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Amplitude of Biceps Femoris Activation and Triaxial Acceleration in a 50-Meter Test in Sprinters: Pilot Study

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Abstract: Objective: To describe the relationship between bilateral electrical activity in the biceps femoris and the variation of triaxial acceleration in three 50 m sprints. Methods: Biceps femoris muscle activation and acceleration in the anterior–posterior, mediolateral, and superior–inferior axes were measured in three 50 m sprints in nine national-level sprinters. Results: There was significant asymmetry between both legs, and the variations between axes were significant between the anterior–posterior with respect to the lateral and superior–inferior, and between the lateral and superior–inferior ($p < 0.05$). Conclusions: Increased biceps femoris activation during running increases speed regardless of asymmetry in force application. In the maintenance of horizontal velocity, acceleration of the anterior–posterior axis is the most relevant and depends on the flexion-extension muscle actions contained in the lateral axis.

Keywords: sport biomechanics; electromyography; accelerometry; exercise performance; sprint

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1. Introduction

In sports, an appropriate speed can define game actions or unbalance the initial equality of forces [1]. During running, it is necessary to counteract the negative and positive phases, the latter being accelerations [2] that are common in monostructural cyclic, acyclic, and mixed techniques in athletics [3].

Sprinting with anaerobic-alactic characteristics [4], whose maximum energy transfer occurs at usual conditioning distances [5] between 55 and 60 m for men and between 46 and 53 m for women [6], depends on the neuromuscular capacity to recruit the highest number of motor units per unit time for 4–5 s [7]. This is performed in confrontation with different resistances that converge (ground, gravity, and wind), where the reactive action of the support is the only modifiable one, varying the relationship between the braking and accelerating forces [8] (7 and 57%, respectively), leaving the rest (36%) for the flight phase.

In the optimization of this aspect, at a technical level, the increase in hip flexion of the free leg, whose range predicts the rest of the articular angles of the action, has an influence [9] on its different phases ($p < 0.001$), hip and knee extension of the supporting limb, and the trajectory of the center of gravity as influenced by horizontal forces [10], which experienced sprinters manage to remain constant throughout the course [11]. Babić et al. [12] indicate that good management of these elements means that the loss of speed in contact does not represent more than 2–3% of the total, while deficient management would raise this figure to 6%. This highlights the importance of contact, where the activation of the extensors must occur prior to support [13], giving more relevance to the eccentric phase to generate speed, which is something applied in supramaximal methods that is suitable for both increasing acceleration and mitigating injuries [14]. The change from knee extension to hip extension is the most critical moment [15].

These characteristics demand greater muscular tension [16], and on the positive side of acceleration, the knee extensors are synergistic, with greater efficiency at 60° flexion [17] in tandem with the hip extensors, the rapid contraction of which is decisive in the transition to impulsion [18]. In the first instance, the gluteus maximus acts, followed by the biarticular musculature, which is fundamental in transferring articular force in the proximal-distal direction [19]. The biceps femoris has an optimal capacity to adapt to training, and many fibers have mixed aerobic and anaerobic characteristics with high resistance to fatigue [20]. In addition, it can significantly reduce its contraction time with training; 19.5 ± 2.4 ms in trained subjects, with respect to sedentary subjects [21] (30 ± 3.5 ms). Their conditioning is not very important because of their size, as the length of the fibers is not a definitive factor in predicting the performance of an athlete [22] but rather by the tendon stiffness that it harbors to produce greater tension in the drive [23].

Surface electromyography (EMG) can detect this activation during running and is widely used in this field. Kyröläinen et al. [24], over three maximal sprints, determined that biceps femoris activation increased at the same time as the running speed [25] by generating a high elastic energy in the eccentric phase, which is released in the swing phase. Along these same lines, Kakehata et al. [26] indicate that the loss of activity of both the biceps femoris and the rectus femoris has an impact on the loss of velocity and step frequency. Its importance was confirmed by observing that it was much higher in contact mode (442 ± 123 μV) than in impulse mode (116 ± 37 μV), outperforming pre-activation before support [24] (343 ± 127 μV). Sigiura and Aoki [27] supported this argument by detecting a shorter contact time and greater activation of the biceps femoris at contact. Kyröläinen et al. [24] found that activation of the gluteus, biceps femoris, soleus, and gastrocnemius during running was much higher in this phase, even at maximum voluntary contraction.

In this line, Mero et al. [28] measured the electrical activity over a 45 m sprint in the gastrocnemius, biceps femoris, gluteus maximus, rectus femoris, and vastus lateralis, calculating the speed in m/s, contact time, impulsion and flight, also concluding that the force was greater in the eccentric phase (465 N) than in the concentric phase (338 N), without differentiating laterality.

In addition to electromyography, devices such as accelerometers are useful for objectification and optimization of running techniques. They combined kinematics and kinetics [29] to reflect the transmission of impact forces with a signal obtained using a transducer that picks up the position over time. They have been used for the detection of pitch symmetry or morphological stability [30–32], and their application to running would help to quantify total energy expenditure, neuromuscular fatigue [33], and the optimum ratio between amplitude and frequency [34], or to optimize the technique to assess whether the application of forces in the support is adequate for maintaining trajectories that allow for greater horizontal speed.

Despite the advantages of both instruments, biomechanical measurements in sprinting in official competitions have focused on the measurement of split times and average and maximum speed data, contact and flexion times of the knee in the damping phase [35–37], or more recently in the first steps of the acceleration technique without including maximum velocity momentum data [38]. The combined use of both devices would help not only in the calculation of activation patterns, but also in the identification of very long flight phases or decompensations between axes owing to the torque produced in the running technique.

Given the lack of background information on biceps femoris muscle activation and accelerometry in acceleration tasks, the purpose of this study was to describe the relationship between the electrical activity produced by each leg in the biceps femoris and the acceleration variation in each axis. Likewise, the relationship between the acceleration produced in the X, Y, and Z axes and the athlete's best record in competition was also examined. Finally, we quantified the relationship that the higher acceleration of an axis has on the final time with respect to the others.

Working on these variables will allow us to deepen our knowledge of a better acceleration technique by describing muscle activation, its level of symmetry in the application of force, and its role in the maintenance of maximum horizontal speed. Our hypothesis was that greater activation allows greater acceleration in the anterior–posterior axis, favoring running speed.

2. Materials and Methods

2.1. Participants

Three 50 m accelerations were performed to identify the change in muscle activation and triaxial accelerometry of national-level sprinters with at least three years of previous experience. Nine male athletes at the national level with experience in sprint and hurdle events participated in this study. The difficulty in finding a larger sample was due to the unavailability of more national-level athletes present in the same city and not wanting to run the risk of injury when performing the test; hence, the pilot study character. Anthropometric data are shown in Table 1.

Table 1. Characterization of the sample of sprinters participating in the study.

Variable	Quantification
n	9
Age (years)	20.77 ± 10.41
Weight (kg)	60.33 ± 10.12
Height (m)	1.73 ± 0.04
BMI (kg/m^2)	20.09 ± 2.35
Laterality	Dexterous (7) Left-handed (2)

Prior to the study, participants voluntarily signed an informed consent form to participate in the study. In this first contact with the athletes, they were informed about the convenience of wearing a garment covering at least two-thirds of the thigh (to fix the measuring device) and spike shoes (with a length between 6 and 8 mm) on the day of the test. Each athlete's coach was asked to give his or her subjective evaluation of the technical level of his or her athlete from 0 to 10 points and his or her best record in the 60 m dash.

All the procedures followed the guidelines of the Declaration of Helsinki for human clinical trials.

2.2. Procedure

Each participant underwent two anthropometric tests to calculate height and weight. In the case of height, the subject was placed barefoot in an upright bipedal position, manipulating the head until the Frankfort angle was reached, and the stadiometer was placed on the head (Seca 213, Hamburg, Germany) on the vertex. Weight was then calculated using a scale (Seca 803, Hamburg, Germany) for 2 s, and the body mass index was calculated by weighing both measurements. Additionally, they were asked which leg was dominant, following the criterion that the leg was located at the front of the cue start of the speed test.

They were instructed to perform a free competition warm-up appropriate to their habits. Vaz et al. [39] demonstrated that in a group of adolescents, the final mark in the 100 m did not differ between athletes who performed a specific warm-up and those who did not; therefore, the heterogeneity of the warm-up did not indicate differences in final performance.

Then, with a dermographic pencil, the point of placement of the electrodes on the biceps femoris was drawn for each athlete following these indications. From the initial standing position, the athlete placed one foot on a chair with a hip flexion close to 90°.

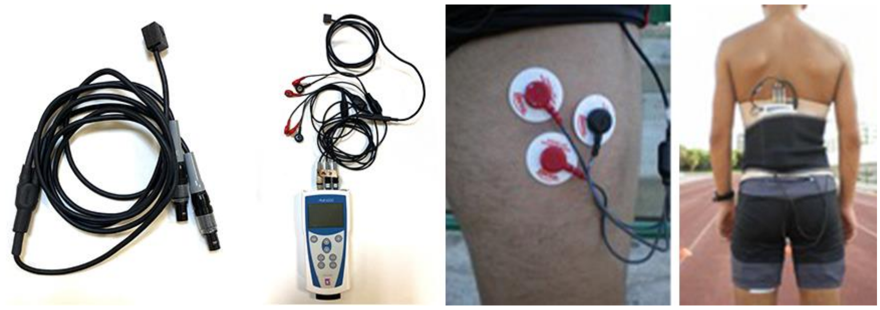
From this point, the ischium of the leg was markedwith the anthropometric tape at this point. Return to the initial position, leaving the foot on the ground without removing the hand from the strap and ischium, and tighten the strap by bringing it to the external lateral part of the popliteal fossa. Of the proximal distance between these two points, 35.3% were collected, resulting in an average of 12.74 ± 0.062 cm for the participants [40].

Then, with the subject in a standing position, the area where the electrodes were to be placed was wiped dry from any possible perspiration, using absorbent cotton. With alcohol impregnated in another portion of this material, the area was cleaned, and with a disposable razor, the area was shaved to avoid possible interference with the electrode adhesive and impedance distortions of the electrical signal. The area was cleaned with alcohol and dried with cotton to ensure that the skin was clean and dry. Electrodes were placed bilaterally on the biceps femoris, dorsally on the distal third of the femur, and obliquely.

In all cases, two electrodes were placed with a maximum separation of 2 cm on the muscle belly and a third (grounding) electrode was placed perpendicular to the previous electrodes. The model was a Lessa Pediatric Electrode with a diameter of 30 mm. These were placed as previously described by Rainoldi et al. [40].

For the electromyographic recording, the device used was the Megawin ME6000-T8 (Bittium Corporation, Oulu, Finland), 8-channel, with a weight of 344 g. The sampling frequency was 1 kHz, and each stored recording lasted for 30 s. It was deposited in a breathable multiband elastic fabric belt with a Velcro closure (size L 95–105 cm and width 25 cm).

For acceleration, a triaxial accelerometer model VP00355-6G/3D (Bittium Corporation, Oulu, Finland) was used to record the data at 1 kHz, integrated with the Biomonitor Megawin ME6000-T8 (Figure 1), and was fixed to the body with adhesive tape so that it would not move from the reference point (lumbar vertebra 3). Both the devices were calibrated according to the manufacturer's recommendations.



(**1**) (**2**) (**3**) (**4**)

Figure 1. Placement of electrodes and final equipment. From left to right: (**1**) accelerometer, (**2**) EMG and accelerometer, (**3**) electrode arrangement, and (**4**) final placement.

After the data were recorded, they were converted from analog to digital formats (12-bit; DAQCard–700; National Instrument, Austin, TX, USA) using Biomonitor Megawin ME6000-T8 software (v 3.1.) and were saved on a hard disk for protection and subsequent analysis in files with the extension .ASC. For signal analysis, a specific program was used, MATLAB (R2024a) (MathWorks Inc., Natick, MA, USA).

First, a fourth-order Butterworth bandpass filter was applied between 20 and 400 Hz for the electromyographic signal filtering and between 1 and 20 Hz for the accelerometer. Subsequently, the signal was rectified, or the root mean square (RMS), by dividing the measurement section into 100 points. The signal was measured by considering its amplitudes, using the most stable part of the signal between the 3rd and 5th seconds of data acquisition. Finally, records were collected in a smoothed form using the smooth-data function.

Three 50 m sprints were performed on the athletics track at the maximum speed, a distance in line with the 60 m indoor track and field competition, in which the participating athletes had average marks of 6.81 ± 0.05 s. The proposed interval between each series was

8 min, during which complete recovery was performed to avoid fatigue [41]. While some participants decided to remain calm and active before the next sprint, others opted for a more active recovery based on a 1–2 min continuous run at the end of each sprint.

2.3. Statistical Analysis

Statistical analysis was performed using the SPSS software version 26 (SPSS Inc., Chicago, IL, USA). A descriptive analysis was conducted that required the Mann–Whitney test for the inter-leg dominance study. The non-parametric Spearman's rho correlation was used, with a reduced sample size, to determine the influence of acceleration of the anterior–posterior, lateral, and superior–inferior axes. The same test was used to describe partial correlations that may influence the main correlation and determine whether the coach's criteria coincided with the best performance of the athletes. Similarly, the Kruskal–Wallis nonparametric test was used to test the differences in acceleration of the different axes.

Statistical significance was set a priori at $p < 0.05$.

3. Results

3.1. General Descriptions

The values obtained in the nine subjects studied ranged from 329.90 to 443.69 µV for the dominant leg and 318.61 to 356.17 µV for the non-dominant leg. Table 2 details the activation of both legs. The data show the averages of the records of the three series of 50 m run, with the values of the electrical activity of the biceps femoris.

Table 2. EMG values in the dominant and non-dominant legs of each participant.

Subject	Dominant (µV)	Non-Dominant (µV)
1	350.46	354.13
2	388.84	318.61
3	434.12	320.08
4	443.69	345.98
5	393.18	339.83
6	344.64	328.80
7	329.90	341.98
8	353.05	325.88
9	384.62	356.17
Average (SD)	380.279 (39.715)	336.829 (14.095)

Note: µV = Microvolt.

Regarding the accelerations obtained in the anterior–posterior, lateral, and superior–inferior axes, their results in G (1 G = 9.80 m/s) are shown in Table 3.

Table 3. Acceleration in the anterior–posterior (AP), mediolateral (ML), superior–inferior (SI), and superior–inferior (SI) axes.

Subject	AP (G)	AP (m/s^2)	ML (G)	ML (m/s^2)	SI (G)	SI (m/s^2)
1	1.55	15.20	1.86	18.24	1.38	13.53
2	1.47	14.42	1.81	17.75	1.40	13.73
3	1.39	13.63	1.76	17.26	1.37	13.44
4	1.26	12.36	1.67	16.38	1.28	12.55
5	1.24	12.16	1.67	16.38	1.18	11.57
6	1.24	12.16	1.68	16.48	1.09	10.69
7	1.24	12.16	1.68	16.48	1.00	9.81
8	1.31	12.85	1.68	16.48	0.99	9.71
9	1.32	12.94	1.68	16.48	1.01	9.90
Total	1.33	13.04	1.68	16.48	1.19	11.65

Note: AP = Anterior–posterior. ML = Mediolateral. SI = Superior–inferior. G = Gravity force. m/s^2 = meters per second squared.

3.2. Differences in Averages

3.2.1. Difference of Averages between Axes

When studying the differences between the accelerations in the different axes, the Kruskal–Wallis test yielded differences ($p < 0.001$) between all of them (Table 4).

Table 4. Descriptive statistics and differences between the three axes.

	N	Average (G)	Average (m/s^2)	SD (G)	SD (m/s^2)
Acceleration AP RMS	9	1.3337 *	13.079	0.11175	1.096
Acceleration ML RMS	9	1.7023 **	16.694	0.08483	0.832
Acceleration SI RMS	9	1.1884	11.654	0.17284	1.695

Note: * Indicates a significant difference ($p < 0.05$) between AP-ML and AP-SI. ** Significant difference ($p < 0.05$) between the ML-SI. AP = Anterior–posterior. ML = Mediolateral. SI = Superior–inferior. RMS = Root mean square. G = Gravity force. m/s^2 = meters per second squared. SD = Standard deviation.

3.2.2. Mean Difference in EMG Activity as a Function of Leg Dominance

The Mann–Whitney U test showed significant differences ($p < 0.01$) between the muscle activation of both legs during the attempts. Table 5 presents the average values for each leg. The differences between the legs of the nine subjects are shown graphically (Figure 2).

Table 5. Mean EMG (RMS) and statistical differences between both legs.

Dominance	Average	Standard Deviaton
Dominant	380.2793 *	39.71530
Non-dominant	336.8291	14.09551
Total	358.5542	36.54453

Note: * Indicates a significant difference ($p < 0.05$) between the dominant and non-dominant legs.

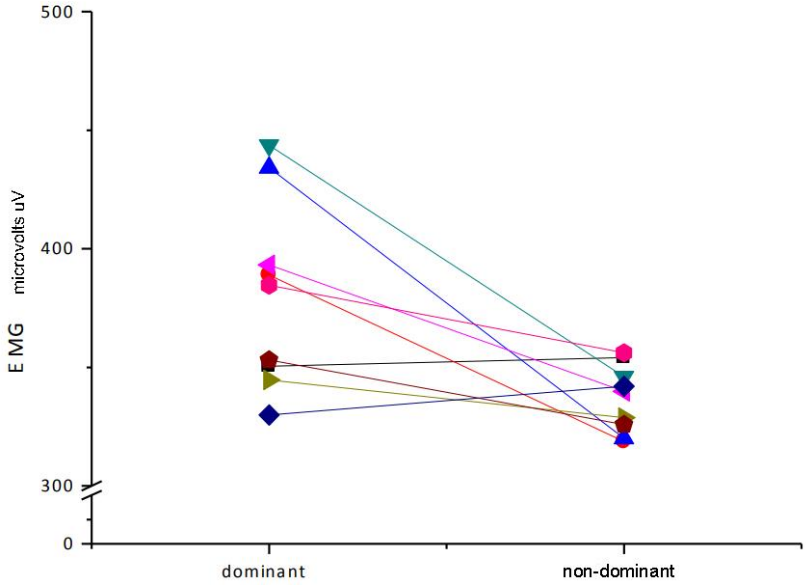


Figure 2. Description of the EMG of each leg by subject. Each color represents the research subjects with their dominant and non-dominant legs.

3.2.3. Differences According to Technical Quality

A Mann–Whitney U test was performed to determine whether differences were established in any of the acceleration axes depending on the technical quality defined by the trainer; however, no significant differences were found ($p > 0.05$) (Table 6).

Table 6. Differences according to acceleration and technical quality of participants.

Technical Quality		Acceleration AP (RMS)	Acceleration ML (RMS)	Acceleration SI (RMS)
>7 Points	Average	1.453	1.663	1.135
	SD	0.224	0.0201	0.118
<7 Points	Average	1.569	1.733	1.230
	SD	0.198	0.106	0.210
Total	Average	1.518	1.702	1.188
	SD	0.212	0.084	0.172

Note: AP = Anterior–posterior. ML = Mediolateral. SI = Superior–inferior. RMS = Root mean square.

3.3. Correlations

The correlation study between the different accelerations showed positive relationships ($p > 0.05$) between lateral acceleration and superior–inferior acceleration. The correlations between the best competition times of each subject over 60 m and the acceleration on the different axes are as follows:

Relationship between the best time and acceleration in the anterior–posterior axis: A non-parametric correlation was established using Spearman's rho, with a correlation coefficient of 0.238; both variables shared 5% of their variances, with a significance level of 0.570.

Relationship between best time and acceleration in the lateral axis: The correlation coefficient is 0.048; they share 0.2% of their variances, and their significance level is 0.911.

Relationship between personal best and acceleration in the superior–inferior axis: The correlation coefficient was 0.190, and they coincided with 3% of their variances, with a significance level of 0.651. Table 7 presents the results of this study.

Table 7. Correlations between the accelerations of the different axes and the best time obtained in the 60 m competition.

		Acceleration AP RMS	Acceleration ML RMS	Acceleration SI RMS	Personal Best
Acceleration AP (RMS)	Correlation coefficient	1.000	0.467	0.633	0.238
	Sig. (bilateral)	.	0.205	0.067	0.570
Acceleration ML (RMS)	Correlation coefficient	0.467	1.000	0.867 **	0.048
	Sig. (bilateral)	0.205	.	0.002	0.911
Acceleration SI (RMS)	Correlation coefficient	0.633	0.867 **	1.000	0.190
	Sig. (bilateral)	0.067	0.002	.	0.651
Personal best	Correlation coefficient	0.238	0.048	0.190	--
	Sig. (bilateral)	0.570	0.911	0.651	--

Note: ** The correlation is significant at a 0.01 level (bilateral). AP = Anterior–posterior. ML = Mediolateral. SI = Superior–inferior. RMS = Root mean square.

The anterior–posterior axis, although small and insignificant, was the largest of the three axes studied. A positive sign indicates that as one variable increases, the other will also increase. This finding is relevant, although the results were not significant because they indicate that activation in the biceps femoris tends to favor a higher horizontal speed that could optimize running time.

4. Discussion

Velocity is defined as a fast component of force [20], establishing a direct relationship between the gain of one force and the increase in the other after a specific job [42]. Considering that the aim of the study was to calculate the biceps femoris muscle activation and triaxial acceleration in a 50 m sprint, it can be said that the results of muscle activation indicated that the highest acceleration in the axes was obtained with significant electrical activity values, regardless of whether they occurred in a compensated manner between both legs. This may be due to the difference in joint angulation and the resulting torque, which is different for each athlete [43], and is a common phenomenon even in other sports [44]. Over time, it has been shown that the bilateral force is always lower than that produced by the sum of the force produced with both legs and reduces its generic activation [45,46]; however, in experienced practitioners, these decompensations tend to be moderate [47–49] and must be worked specifically in the case of the biceps femoris owing to the behavior it demands during running [50]. Runners with greater muscle activation, regardless of whether there is a deficit in strength between both legs, achieve better results in the final mark by expressing greater strength, which can directly influence the best disposition for speed development [46,48]. González and Rivas [51] established a classification of sports that includes sprinting in the scale of practices that require strength conditioning based on high and very high dynamic loads, reflecting the need not for total symmetry between limbs, as in this work, but for the ability to generate force in a unit of time.

The results in some of the cases it are in line with Kyröläinen et al. [24] and probably not in more subjects because of the small sample. This author exposed 442 $\pm$ 123 μV in the eccentric phase of the contraction, data similar to that of this study (443.69 μV), although it is not possible to differentiate in this case whether it refers to the eccentric or concentric phase. They are also in line with Girard et al. [52], who found an increase in this activation at the beginning of a sprint over 30 m, emphasizing the fact that this increase in tension must be duly monitored and accompanied by a preventive process [16], given the instability of its strength during an athletic season [53], which indicates that it should be integrated into training in a double facet, such as technical work and preventive tasks.

From a kinematic point of view, angular or curvilinear movements are involved in the displacement of the stroke [29], the axes of which are the references for describing rotations in motion [54]. They are perpendicular to each other, and as one dominates over the others, the moments of inertia will be greater in one with respect to the others; therefore, it is important to understand their interactions. Significant differences were found in the different axes, especially in the anterior–posterior axis ($p < 0.05$), the main axis in directing the stroke, which depends, among other factors, on the relative speed of the foot in the stance and the direction in which the rest of the body parts move [55], followed by the lateral and superior–inferior axes, which reflect the relationship between them.

However, the one with the highest value corresponds to the lateral direction; it dominates over the others in this type of maximum intensity effort, which is in line with studies that have implemented IMU systems and have verified that maximum speed occurs in actions with a fast combination of joint flexion and extension [56]. This pattern has been confirmed in other sports, such as the study by Tella et al. [57], in which a greater relationship was found between the activity of both arms with respect to the acceleration of the subject in water. Although this is a known fact, it confirms that an active search for the ground in the race will favor a higher horizontal speed, highlighting the importance of the development of the contractile capacity of this musculature for trainers, who must design specific tasks to achieve this objective (unilateral work, inertial loads, etc.).

The availability of these data is of great relevance, since the bibliography consulted only considered the use of one device or another when González et al. [58] showed that running accuracy with the use of the accelerometer alone decreases in the absence of EMG. Therefore, it is necessary to analyze each phase of the running cycle with contrasting instruments to correct widespread errors in this sport, such as thinking that a technical error is only due to poor physical condition.

5. Conclusions

It has been confirmed in the literature that athletes with greater muscle activation are more efficient, regardless of whether it occurs symmetrically [28], as is the case in this study, which is an aspect of low technical influence. In this case, it cannot be applied to women, and it would be interesting to conduct this comparison, which is a limitation of this study.

Second, acceleration in the anterior–posterior axis is the most relevant; it helps achieve better times in competition than the superior–inferior axis. This depends on the acceleration in the lateral axis; therefore, an increase in this axis (hip flexors and extensors) will improve athlete performance. This explanation could be further detailed and visualized using results from a larger sample, which we hope will be obtained in future research.

Although it is not possible to generalize the results owing to the small sample size, it can be confirmed that this opens a research avenue for the optimization of the running technique, with the possibility of deriving a master's program that detects activation and speed thresholds to facilitate technical feedback to the athlete. This could be feasible by calculating the time delay in achieving maximum activation between the ipsilateral and contralateral muscle groups and determining the ideal time threshold to consider that a running technique is adequate.

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