Original Research

Muscle Activity of the Triceps Surae With Novel Propulsion Heel-Lift Orthotics in Recreational Runners

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Background: The triceps surae muscle has been identified with propulsion during running gait, and typical heel-lift orthotics (THOs) have been used to treat some sports injuries of this structural-biomechanical unit. The effects of a novel propulsion heel-lift orthotic (PHO) on surface electromyography (EMG) activity of the gastrocnemius during a full cycle of running have yet to be tested.

Purpose/Hypothesis: We aimed to assess EMG changes in gastrocnemius medialis and lateralis muscle activity when wearing THOs, PHOs, or neutral sports shoes only (SO) during running. We hypothesized that EMG activity of the triceps surae muscle would be lower for PHOs than THOs or SO during running.

Study Design: Controlled laboratory study.

Methods: A total of 26 healthy, regular recreational runners of both sexes (mean age, 33.58 ± 6.02 years) with a neutral Foot Posture Index and rearfoot strike pattern were recruited to run on a treadmill at 9 km/h using aleatory THOs of 6 and 9 mm, PHOs, and SO while EMG activity of the gastrocnemius medialis and lateralis muscles was recorded over a 30-second period. Intraclass correlation coefficients were calculated to assess reliability.

Results: The intraclass correlation coefficient values indicated near perfect reliability, ranging from 0.801 for 6-mm THOs to 0.959 for SO in the gastrocnemius lateralis muscle. EMG activity of the gastrocnemius lateralis muscle was greater for PHOs (25.516 ± 4.780 mV) than for SO (23.140 ± 4.150 mV) ($P < .05$), but EMG activity of the gastrocnemius medialis muscle did not show any statistically significant difference between conditions (23.130 ± 2.980 mV vs 26.315 ± 2.930 mV, respectively) ($P = .3$).

Conclusion: A novel PHO may increase muscle activity of the gastrocnemius lateralis during a full cycle of running gait; consequently, its prescription to treat triceps surae muscle injuries is cautioned.

Clinical Relevance: The prescription of novel PHOs could increase EMG activity, which has not been previously described.

Keywords: triceps surae; propulsion; heel-lift orthotics; surface electromyography

In modern times, running is a prescribed sports activity for the improvement of health. Nevertheless, data on novice athletes have shown that approximately 17.8 injuries occur every 1000 hours of running-based training and that approximately 7.7 injuries occur every 1000 hours in habitual runners,[38] with Achilles tendinopathy as one of the most prevalent injuries.[10] Although some authors have shown several benefits of wearing a foot orthotic on preventing sports injuries,[22] it remains unclear what effects it may have on soft tissues.[2]

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Studies on human running kinetics have shown that lower limb muscle preactivation during the unloading phase of gait was related to an improvement in running economy (RE)[36] and a decrease in the incidence of injuries.[35] Preactivation, with the best RE, has been associated with a more perfect biomechanical gesture[32] focused concretely on a reduction in contact duration with the ground, which is typical in forefoot and midfoot runners[11,34]; however, other studies have attributed these conditions to inevitable muscle and tendon overuse and higher metabolic consumption.[37] In addition, runners were more exposed to injuries of the Achilles tendon and triceps surae muscle because they were unacclimated to active ankle joint plantarflexion (mandatory tiptoe) during the first phase of running gait.[31]

The effects of heel pain syndrome[28] and forefoot/rearfoot load changes[42,43] have been studied, and a decrease in Achilles tendon tension values using typical heel-lift orthotics (THOs) of 15 mm[41] and 18 mm[8] has been found. Other groups, however, have reported a decrease[20,21] and increase[17] in triceps surae muscle electromyography (EMG) activity during normal gait while wearing THOs. Moreover, walking and running muscle activities of the triceps surae were also previously assessed using surface EMG,[30] with changes observed according to the type of sports shoe worn; however, the response of calf muscle activity while wearing a novel propulsion heel-lift orthotic (PHO) remains unknown. It has been thought to save thigh triceps muscle activity based on its spring design, comparable with the design of biomimetic ankle prostheses.[14,23]

The purpose of the present study was to evaluate the changes in muscle activity of the triceps surae during running while wearing sports shoes only (SO), 2 different THOs (6 and 9 mm), or a novel PHO. The EMG activity of the triceps surae muscle was expected to be lower while wearing PHOs than THOs.

METHODS

The institutional review board of Hospital Virgen del Rocío approved the study. Ethical and human rules dictated by the Declaration of Helsinki were followed, and signed informed consent was obtained from all participants.

Study Design and Sample Size

In this cross-sectional observational study, statistics and research software from a public university were used to calculate the sample size to detect any measurable difference in gastrocnemius medialis and lateralis muscle activity among SO, THO, and PHO use during running. A previous study found a value of 7.0 ± 0.6 mV while wearing 9-mm THOs versus 4.9 ± 0.6 mV while wearing typical shoes.[17] Considering a statistical power of 80%, beta of 20%, 95% CI, and alpha of .05, a total of 33 participants were required to execute the study. Taking into account the typical loss of 20% of participants, 26 participants were ultimately recruited. Strengthening the Reporting of Observational Studies in Epidemiology criteria[39] and a random consecutive sampling technique were followed.

Participants

Participants were recruited from a biomechanical clinic in Madrid, Spain, over a 3-month period (July-September 2019). A total of 48 participants were invited to participate in the study and assessed for eligibility. The eligibility criteria were as follows: (1) healthy male or female participants aged between 18 and 30 years, (2) recreational runners who had a neutral rearfoot strike pattern and ran between 25 and 30 km/wk, and (3) a neutral Foot Posture Index with values between 0 and +5 points.[29] The exclusion criteria were as follows: (1) limited dorsiflexion in the ankle joint complex of more than 10° according to a lunge measure[1]; (2) limitation in midtarsal and/or Lisfranc joint mobility; and (3) use of any type of medication at the time of the study. Body mass index (BMI) was considered to select a homogeneous sample, applying the Quetelet equation as BMI = weight (kg)/height (m^2).[12]

Instruments and Assessments

The NeuroTrac Simplex Plus (Verity Medical) EMG device with a USB-Bluetooth (Bluetooth SIG, Inc) transmitter[26] was used to assess the contraction and rest signals of the triceps surae muscle during the test. This device had an EMG measurement range of 0.2 to 2000 mV, a sensitivity of 0.1 mV root mean square, and 10 m of wireless (Bluetooth) connection range. Self-adhesive surface electrodes with a circular shape of 30 mm in diameter made using high-quality hydrogel and conductive carbon film were worn to detect the muscle signals.

Materials

The PHO was made using a flat 3-mm layer of polypropylene without any orthotic element that could interface with the foot architecture and into which a flexible polycarbonate spring of 3-mm thickness and 45° angle was added on the rear of the flat orthotic insoles to produce 14 mm of height at the rearfoot. A viscoelastic rubber piece of ethylene-vinyl-acetate (EVA) of medium hardness and 2-cm thickness was used to cushion the angular corner of the polycarbonate spring, 1-mm thickness of low-hardness EVA was used to cushion the joint of the polycarbonate piece to polypropylene, and a 1 mm–thick EVA cover sheathed the upper layer (Figure 1). On the other hand, the THO was made with a rigid 6- or 9-mm[17] thickness of

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Figure 1. Propulsion heel-lift orthotic. A flexible spring of polycarbonate (bent black piece) was placed under the rear side of the polypropylene flat layer of 3 mm (black fiber). Red low-hardness ethylene-vinyl-acetate (EVA) was used to cushion the polycarbonate junction with polypropylene on the upper layer, and green medium-hardness EVA was used to cushion the angular corner of the spring.

Figure 2. Typical heel-lift orthotic. A rigid piece of high-hardness ethylene-vinyl-acetate (EVA; brown piece) was placed under the rear side of the 3 mm–thick flat polypropylene layer (black fiber). A flat sheet of 2 mm of flexible medium-hardness EVA covered the lower layer of the orthotic.

high-hardness EVA placed properly on the rear side of a flat layer of 3 mm–thick polypropylene (Figure 2). The neutral SO was the PW 100 Men's Fitness Walking Shoes in medium grey (No. 2018022; Newfeel).

Procedure

An expert podiatric researcher (R.S.-G.) performed the physical evaluations of participants and applied the eligibility criteria. In a seated position, each participant was asked to perform plantarflexion of the ankle joint for a few seconds to highlight the belly of the gastrocnemius medialis muscle, and we placed the surface electrode longitudinally on the most prominent bulge of the muscle per the European recommendations for surface EMG.[15] Then, participants were asked to stand and remain on the tiptoes of their right foot for 5 seconds to set the maximal voluntary contraction needed to calibrate the device software and to normalize EMG data amplitudes of each assessment. Afterward, participants were asked to walk on a motorized electric treadmill (Domyos Soft Impact TF5; OXYLANE) at 5.17 km/h[30] for 3 minutes to adapt, then participants performed the test while running at 9 km/h[33] under 4 different conditions (SO, PHO, 6-mm THO, and 9-mm THO) randomly on the same day. For each participant, the mean EMG amplitude of muscle activity of the gastrocnemius medialis of the right leg was recorded 3 times for 30 seconds each, leaving 5 minutes of rest during which participants remained seated.[9] All 4 conditions were imposed on the left foot to avoid the imbalance of body biomechanics. An identical test was performed with sensors placed on the gastrocnemius lateralis muscle.

Statistical Analysis

Statistical analysis followed the methodology of a prior study.[27] Within-day trial-to-trial intraclass correlation coefficients (ICCs) and standard errors of the mean[32] for the participants under 4 conditions (SO, 6-mm THO, 9-mm THO, and PHO) were recorded for the gastrocnemius medialis and lateralis muscles during a running test to assess for reliability. This previous study reported that ICCs <0.20 indicated slight reliability, 0.20-0.40 indicated fair reliability, 0.41-0.60 indicated moderate reliability, 0.61-0.80 indicated substantial reliability, and 0.81-1.00 indicated almost perfect reliability.

In the current study, we considered ICCs of ≥ 0.81 to have enough magnitude of reliability to validate the measurements. The SEM was used to quantify the minimal detectable change (MDC) to determine the clinical significance of all measurements; the MDC is alternatively called the Reliable Change Index according to Jacobson and Truax.[16] The Shapiro-Wilk test was applied to assess the normality of the sample, establishing a normal distribution when $P > .05$. Demographic characteristics of age, sex, height, and weight were obtained, and descriptive quantitative data were shown as the mean and SD. The nonparametric paired Friedman test was performed to detect differences among the SO, PHOs, and THOs; the Wilcoxon test with Bonferroni correction was used to analyze differences among the 4 conditions, with statistically significant differences indicated when $P < .05$ with a 95% CI. Data recorded using the NeuroTrac software (Figure 3) were loaded onto an Excel template (Windows 97-2003; Microsoft Corp). Data analysis was performed using SPSS Version 19.0 (IBM Corp).

RESULTS

According to the Friedman test results, statistically significant differences were found among the variables ($P < .05$). Nineteen did not meet the inclusion criteria, and an additional 3 did not present for the evaluation. Ultimately, 26 participants (18 male and 8 female) were enrolled, and their anthropometric characteristics are shown in Table 1. The Shapiro-Wilk test showed that the sample was not normally distributed ($P < .05$).

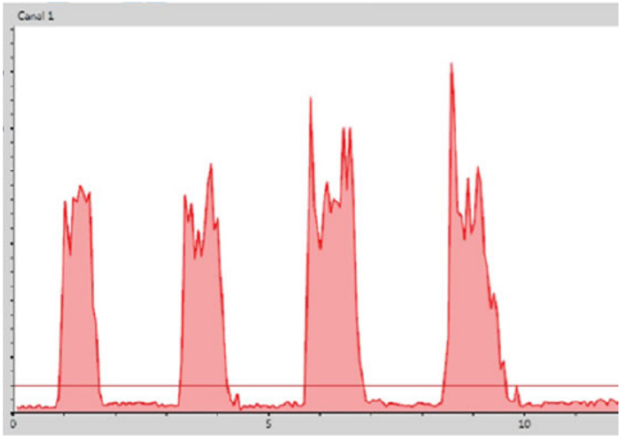

Figure 3. NeuroTrac signal capture screen. Example of 4 electromyography gastrocnemius medialis muscle contractions. The *y*-axis shows the power of muscle activity, and the *x*-axis shows time (seconds).

TABLE 1
Participant Characteristics[a]

Variable	Mean ± SD (95% CI)
Age, y	33.58 ± 6.02 (31.26-35.89)
FPI	3.02 ± 0.70 (2.75-3.28)
Weight, kg	69.50 ± 6.26 (66.24-71.06)
Height, cm	173.58 ± 4.87 (171.70-175.45)
BMI, kg/m^2	23.08 ± 3.85 (21.60-24.50)

[a]BMI, body mass index; FPI, Foot Posture Index.

The reliability of muscle activity variables in any of the 4 conditions, expressed as ICC values, is summarized in Table 2. These values met, at minimum, the condition of "almost perfect reliability,"[16] ranging from 0.801 for 6-mm THOs to 0.959 for SO in the gastrocnemius lateralis muscle and from 0.875 for PHOs to 0.942 for SO in the gastrocnemius medialis muscle. In addition, all of the interrater MDC values were lower than those of EMG, ranging from 2.093 mV for SO in the gastrocnemius medialis muscle to 5.289 mV for 6-mm THOs in the gastrocnemius lateralis muscle. The SEM reached a lower value for SO in the gastrocnemius medialis muscle (0.755 mV) and a higher value for 6-mm THOs (1.908 mV) in the gastrocnemius lateralis muscle (Table 2).

EMG muscle activities of the gastrocnemius medialis and lateralis muscles for SO and with 3 types of heel lifts (6-mm THO, 9-mm THO, and PHO) are shown in Table 3. The mean EMG amplitude of the gastrocnemius lateralis muscle was statistically significantly greater ($P = .034$) for PHOs (25.516 ± 4.780 mV) than for SO (23.140 ± 4.150 mV). Other comparisons did not reveal significant differences. When compared with values of SO, values for 6-mm THOs (24.227 ± 3.590 mV) and 9-mm THOs (24.379 ± 3.790 mV) were slightly greater but without statistical significance ($P > .05$). Likewise, statistically nonsignificant differences were found between 6- and 9-mm THOs, between PHOs and 6-mm THOs, and between PHOs and 9-mm THOs.

EMG values for the gastrocnemius medialis muscle showed a noteworthy difference between SO (23.130 ± 2.980 mV) and PHOs (26.315 ± 2.930 mV), but this failed to reach statistical significance. The other remaining measurements of SO versus 6-mm THOs (25.216 ± 4.100 mV) and 9-mm THOs (25.611 ± 4.670 mV) showed greater values for THOs, also without statistical significance ($P > .05$). Comparing 6- and 9-mm THOs, a statistically nonsignificant difference was found, and this was also the case between PHOs and 6-mm THOs and between PHOs and 9-mm THOs.

DISCUSSION

The triceps surae is one of the most important muscles to carry the heel in a normal cycle of running and, for this reason, is one of the most injured muscles during sporting activities.[13] The current study aimed to assess the EMG effects of PHOs and THOs on the triceps surae muscle, which has never previously been done. The wide variability in experimental conditions, such as walking[17-20] versus running[30]; the phases of gait[17,20,30]; and the influence of normal shoes, neutral orthotics, heel-lift orthotics, and sports shoes[25,27] render any meaningful comparison between results difficult to make. For example, no studies about EMG muscle activity of the gastrocnemius during running while wearing heel lifts have been reported. The novel PHO showed higher EMG values than did the THOs in both the gastrocnemius medialis and lateralis muscles, and it was statistically significant in the gastrocnemius lateralis muscle. Walking in high heels has been reported to increase muscle activity of the triceps surae,[4,18] presumably to compensate for the decreased stability generated by their height.[7,18] The PHO with 14-mm height on the rearfoot used in this experiment did not have a rearfoot cup, which could explain the instability and resultant muscle activity. In addition, it is possible that heel lifts (PHOs and THOs) could relax noncontractile portions of the muscle-tendon unit and increase the active portion of the triceps surae muscle[17]; for this reason, Achilles tendon injuries ameliorate with heel lifts,[8] but they also increase muscle activation. Also, the tonic vibration reflex present with soft tissue resonance damping at heel strike during running[40] could increase the EMG activity of PHOs.

In general, the present research, with results of near perfect reliability, has shown that the use of PHOs that raise the heel during running produced higher EMG muscle signal values and presumably affected the energy cost of gait, as other authors have proposed.[7] For these reasons, if the clinician wants to unload the energy cost of the calf muscles to prevent injuries, heel lifts should be used with caution because perhaps the goal is not to unload but to overload.

Gastrocnemius Medialis Muscle Activity

According to our results, the EMG pattern of the gastrocnemius medialis muscle tended to be higher when

TABLE 2
Reliability of Muscle Activity Variables by Condition[a]

Variable	SO			6-mm THO			9-mm THO			PHO		
	ICC (95% CI)	SEM	MDC	ICC (95% CI)	SEM	MDC	ICC (95% CI)	SEM	MDC	ICC (95% CI)	SEM	MDC
Gastrocnemius lateralis, mV	0.959 (0.921-0.980)	0.879	2.437	0.801 (0.617-0.900)	1.908	5.289	0.934 (0.872-0.968)	1.043	2.891	0.929 (0.865-0.966)	1.362	3.777
Gastrocnemius medialis, mV	0.942 (0.890-0.972)	0.755	2.093	0.900 (0.810-0.952)	1.450	4.019	0.930 (0.874-0.968)	1.281	3.550	0.875 (0.762-0.940)	1.100	3.210

[a]ICC, intraclass correlation coefficient; MDC, minimal detectable change; PHO, propulsion heel-lift orthotic; SO, shoes only; THO, typical heel-lift orthotic.

TABLE 3
EMG Muscle Activities[a]

Variable	Mean ± SD (95% CI), mV				P Value					
	SO	6-mm THO	9-mm THO	PHO	SO vs 6-mm THO	SO vs 9-mm THO	SO vs PHO	PHO vs 6-mm THO	PHO vs 9-mm THO	6-mm vs 9-mm THO
Gastrocnemius lateralis	23.140 ± 4.150 (21.544-24.734)	24.227 ± 3.590 (22.843-25.610)	24.379 ± 3.790 (22.920-25.837)	25.516 ± 4.780 (23.675-27.350)	.218	.073	<.05[b]	.096	.238	.869
Gastrocnemius medialis	23.130 ± 2.980 (21.900-24.300)	25.216 ± 4.100 (22.060-25.827)	25.611 ± 4.670 (22.812-26.400)	26.315 ± 2.930 (24.185-26.444)	.107	.078	.3	.238	.2	.889

[a]EMG, electromyography; PHO, propulsion heel-lift orthotic; SO, shoes only; THO, typical heel-lift orthotic.
[b]$P < .05$ was considered statistically significant.

participants wore high-lift orthotics, including novel PHOs, which had the highest value compared with SO during the full cycle of running gait but without statistical significance. These values align with those of other researchers[30] who have reported an increase in EMG activity of the gastrocnemius medialis muscle during the preactivation and midstance phase of running gait while wearing sports shoes with 11-mm drop. While this differed from the heel lifts used in the present study, the biomechanical effects were nevertheless similar.[3] However, other authors[6,9] have shown an increased pattern of EMG activity of the gastrocnemius medialis muscle during barefoot running or even during walking.[17,20]

Gastrocnemius Lateralis Muscle Activity

Previous studies have reported decreased EMG values in the gastrocnemius lateralis muscle while wearing sports shoes during different phases of running gait,[6,9,30] which conflicts with our results that showed an increase in muscle activity when wearing both types of THOs and a statistically significant increase for PHOs.

Running Economy

Some studies[5,7,24] have reported an increase in RE caused by a higher heart rate and oxygen consumption that accompanies walking in high heels, related to biomechanical changes, such as incremental ankle plantarflexion, knee flexion, or anteroposterior braking force. At present, no research exists on these parameters during running, but these results could be in agreement with ours, given that we found higher EMG values in muscle activity for PHOs.

Limitations

The high sensitivity of heel lifts could show high SD values because of changes in the motor units of the muscles among conditions. Furthermore, the maximum voluntary isometric contraction may differ among participants and trials, and the recruited motor units can vary[4]; the calibration and normalization of the signal of each test could be influenced by these circumstances.

CONCLUSION

Wearing PHOs may increase gastrocnemius lateralis muscle EMG activity relative to wearing THOs and SO during running. Future research will need to detect when increased muscle activity occurs during different phases of running gait, and future cohort studies will have to be designed to establish the length of time that PHOs need to be worn to produce a permanent muscle cost-energy response.

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