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Title: Temporal differences in the myoelectric activity of lower limb muscles during rearfoot and forefoot running: A statistical parametric mapping approach

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Abstract

Forefoot (FF) and rearfoot (RF) running techniques can induce different lower-limb muscle activation patterns. However, few studies have evaluated temporal changes in the electromyographic activity (EMG) of lower limb muscles during running. The aim of this study was to compare temporal changes in EMG amplitude between RF and FF running techniques. Eleven recreational runners ran on a treadmill at a self-selected speed, once using a RF strike pattern and once using a FF strike pattern (randomized order). The EMG of five lower limb muscles [rectus femoris (RFe), biceps femoris (BF), tibialis anterior (TA), medial and lateral gastrocnemius (MG and LG)] was evaluated, using bipolar electrodes. EMG data from the RF and FF running techniques was then processed and compared with statistical parametric mapping (SPM), dividing the analysis of the running cycle into stance and swing phases. The MG and LG muscles showed higher activation during FF running at the beginning of the stance phase and at the end of the swing phase. During the end of the swing phase, the TA muscle's EMG amplitude was higher, when the RF running technique was used. A higher level of co-activation between the gastrocnemius and TA muscles was observed in both stance and swing phases using RF. The myoelectric behaviour of the RFe and BF muscles was similar during both running techniques. The current findings highlight that the two running techniques predominately reflect adjustments of the shank and not the thigh muscles, in both phases of the running cycle.

Highlights

- Statistical parametric mapping (SPM) can reveal temporal differences in muscle activity between running techniques.
- The medial and lateral gastrocnemius muscles were more active at specific time-instants of the initial stance and late swing phases during forefoot (FF) running compared to rearfoot (RF) running.
- Higher activation was observed for the tibialis anterior muscle at the end of the swing phase during RF running
- Contrary to the muscle activity differences observed in the leg muscles, the muscle activity of the thigh muscles was similar during RF and FF running.

Keywords: Statistical parametric mapping, running, surface electromyography.

Introduction

In recent years, running has become one of the most popular physical activities, as it is a simple, cost-efficient solution for many people who wish to maintain a healthy lifestyle (e.g., improve their cardiovascular fitness and/or reduce stress levels) (Landreneau, Watts, Heitzman, & Childers, 2014). Unfortunately, the increase in the popularity of running has been followed by an increase in the prevalence of running-related injuries (Daoud et al., 2012). Running is commonly performed by both amateur and elite athletes (Andersen, 2020), however, the most common cohort within the running community, are probably recreational runners, i.e., people that run exclusively for fun and rarely participate in running competitions (Hespanhol Junior, Pena Costa, & Lopes, 2013). Training characteristics play an important role in the incidence of running-related injuries in recreational runners, as training errors can lead to overloading of the musculoskeletal tissues and predispose them to injury (Hespanhol Junior et al., 2013). An example of training characteristics that has a huge effect on running biomechanics and thus, the distribution of the biomechanical loads across the lower limbs, is the foot strike pattern employed during running (Xu et al., 2021). Runners commonly use rearfoot (RF) or forefoot (FF) running techniques, which are characterised by landing on the heel or by landing on the ball of the foot respectively (Yong et al., 2020).

A common way to evaluate changes in lower limb neuromuscular behaviour during different running techniques, and possibly understand the development and risk of injuries, is by using surface electromyography (sEMG) (Landreneau et al., 2014). sEMG is a non-invasive technique that has been widely used in sporting environments as a fundamental tool to quantitively evaluate and record the electrical activity of multiple muscles, during different sport activities (e.g., soccer, volleyball, basketball, outdoor sports), including running (Cavalcanti Garcia & Vieira, 2011; Landreneau et al., 2014). Many studies have previously evaluated the sEMG activity (commonly measured as sEMG amplitude) of lower limb muscles during running (Lucas-Cuevas et al., 2016; Nüesch, Roos, Egloff, Pagenstert, & Mündermann, 2019; Valencia et al., 2020; Yong et al., 2020), using measures of centrality and dispersion, such as the mean and standard deviation of the interference sEMG signal (Landreneau et al., 2014; Olin & Gutierrez, 2013; Trégouët, Merland, & Horodyski, 2013). For example, one study compared RF and FF running techniques by calculating the mean difference in sEMG amplitude and reported significant differences in the sEMG amplitude of the medial, lateral gastrocnemius, and tibialis anterior muscles (Lucas-Cuevas et al., 2016). However, an important limitation of these measures is that they just provide a general overview of the myoelectric behaviour of the leg muscles for the full running cycle, not allowing the identification of changes at different time-points or phases during the running cycle (Pataky, Robinson, & Vanrenterghem, 2016; Robinson, Vanrenterghem, & Pataky, 2015). Therefore, it is important to employ signal-processing techniques which allow the evaluation of temporal differences in muscle activity during the entire time series of a task (e.g., full running cycle), rather than comparing ensemble averages for the full running cycle, which provides results with poor temporal resolution.

A statistical-processing technique that has allowed biomechanical variables to be examined in function of the time series of a task, is statistical parametric mapping (SPM) (Pataky, 2010; Pataky et al., 2016). This technique was first described by Friston et al. (1995), and then validated by Pataky based on kinematic and kinetic data (Pataky, 2010; Pataky et al., 2016). SPM is based on an inferential method, where hypothesis testing is directly applied to the signal (Pataky et al., 2016). More specifically, random field theory determines the appropriate threshold to maintain alpha at 0.05 across the time-series, where the null hypothesis is either accepted or rejected if the experimentally observed test statistic {t} exceeds this threshold. SPM has been recently used to evaluate temporal differences during the whole cycle of several tasks, including gait (Abbasi et al., 2020), jumping (Moisan, Mainville, Descarreaux, & Cantin, 2020), and running (Nüesch et al., 2019). In terms of the running task, SPM has already been used to compare curves of kinematic, kinetic, and sEMG data during running (Abbasi et al., 2020; Nüesch et al., 2019; Yong et al., 2020). However, only a few studies have focused on assessing temporal differences in the activity of lower limb muscles (i.e., gastrocnemius) when comparing different types of running techniques, such as RF and/or FF running (Luciano, Zilianti, Perini, Guzzardella, & Pavei, 2020; Valencia et al., 2020). Additionally, to date no studies have evaluated temporal differences in the behaviour of the thigh muscles during RF and FF running. Since these muscles are one of the main muscle groups used during running, this evaluation could provide information regarding the effect of the strike pattern on their activity throughout the running cycle. Importantly, even though many studies have commonly used the ratios between agonist/antagonist muscle activity to describe the levels of co-activation during dynamic tasks (e.g., gait, trunk and hip movements) (Aslan, Batur, & Meray, 2020; Rojas-Quinchavil et al., 2021; Tretriluxana, Nanbancha, Sinsurin, Limroongreungrat, & Wang, 2021; Vanderstukken, Borms, Berckmans, Spanhove, & Cools, 2020), there are currently no studies evaluating co-activation using the whole time series of a task by using SPM.

Therefore, the aim of this study is to compare the temporal shape of the electromyographic amplitude of thigh and calf lower limb muscles, between RF and FF running, considering the stance and swing phases of the running cycle. The current study will also evaluate differences in the ratio of the gastrocnemius/tibialis anterior activity (co-activation) during the different phases of RF and FF running. We hypothesised that (1) the muscle activity of the lower limb muscles will differ between the FF and RF running techniques, in both phases of the running cycle and (2) the level of co-activation between the gastrocnemius and TA muscles will be higher during RF running.

Methods

Participants

Eleven healthy recreational runners (7 men and 4 women; age: 22.3±2.4 years; mass: 66.8±5.6 kg; height: 1.7±0.1 m) from the University XX, XX, XX were recruited for this observational, cross-sectional study. The sample size was calculated based on data collected previously from the tibialis anterior muscle (Valencia et al., 2020), considering an effect size of 1.33, alpha of 0.05, and power of 80%. The GPower software (version 3.1.9.2, Kiel Universität, Germany) was used to perform the power calculation. A minimum sample size of 8 runners was required for this study; however, 11 runners were recruited. Participants were eligible to participate in this study if they run (1) $\geq$ 3 times/week and (2) for at least 5km each day. All volunteers routinely used the RF technique during running. However, this was not a requirement of the current study, but an unintended characteristic of the recruited sample. Participants were excluded from the study if they had a musculoskeletal injury or surgery in their lower limbs over the last 6 months. All participants provided written informed consent before evaluation. Ethical approval was obtained by a local ethics committee (CEC201905). This study was conducted in accordance with the Declaration of Helsinki.

Experimental protocol

Prior to the laboratory visit, all participants were advised to wear athletic clothing and their personal running shoes, which should have been used for at least one month. At the beginning of the experiment, all participants were given a few minutes to familiarise themselves on a treadmill (H/P/Cosmos®, Model LE200 CE, Germany). All volunteers routinely used the RF technique. Then, the principal investigator trained each participant on how to run, using the two different running techniques (i.e., RF and FF) on the treadmill for five minutes. During this process, each participant's preferred running speed was also calculated (Nüesch et al., 2019; Yong et al., 2020), based on the average of three consecutive trials (the average self-selected running speed of all participants was 8.6 ± 1.3 km/h). More specifically, the treadmill speed was progressively increased by the investigator, up to the participant's desired level (i.e., the point that the participant felt comfortable to run for 5 minutes). The participant was blinded to the treadmill speed during this process. Once the participant's preferred running speed was calculated and felt comfortable to run with both techniques, each volunteer ran for five minutes, once using the RF and once using the FF running techniques at the same speed. The order in which the runners had to perform each technique was randomised. They were then asked to perform three 5s isometric maximal voluntary contractions (MVCs) for each muscle separately. During this procedure, all participants were verbally motivated in a similar manner. Each trial was separated by 1 min of rest. For the assessment of tibialis anterior (TA), medial (MG) and lateral (LG) gastrocnemius muscles' MVCs, all participants were in a prone lying position with their dominant foot strapped to a custom-made metal structure and their ankle at a neutral position. From this position, they were instructed to perform ankle dorsi flexion/extension MVCs to assess the gastrocnemius and TA muscles, respectively. For the evaluation of rectus femoris (RFe) and biceps femoris (BF) muscles' MVCs, all participants were seated on a quadriceps bench, with their hips at 90° of flexion and their knees at 50° of flexion. From this position, they were instructed to perform knee extension/flexion MVCs to assess the RFe and BF muscles, respectively. The highest MVC value for each muscle was used as a reference to normalise the electromyographic signals (%MVC), considering as maximum the average value of a window of 10ms around the peak.

sEMG and kinematic data were acquired simultaneously from the dominant lower limb of all participants while they were running on the treadmill. Participants were asked to perform a dynamic task (i.e. to kick a soccer ball), in order to determine the lower limb dominance (Brown, Zifchock, & Hillstrom, 2014). Data (i.e., sEMG signals and kinematic marker trajectories) were recorded during the last minute of each running trial (i.e., between minutes 4-5) and for 20 running cycles. This process was performed once while participants were running using the RF technique and once while they were running using the FF technique (i.e., 40 cycles in total).

Kinematics

Kinematic data were captured using a 3D motion system with eight infrared cameras (T-Series, Vicon Motion Systems, Oxford, UK) at 200 Hz. Two reflective markers (14mm diameter) were firmly attached on the shoe of all participants over the calcaneus (rearfoot) and on the base of the second metatarsal phalangeal joint (forefoot), as described previously (Landreneau et al., 2014). This enabled us to export information about the time that the foot contacted the treadmill, as well as on the time that the foot was lifted from the treadmill (defined as foot strike and foot off in the software NEXUS, Vicon®). Thus, we were able to determine the running cycle, including both the stance and swing phases. This information was then used for the sEMG analysis.

Electromyography recording

Simultaneously with the kinematic measurements, sEMG signals were recorded in single differential mode using a Bagnoli^{TM} 16-channel sEMG system (Delsys® Inc., Boston, MA, USA; sampling frequency: 1kHz, converter 12-bit A/D), with a common-mode rejection ratio of 92 dB, input impedance > 1015 Ohms, estimated noise ≤ 1.2 mV, overall amplification of 100–10000 (v/v) and bandwidth 20-450Hz. The signals were acquired at 1kHz using bipolar electrodes (parallel-bar Ag/AgCl, contact dimension:10x1mm, interelectrode distance:10mm). The electrodes were placed over the muscle bellies of the RFe, BF, TA, MG, and LG respectively muscles, in accordance with the SENIAM protocol guidelines (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Prior to electrode placement, the skin was shaved and then cleaned with alcohol cotton swabs to reduce electrode-skin impedance. The kinematic and sEMG signals were synchronised with the 3D motion capture system (Vicon®).

Data processing

The sEMG data were processed based on the selection of ten central running cycles (defined as two consecutive foot-strikes of the same foot on the ground treadmill) for each of the two running techniques (i.e., 10 for RF and 10 for FF). The vertical axis of the trajectories recorded by the two reflective markers which were located on the participants' shoes, was used to identify the stance and swing phases, using the events of foot strike and foot off. This was manually performed using the Nexus software (version 2.8, Vicon Motion Systems, Oxford, UK). The raw sEMG signals of all muscles were rectified and filtered with a low-pass filter (Butterworth; 4th order; cutting off frequency 20Hz) (Flores-Leon, Soto, Araneda, Guzman-Venegas, & Berral de la Rosa, 2018). The signals of each muscle were then normalised to its MVC and were cut according to the stance and swing phases, generating 101 data points per phase. The function *spm1d.util.interp* (SPM1D, www.spm1d.org) was used to do this, as presented previously (Nüesch et al., 2019). Once the results for each participant were acquired, an average curve from 10 running cycles was calculated for each muscle (RFe, BF, MG, LG, and TA). Additionally, the level of co-activation between MG + LG and TA during the two running techniques was calculated. For this purpose, we employed two formulas, first we used MG activity + LG activity (total gastrocnemius activity, defined as GAS)/TA * 100, when co-activation was calculated during the swing phase and second, TA/GAS * 100, when co-activation was calculated during the stance phase. Co-activations were determined in this way considering which muscle was acting as agonist or antagonist during the running cycle (i.e., TA is predominately active during the end of the swing phase and GAS muscles are predominately active at the beginning of the stance phase, see results). The levels of co-activation were calculated only for the temporal regions that GAS and TA showed significant differences when running with a RF or a FF strike pattern (revealed by the SPM analysis).

Statistical analysis

Descriptive statistics were used to report the anthropometrics characteristics of the eleven participants (i.e., mean ± standard deviation). A paired-sample t-test using the open-source Statistical Parametric Mapping 1D package (SPM1D, www.spm1d.org) was applied to compare the electromyographic activity (RFe, BF, MG, LG and TA) between running techniques (RF vs FF) during the stance and swing phase and its respective temporal variation in one dimension (1D). This was calculated using a threshold value estimated by SPM {t}, where the null hypothesis was rejected if the trajectory of the 1D data exceeded the critical value. The threshold t-value was estimated by using an α of 0.05, similarly to others (Moisan et al., 2020; Pataky et al., 2016; Yong et al., 2020). Our null hypothesis for each muscle measured was that there will be no differences in 1D sEMG data between the two different running techniques (i.e., RF and FF). All SPM analyses were implemented using the Python 3.5 software (Van Rossum, 2016). Moreover, a Shapiro Wilk test was performed to assess if the ratios between antagonist muscles (GAS/TA) for both techniques follow a normal distribution. Once the normality of this data set was confirmed, the ratios between the RF and

FF techniques were compared with a t-test or Wilcoxon for paired data. The level of significance α, was set at 0.05 (GraphPad 9v Software, San Diego, California, USA).

Results

SPM analysis - stance phase

For the MG muscle we observed that two supra-threshold clusters exceeded the critical value t' =4.195 at the beginning of the stance phase, indicating greater MG activity during FF running compared to RF running at the same time-instant (RF, initial contact; 0-13%, p<0.001 and 18-19.5%, p=0.041; figure 1). Similarly, for the LG muscle, two supra-threshold regions (critical value t' =4.138) were observed, suggesting greater activation of the LG muscle during the beginning of the stance phase, when the FF running technique was used (0-6%, p=0.008 and13.5-19%, p=0.012; figure 1). No significant differences between RF and FF running were observed in the activation of the RFe, BF, and TA muscles (figure 1) during stance phase (p>0.05).

SPM analysis - swing phase

For the MG muscle we observed that one supra-threshold region exceeded the critical value t' =4.593, suggesting a higher activation of the MG muscle at the end of the swing phase during FF running (66-100%, p<0.001). The LG muscle showed two supra-threshold regions which exceeded the critical value t' =4.704 (figure 1) at the end of the swing phase, suggesting a higher activation of the LG muscle during FF running (75-93% and 95-100%, both with p<0.001). Two infra-threshold regions were observed for the TA muscle, during the swing phase, one between 59% and 60% of the running cycle, and one between 82-94% (p=0.04 and p<0.001, respectively). Both exceeded the critical value t' =4.387, indicating a higher activity of the TA muscle when the RF running technique was used (figure 1). No differences in the activity of the RFe and BF muscles between the two running techniques were observed (p>0.05).

*** Add Figure 1 here, please***

Co-activation

Considering that the muscle activity of GAS and TA (antagonistic muscles), differed significantly between the two running techniques, the co-activation was calculated for the beginning of the stance phase (0-19%) and end of the swing phase (82-100%). The results showed a higher level of co-activation (both GAS/TA and TA/GAS) with the use of RF, described in both phases (stance phase: FF= 5.102 ± 3.95% vs RF= 14.76 ± 8.92%; 95% confidence interval= 3.38 to 15.93; p=0.0029; swing phase: FF= 8.56 ± 6.47% vs RF= 41.23 ± 20.94%; 95% confidence interval= 17.59 to 47.74; p=0.0007 figure 2)

*** Add Figure 2 here, please***

Discussion

We investigated temporal differences in muscle activity of a group of lower limb muscles (LG, MG, TA, RFe, and BF) during RF and FF running, using SPM. When comparing the two running techniques, SPM revealed differences in the muscle activity of the leg muscles (LG, MG, and TA), during both stance and swing phases of the running cycle. The SPM analysis revealed that the LG and MG muscles' activity was higher during FF running, for both the stance and swing phases. More specifically, in terms of the stance phase, temporal differences in the activation of MG and LG were identified at the initial contact (approximately between the 0-20% phase of the running cycle). This suggests that both the gastrocnemius heads were more active at the beginning of the stance phase (initial contact). This finding is in line with previous observations (Lieberman et al., 2010; Lucas-Cuevas et al., 2016; Xu et al., 2021) and likely suggests that both the MG and LG muscles significantly increase their activity during this phase of the running cycle, possibly to improve the control of the ankle joint at the initial contact of the forefoot with the ground. More specifically, this higher activation could improve the position of the leg-foot segments by placing it in a more plantar flexed position, which enables the absorption of the ground forces at the initial foot contact, through the decelerating eccentric (lengthening) contraction of those muscles and storage of elastic energy (Lieberman et al., 2010; Xu et al., 2021; Yong et al., 2020). Considering that a pre-activation phase was observed only during FF running and then there was a similar activation of the gastrocnemius muscles between FF and RF running (40-100% of the stance phase, or also described as impulse region), this could suggest that the gastrocnemius muscles are activated for a longer time during FF running. This is an interesting finding, and even though quite speculative, it could suggest that RF running does not sufficiently activate the triceps surae and could possibly explain a less use of elastic energy with the RF technique, as also proposed by others (Yong et al., 2020). Nonetheless, another strategy that could also be used by the RF technique to improve the stability of the ankle is to increase the co-activation between antagonist muscles, which could be a consequence of the greater time of contact of the foot with the ground (38% stance in RF vs 28% stance in FF, according to our results). This factor could be in concordance with a higher co-activation level observed at the beginning of the stance phase (0-19%).

Moreover, the SPM analysis revelated significant differences in the activation of the MG, LG and TA muscles between the two running techniques, at the end of the swing phase (i.e., between 80-100% of the running cycle). These findings could indicate that both gastrocnemius portions contribute to high mechanical demand developed during the final phase of the swing phase (temporally greater for MG, between 66 and 100%). This could be possibly seen as a pre-activation strategy, which aims to achieve the optimal foot position prior to initial contact. In this context, the findings from the MG are similar to those observed in a recent study, which reported a higher activation of this muscle with the FF technique, however, in a smaller range of the swing phase (91-100% of the running cycle) (Yong et al., 2020). For the TA muscle, the SPM analysis revealed two temporal regions during which TA muscle's activation was higher when the RF running technique was used, during the swing phase (between 59-60% and 82-94% respectively). This finding is likely related to the greater ankle dorsiflexion observed before the initial contact of the foot with the ground, preventing the drop of the forefoot during heel strike. The higher level of co-activation between GAS/TA observed during the swing phase with RF running, could also reflect a (stiffening) strategy to improve ankle control before of the initial contact of the foot with the ground. Previous studies have also reported similar findings, but their results were based on simple measures of centrality and dispersion (i.e., comparing mean values of EMG amplitude) and not based on SPM analysis which considers the full time series of a task (Clarke, Frederick, & Cooper, 1983; Lucas-Cuevas et al., 2016; Yong, Silder, & Delp, 2014). Therefore, these studies were not able to identify temporal differences in activation between running techniques. On the contrary, in the present study we were able to identify the exact time-instants where the EMG activity varied between running techniques, including thigh muscles that are not commonly investigated. This highlights the usefulness and the superiority of the SPM analysis compared to more simple statistical analysis approaches.

Moreover, considering the interesting differences in the muscle activity of the leg muscles during the stance and swing phase, in particular with use to the FF technique, it is important to mention that some studies have described that an increased gastrocnemius muscle activation also increases the stress in the muscle-tendon unit, causing a higher plantar flexor tendon energy storage (Yong et al., 2020). This could increase the work of the Achilles tendon (Kernozek, Knaus, Rademaker, & Almonroeder, 2018), potentially generating serious injuries related to the cyclical loading of the triceps surae muscle-tendon complex during long-distance running (Kernozek et al., 2018; Raichlen, Armstrong, & Lieberman, 2011; Yong et al., 2020). Thus, future studies should try to investigate the optimum training volume for FF running, since the cyclical demand on the Achilles tendon during a race can potentially induce muscle-tendon injuries to this region.

Importantly, there is currently only one study that has assessed the temporal variation of LG, MG and TA EMG amplitude during these two running techniques (Yong et al., 2020), however, without assessing the behaviour of the RFe and BF (thigh) muscles. With regards to the thigh muscles, our results indicated that their level of activation was similar between the two running techniques across the whole running cycle (i.e., during both the stance and swing phases) (figure 1). This could suggest that the mechanical adjustments required to perform each of these techniques, do not affect the behaviour (i.e., activation level) of the thigh muscles. This is an interesting finding, as each of the running techniques requires modification of the motion patterns across the lower limb joints (Xu et al., 2021), which could possibly alter the muscle activity levels of the muscles in this region. Contrary to this, our results showed that the RFe and BF muscles' activity did not differ between the two running techniques. However, this could be possibly attributed to the fact that the foot strike pattern has little biomechanical effect on the hip and knee joints during running, with the differences being more evident in the ankle-joint (Xu et al., 2021). Thus, this could partly explain the lack of differences for these two muscles (RFe and BF) between running techniques.

Lastly, some limitations need to be acknowledged. Firstly, the environment where the runners were evaluated did not represent the real place where they usually train. Secondly, all participants routinely used the RF technique, and therefore, they were exposed to the FF technique for the first time in this study and by a short time of evaluation. Although all participants were familiarised and trained with the FF technique prior to the recording, we cannot exclude the possibility that the results were affected by this issue to a certain extent. Future studies should aim to overcome this limitation by recruiting runners who routinely use both running techniques.

Conclusions

This study extends our knowledge about lower limb muscle activity during two commonly used running techniques by using SPM analysis, which allows the identification of the exact time-instants where differences in electromyographic activity exist. During FF running, a higher LG and MG myoelectric activity was observed at the beginning of the stance and at the end of the swing phases respectively. During RF running, at the same time-instant that higher MG and LG muscle activation was observed, i.e., during the end of the swing phase, the TA muscle's activity was also higher. Interestingly, we did not observe any differences in the activity of the RFe and BF muscles, strongly suggesting that these two running techniques predominately reflect adjustments of the shank and not the thigh muscles. These findings highlight the importance of SPM for the accurate assessment of differences in muscle activity during running, as this technique enables the identification of the exact time instants when statistical differences exist.

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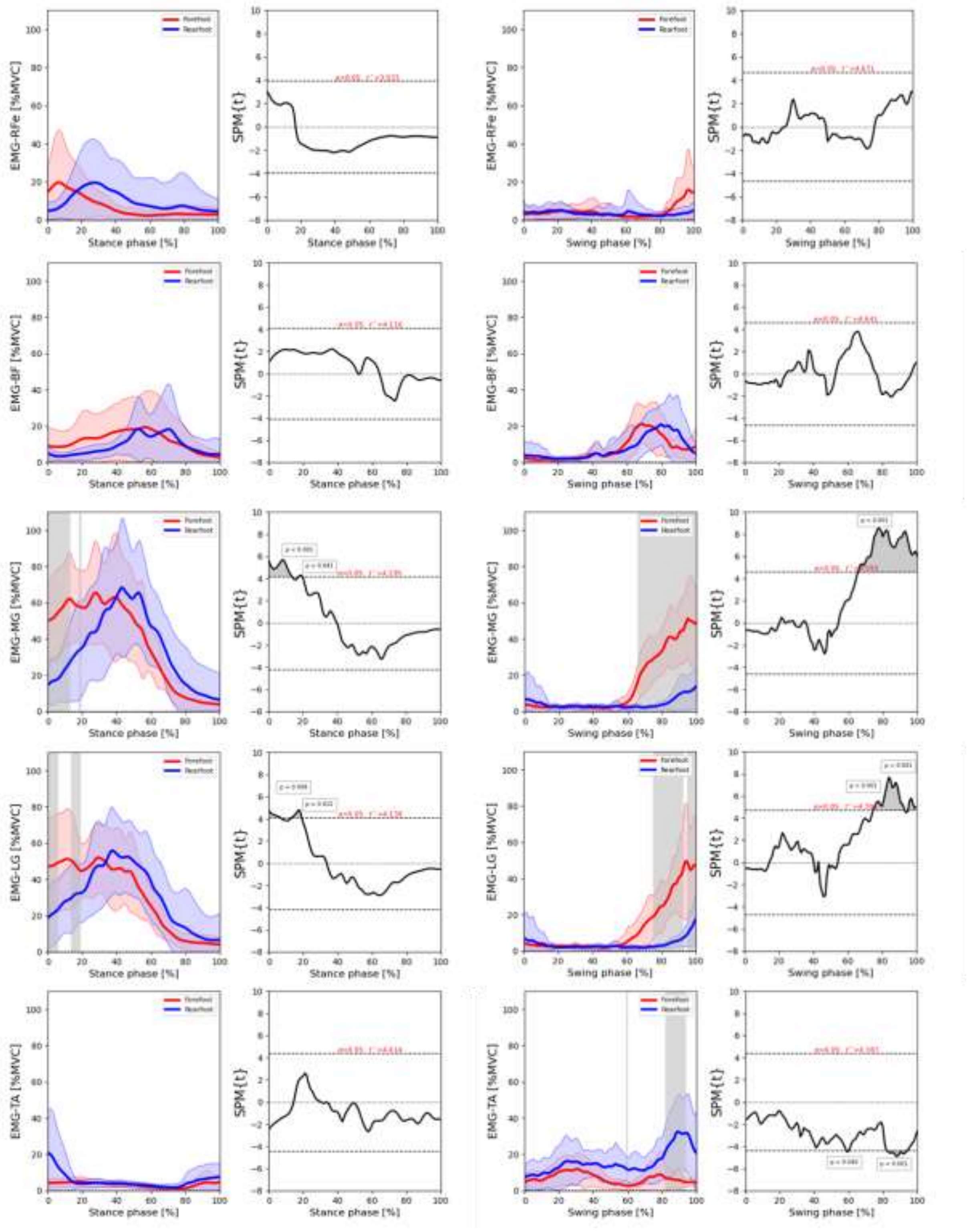

Figure 1: Shows the average activity of the rectus femoris (RFe), biceps femoris (BF), lateral gastrocnemius (LG), medial gastrocnemius (MG), and tibialis anterior (TA) adjusted by %MVC (from superior and inferior image). Statistical differences were analysed with SPM{t} between running techniques (rearfoot: blue; forefoot: red) during the stance (two columns of

the left) and swing phase (two columns of the right). Grey bars show the regions with statistical differences (p<0.05), concordant with the results of SPM{t}.

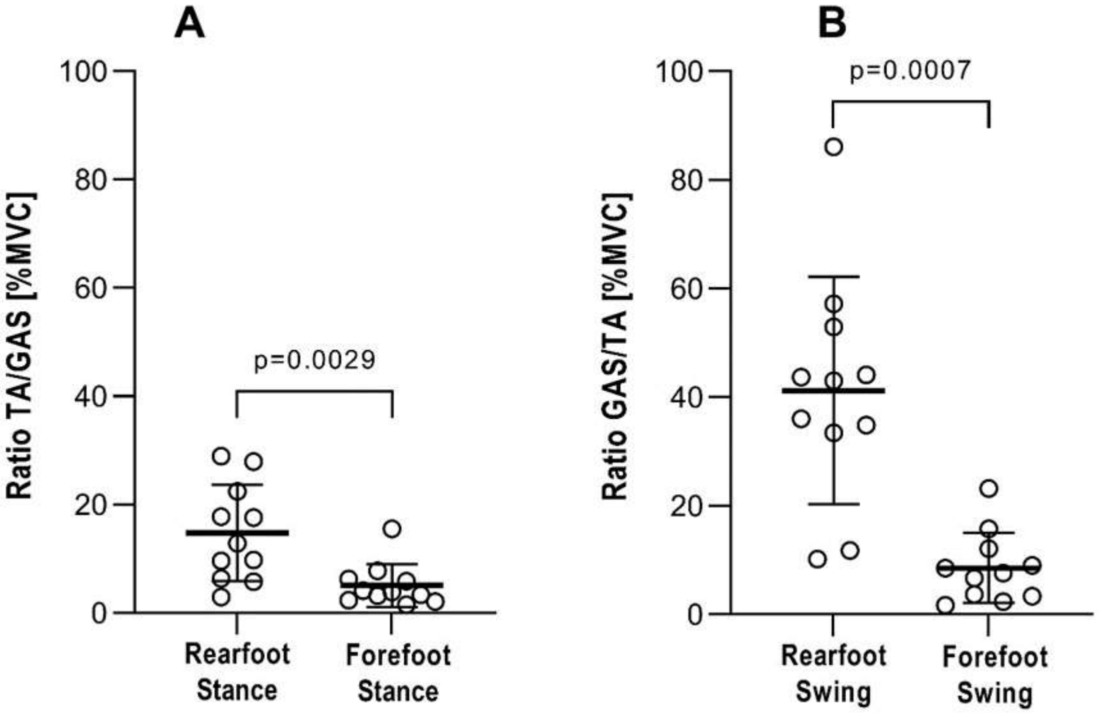

Figure 2: Shows the comparison between the coactivation percentages between the gastrocnemius muscles (GAS) and tibialis anterior (TA) during rearfoot and forefoot techniques, calculated on the regions where significant differences between running techniques were identified with SPM. Accordingly, the figure shows co-activation results at 0-19% of the stance phase (A) and 82-100% of the swing phase (B) phase. *p-value value is indicated in the figure.