condition and wearing shoes such as minimalist and boost.

4.7. Tibialis anterior muscle activity during walking

Our results describing the reduction of the tibialis anterior muscle activity during walking disagree with the findings reported by Scott et al. (2012) and Murley et al. (2009), who observed an increase in tibialis anterior muscle activity during the contact phase with the use of pronation control and flexible sport shoes, as well as with the utilization of medial wedge orthoses. Nevertheless, the medial wedge orthoses were not studied in our research.

4.8. Tibialis anterior muscle activity during running

In accordance with our results regarding the tibialis anterior muscle activity increase during running (pronation control and air chamber sport shoes with respect to the barefoot condition in the contact phase of the gait cycle), the plantar flexor increase of the ankle has been widely reported in runners with traditional boost sport shoes (Shih et al., 2013; Olin and Gutierrez, 2013). In addition, Nawoczenski and Ludewig (1999) found a tibialis anterior muscle activity increase in the first 50% of the contact phase of the gait cycle during running with sandals and postero-medial wedge orthosis in the forefoot and posterior part of the foot, being similar to the conditions under pronation control use in or study.

4.9. Limitations

Regarding the existence of possible limitations in our study, the muscle activity pattern of leg muscles may be altered under ankle chronic instability conditions (Kazemi et al., 2017). In addition, the intrinsic plantar muscles should be studied, due to their activity and morphology may be modified under different foot conditions such as hallux valgus (cross-sectional area and thickness reductions of the abductor hallucis and flexor hallucis brevis) or pes planus (cross-sectional area and thickness increases of the abductor hallucis and flexor hallucis brevis) (Lobo et al., 2016; Angin et al., 2014). Further studies regarding different sport shoe types and various sport activities should be developed regarding different conditions. In addition, future studies with blinded randomized clinical trials using these sport shoes in runners with different pathologies could improve the current evidence and overall determine the effectiveness of the sport shoe type in runners with frequent injuries (Roca-Dols et al., 2018).

5. Conclusions

The triceps surae and tibialis anterior muscles electromyography activity may be modified under the utilization of different sport shoes types such as air chamber, minimalist, pronation control, ethyl-vinyl-acetate and boost with regards to the barefoot condition considering the different gait cycle phases during walking and running. Despite triceps surae and tibialis anterior muscles activity patterns seem to be reduced using different sport shoes types with respect to the barefoot condition in different phases of the gait cycle during walking and running, some sport shoes may increase this muscular activity in specific phases of the gait cycle during running.

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Author contributions

All authors: concept, design, analyses, interpretation of data, drafting of manuscript or revising it critically for important intellectual content.

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