Analysis of Muscle Activation of The Lower Limbs in Variations of Footwork Pilates Exercises

Análise da Ativação Muscular dos Membros Inferiores nas Variações do Exercício de Footwork do Pilates

Análisis de la Activación Muscular de los Miembros Inferiores en Variaciones de Ejercicios de Pilates con Footwork

RESUMO
O método Pilates pode ser realizado em solo ou com aparelhos equipados por molas, como o Reformer. Os exercícios para os pés (footwork) realizados no Reformer podem ter três variações do contato dos pés com a barra do aparelho, o apoio da ponta do pé, do meio do pé e do calcanhar. O objetivo do estudo foi analisar as diferenças na ativação muscular do membro inferior, em diferentes posições dos pés, no exercício de Footwork, do método Pilates, no Reformer. 25 universitários saudáveis, que não praticavam Pilates, foram avaliados por anamnese, exame físico e a atividade elétrica muscular do membro inferior direito (Eletromiógrafo, 8 canais). Durante a eletromiografia, o exercício de Footwork foi realizado no Reformer, com variações do pé na ponta, meio e calcanhar na barra. A ativação elétrica dos músculos vasto medial, vasto lateral, reto femoral e bíceps femoral foi semelhante, independente da posição dos pés. Porém, o músculo tibial anterior teve maior ativação no apoio do calcanhar. O fibular longo, gastrocnêmio e sóleo foram mais ativados quando os dedos foram apoiados no Reformer (em ponta). O estudo contribuiu para uma melhor compreensão da ativação muscular durante os exercícios de Pilates e pode auxiliar a prescrição terapêutica mais individualizada dos exercícios de Pilates para reabilitação e desempenho.
DESCRITORES: Técnicas de exercício e de movimento, Eletromiografia, Serviços de fisioterapia, Extremidade inferior.

SUMMARY
The Pilates method can be performed on the mat or with spring-equipped machines, such as the Reformer. Footwork exercises performed on the Reformer can have three variations of foot contact with the machine's bar: the toes, the mid-foot, and the heel. The aim of the study was to analyze the differences in lower limb muscle activation in different foot positions during the Footwork exercise of the Pilates method on the Reformer. Twenty-five healthy university students who did not practice Pilates were evaluated through anamnesis, physical examination, and electrical muscle activity of the right lower limb (Electromyograph, 8 channels). During the electromyography, the Footwork exercise was performed on the Reformer with foot variations on the toes, mid-foot, and heels on the bar. The electrical activation of the vastus medialis, vastus lateralis, rectus femoris, and biceps femoris muscles was similar, regardless of the foot position. However, the anterior tibial muscle showed greater activation when the heel was in contact with the bar. The long fibular, gastrocnemius, and soleus muscles were more activated when the toes were in contact with the Reformer (on tiptoe). The study contributed to a better understanding of muscle activation during Pilates exercises and may assist in more individualized therapeutic prescription of Pilates exercises for rehabilitation and performance.
KEYWORDS: Exercise and movement techniques, Electromyography, Physiotherapy services, Lower extremity.

RESUMEN
El método Pilates puede realizarse en el suelo o con aparatos equipados con resortes, como el Reformer. Los ejercicios para los pies (footwork) realizados en el Reformer pueden tener tres variaciones del contacto de los pies con la barra del aparato: la punta del pie, el medio del pie y el talón. El objetivo del estudio fue analizar las diferencias en la activación muscular del miembro inferior en diferentes posiciones de los pies durante el ejercicio de Footwork del método Pilates en el Reformer. Veinticinco estudiantes universitarios saludables que no practicaban Pilates fueron evaluados mediante anamnesis, examen físico y actividad eléctrica muscular del miembro inferior derecho (electromiógrafo, 8 canales). Durante la electromiografía, el ejercicio de Footwork se realizó en el Reformer, con variaciones del pie en la punta, el medio y el talón sobre la barra. La activación eléctrica de los músculos vasto medial, vasto lateral, recto femoral y bíceps femoral fue similar, independientemente de la posición de los pies. Sin embargo, el músculo tibial anterior mostró una mayor activación cuando el talón estaba en contacto con la barra. El fibular largo, el gastrocnemio y el sóleo fueron más activados cuando los dedos de los pies estaban en contacto con el Reformer (de puntillas). El estudio contribuyó a una mejor comprensión de la activación muscular durante los ejercicios de Pilates y puede ayudar en la prescripción terapéutica más individualizada de los ejercicios de Pilates para la rehabilitación y el rendimiento.
PALABRAS CLAVE: Técnicas de ejercicio y movimiento, Electromiografía, Servicios de fisioterapia, Extremidad inferior.

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INTRODUCTION

The Pilates method was developed in Germany in the early 1920s by Joseph Hubertus Pilates, under the name "Contrology" or conscious control of body movements through the mind. [1] It is a training and rehabilitation method that presents a series of systematized exercises, which can be performed on the ground or on devices with springs that impose external load on the muscles. [2,3,4] The most commonly used equipment in Pilates are the Chair, the Cadillac, the Barrel and the Reformer. [5] The Reformer consists of a horizontal sliding platform, which allows the individual to perform spring-resistance exercises and control their body while moving in various planes. [6] The method presents a wide range of exercises that can be performed using the equipment. However, when it comes to rehabilitation of the lower limbs, footwork is included in the main group of exercises performed. They are characterized by flexion-extension of the hips and knees, while the feet remain on the support bar of the equipment in variations of support on the tip of the foot, midfoot and heel. [7] However, even with the undeniable popularization and diffusion of Pilates, there is still little published information with scientific evidence regarding the muscular activity associated with the biomechanics of a joint during the exercise of the aforementioned method. And the information in this regard is of great value to Physiotherapy professionals, as it allows them to improve their clinical prescription, with regard to musculoskeletal rehabilitation with Pilates.

And the most effective way to assess muscle activity in certain movements is surface electromyography (sEMG) 8, because data acquisition with the electromyograph allows the collection of information such as the co-contraction index of different muscles simultaneously, which makes it possible to know the data on the pattern of muscle coordination during the gesture of the exercise analyzed. [9]

Regarding how evidence of the applicability of electromyography in relation to the biomechanical analysis of movements during exercises can help to develop broader reasoning, a study by Barbosa et al.[10] is cited, in which the authors evaluated the activation

of the rectus abdominis, transverse abdominis, and internal oblique muscles during trunk flexion, with and without the Pilates breathing technique. The hypothesis of this study was that these muscles would be more recruited during the breathing technique, but it was concluded that the breathing technique of the method, associated with trunk flexion, increased the electromyographic activity in the transverse abdominis and internal oblique muscles. This suggests that breathing played an important role in muscle activation and that the transverse abdominis muscle may present stronger contraction during maximum expiration, although muscle strength was not evaluated.

In this way, electromyography could contribute to the understanding of the best way to perform Pilates exercises to work specific muscle groups. This information could be useful for the clinical prescription of Pilates exercises. However, to date, there is no information available in the literature on muscle activation of many Pilates exercises. The footwork exercise, for example, which occurs with variations in foot positioning, has not yet been described through an electromyographic analysis.

The need for investigations into the electromyographic levels and patterns of Pilates exercises is highlighted, especially given the widespread popularity of the method and the growing commercialization of equipment. [6,11] Since footwork exercise is commonly used for musculoskeletal rehabilitation of the lower limbs, the importance of analyzing muscle activation during this exercise is evident. Therefore, the objective of this study was to analyze the electromyographic activation of the quadriceps, triceps surae, tibialis anterior, peroneus longus and biceps femoris muscles in variations of the footwork exercise performed on the Reformer.

METHOD

Study type and participants

This is a cross-sectional study that used a convenience sample of 25 healthy university students. The inclusion criteria were to be 18 years of age or older, not to practice or have practiced Pilates, and not to require assistance to walk.

The study was previously approved by the Ethics Committee of the XXXX University CAAE: 14139119.0.0000.5060; Opinion Number: 3,411,591. All individuals read and signed the Free and Informed Consent Form (FICF). The data collection was carried out at the Physiotherapy Gymnasium of the XXXXX Interprofessional Health School Clinic, in the city of XXXX.

Assessment instruments

The individuals underwent a physiotherapeutic evaluation, consisting of a brief anamnesis and sociodemographic data such as gender, age, education and marital status. The Visual Numeric Scale (VNS) was applied, graded from zero to ten, in which zero means no pain and ten, the worst imaginable pain. [12] Anthropometric characteristics such as shoe size, weight and height were collected. In addition, vital signs (blood pressure, oxygen saturation, heart rate and respiratory rate) were assessed.

To categorize the level of physical activity, the short version of the International Physical Activity Questionnaire (IPAQ) was applied. [13] Individuals answered questions estimating the time spent per week in different dimensions of physical activity, such as walking and physical exertion between light, moderate and vigorous intensities. The IPAQ physical activity level classification is divided into: very active, active, irregularly active A, irregularly active B and sedentary.

The Modified Borg Scale was also applied to obtain the classification of subjective perception of effort, before and after performing the footwork exercise. The BORG scale assesses the intensity of effort according to the individual's perception, which is classified by symptoms in a table numbered from 0 to 10, with 0 representing no symptoms and 10 representing maximum symptoms. [14]

Research protocol

After the anamnesis and physical examination, a surface electromyographic evaluation was performed. The procedures recommended by Surface ElectroMyoGraphy for Non Invasive Assessment of Muscles (SENIAM) were used as a reference. [15]

Regarding electromyography collection, a Miotec® (New Miotool Wireless/USB®) biological signal acquisition module with eight channels and analog inputs was used. The signals were collected at a frequency of 2,000 samples per second, in USB mode and with frequency band filters between 20 Hz (high-pass filter) and 450 Hz (low-pass filter), with NOTCH of 60 Hz. Two surface electromyography electrodes (Medix Brasil, EMGs) with fixation adhesive were fixed in the center of the muscle belly with a distance of 20 mm between them and parallel to the muscle fibers, after adequate cleaning with 70% alcohol in the region. [16] The reference electrode was positioned on the right lateral malleolus.

Muscle activation was measured using 8 channels of the electromyograph on the right lower limb during the Footwork exercise [7], in the 3 foot positions: supported on the tip, middle and heel, on the equipment bar. The muscles evaluated were Rectus Femoris (RF), Vastus Medialis (VM), Vastus Lateralis (VL), Tibialis Anterior (TA), Peroneus Longus (PL), Gastrocnemius (GL), Soleus (SO) and Biceps Femoris (BF). All volunteers were individually analyzed by triplicate of the maximum voluntary isometric con-

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traction (MVIC) test of the muscles evaluated.

Before the assessment, the individual was positioned on the Reformer with their feet resting on tiptoe on the equipment bar to perform knee joint goniometry using a manual goniometer. The angle determined for this study ranged from 60º to 90º with the knee flexed. When positioning the individual to perform the footwork exercise, instructions from the collection protocol were given to push the bar by sliding the equipment and return by bending the knees. The proposed rhythm was 14 bpm, through the metronome application, with the objective of controlling and adapting the individual's speed. The Reformer used in the research (New Pilates) has 5 springs, 4 of which have different elastic constants (13.8 kg, 10.4 kg, 51.4 kg and two of 52 kg) and are original to the equipment. The resistance of the springs was set according to the individual's feedback. The exercise should be performed with the maximum resistance level supported by the individual. Five springs were placed in each exercise attempt and, based on the volunteer's feedback on their effort to perform the exercise, the number of springs to be used was defined.

Electromyographic collection during footwork exercise on the Reformer

The footwork exercise consists of a series of lower limb exercises in which variations in foot positioning are performed: on tiptoe, midfoot and heel. The first collection was performed with support on the tiptoe, lasting a total of 1 minute and 45 seconds. During this period, the volunteer had to perform 20 cycles in which he pushed the bar towards knee extension and then returned to flexing the knee. After finishing the series with support on the tiptoe, there was a 3-minute rest until the second series began. The second series was performed with support on the midfoot, following the same protocol and rest. In the third series, support was on the heel, following the same protocol and at the end of the exercise, the BORG scale was reapplied (Figures 1 and 2).

Figure 1. Positioning of the feet in the Footwork exercise on the Reformer with the knees flexed. A) Support on the tip of the foot B) Support on the midfoot C) Support on the heel.

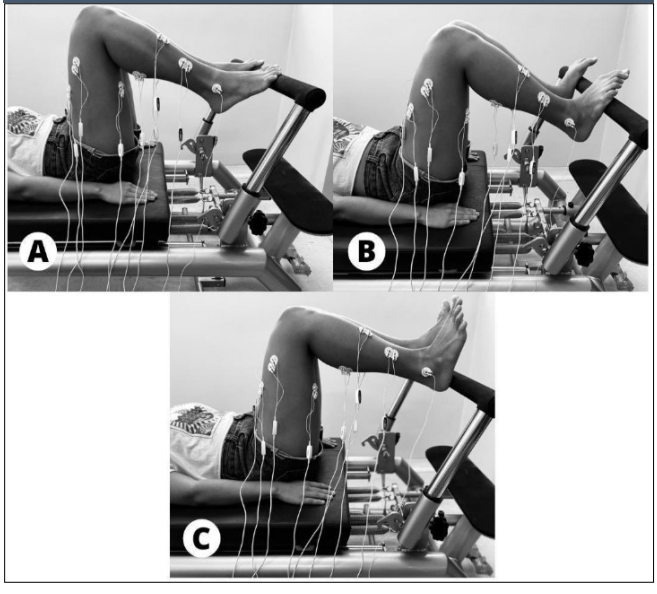
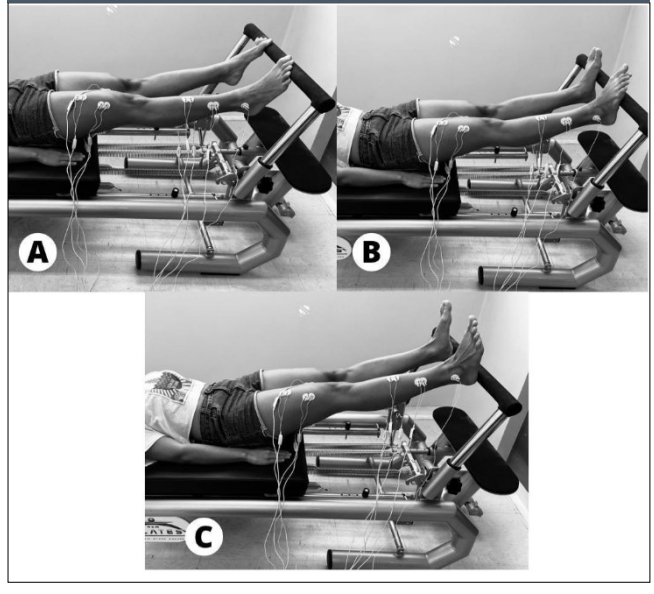


Figure 2. Positioning of the feet in the footwork exercise on the Reformer with the knees extended. A) Support on the tip of the foot B) Support on the midfoot C) Support on the heel.



Statistical analysis of data

Maximum voluntary isometric contraction (MVIC) was used as a standard value for normalizing the muscle activity values obtained in the tests. In this way, these values can be compared independently of strength, since they compare muscle electrical activation and not muscle strength between individuals. Thus, the signals obtained during the activity were reported as a percentage of their maximum activity (%MVIC). Statistical analysis was performed using the GraphPad Prism 5 program. The results were demonstrated by mean ± standard deviation (SD), absolute and relative frequency. The normality of the data was assessed using the Shapiro Wilk test. The variation in muscle activation in the tip of the foot, midfoot and heel was assessed by one-way ANOVA with Bonferroni post hoc. p was considered significant when less than 0.05.

RESULT

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Most of the twenty-five (n=25) participants were female (76%), with a mean age of 23 years and mean weight of 67 kg. According to the mean BMI, all selected individuals were overweight. The majority of the sample self-identified as white (56%). The IPAQ results showed that most individuals were very active (60%). The characteristics of the 25 volunteers are summarized in Table 1.

Table 1. Characteristics of participants submitted to analysis of electromyographic activation of the muscles of the right lower limb during the execution of the Pilates Footwork exercise (n=25).

Variable	Mean	SD
Age (years)	23	1,63
BMI	25,25	6,02
Weight	67,09	16,51
Height	1,63	0,07
Feet size	37,52	2,63
Gender	Fa	Fr (%)
Female	19	76
Male	6	24
Marital status		
Single	25	100
Others	0	0
Race		
White	14	56
Brown	6	24
Black	5	20
Dominant member		
Right	21	84
Left	4	16
IPAQ		
Very active	15	60
Active	2	8
Irregularly active	8	32
Sedentary	0	0
Sleeping Habits		
Good	10	40
Regular	2	8
Bad	8	32
Smoking habits		
Yes	2	8
No	23	92
Alcoholic Habits		
Yes	8	32
No	17	68
Use of medicines		
Yes	10	40
No	15	60

Sample number (n); Absolute frequency (aF); Relative frequency (rF); Standard deviation (SD); Body mass index (BMI); International Physical Activity Questionnaire (IPAQ); Source: authors' production.

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Before performing the footwork exercise, the average degree of effort of the individuals was 0 and after performing the exercise, the average degree of effort was 4±1.6 (Borg Scale) (data not shown in table).

The electromyography results demonstrated that the activation of the Rectus femoris, Vastus medialis and Vastus lateralis muscles, regardless of the positioning of the feet, remained similar. The activation of the Tibialis anterior was greater in the heel support position. The activation of the Peroneus longus, Gastrocnemius lateralis and Soleus were greater in the tiptoe position. The activation of the Biceps femoris did not present a significant difference between the positions of the foot on the Reformer bar (Table 2).

Table 2. Analysis of the electromyographic activation of the muscles of the right lower limb, during the execution of the Footwork exercise on the Reformer, in variations of support on the tip of the foot, middle and heel (n=25).

Muscles	Tip of the foot		Mid of the foot		Heel		
	Activation (%)	SD	Activation (%)	SD	Activation (%)	SD	P
Rectus femoris	19,75	9,84	18,78	8,77	22,61	10,78	>0,5
Vastus medialis	33,38	17,99	32,34	19,45	36,69	22,52	>0,5
Vastus lateralis	44,04	28,75	43,28	33,87	51,44	40,84	>0,5
Tibialis anterior	24,98*+	36,8	12,38	17,26	29,92#	14,25	<0,05
Peroneus longus	32,79*+	18,24	8,24	6,14	14,26#	7,53	<0,05
Biceps femoris	6,658	2,673	5,15	2,53	5,12	2,15	>0,5
Gastrocnemius lateralis	22,34*+	11,02	6,01	4,06	7,21	4,73	<0,05
Soleus	30,81*+	13,27	12,44	11,87	9,71	6,56	<0,05

Data were presented as mean ± standard deviation (SD) of the percentage of maximum voluntary isometric contraction (% MVIC). The p-value was considered significant when <0.05. One-way ANOVA with Bonferroni post hoc.
*p<0.05 when comparing the toe with the midfoot.
+p<0.05 when comparing the toe with the heel.
#p<0.05 when comparing the midfoot with the heel.

DISCUSSION

Studies show that Pilates can be an effective tool for physiotherapists in rehabilitation, as it has few contraindications [17], in addition to various benefits related to improved strength, flexibility, posture and motor skills. [18]

The results of the present study demonstrated that, regardless of the positioning of the feet, activation was similar for the VM, VL, RF, and BF muscles. TA activation was greater in heel support, and GL and SO activation was greater in tiptoe during the footwork exercise on the Reformer. The PL muscle had the greatest activation in the variation of tiptoe support.

The present study found no difference in the muscle activation of the biceps femoris and quadriceps during the footwork exercise in the variations of the positioning of the feet on the Reformer bar. The Pilates footwork exercise is similar to the standing squat or the leg press exercise. However, footwork has the particularity of being performed in the lying position and on a sliding surface, the Reformer carriage. In a study that evaluated the electromyographic activity of the muscles of the lower limbs during the leg press exercise, it was possible to observe that the vastus lateralis and vastus medialis obtained the greatest muscular activation during the leg press exercise, followed by the biceps femoris and the medial gastrocnemius, which showed greater muscular activity when the knee reached full extension, while the vastus lateralis and medialis, the rectus femoris and the tibialis anterior showed a pattern of decreasing muscular activity when the knee reached full extension. [19]

It is worth noting that, while the present study did not analyze muscle activation in separate phases of the Footwork exercise (concentric and eccentric), it did evaluate variations in foot positioning on the Reformer bar. However, what is important is that, in variations in body positioning during the performance of the same exercise, it is possible to obtain different muscle activations. Thus, unlike the results obtained in the systematic review in which the leg press exercise activated muscles differently in different knee positions, in the present study it can be inferred that the variation in foot position was not able to alter muscle activation of the Biceps and quadriceps femoris.

The results demonstrated that the greatest muscle activation obtained by the TA muscle occurred in the variation of heel support. This is an expected result, considering that the TA is considered a dorsiflexor and invertor muscle of the foot [19], This is why, when the heel is supported on the Reformer bar, dorsiflexion is automatically maintained and, when the exercise begins, the muscle reaches even higher levels of activation.

The SO and GL muscles obtained greater muscular activation in the vari-

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ation of the support of the tip of the foot. The soleus and gastrocnemius muscles are activated in the squat position, in which the knees are flexed and the weight bearing is supported on the tip of the foot. [20] This is in agreement with the results found in the present study, which confirm that performing the Footwork exercise on the tip of the foot is more appropriate for activating the muscles of the posterior compartment of the leg.

In a study analyzing the free single-leg squat, without changing the position of the feet, the VM and VL muscles showed the greatest electromyographic activity, followed by the gluteus medius muscle. [21] In the present study, the VM, VL and RF muscles were activated similarly in the different positions. Thus, it is suggested that the three foot positions analyzed provide the same activation of these muscles in the Footwork exercise. According to Catergi et al. [22] the extension movement in the Footwork exercise on the Reformer should strengthen the same muscle group worked in the squat exercise, with the only main difference being the load. In the study cited, the authors demonstrated that individuals use different strategies to perform knee extension on the Reformer, contributing to different muscle activation results. Catergi et al. [22] suggest that in order to control hip and knee movements and achieve the desired result of the exercise, the direction of force application on the Reformer bar must be carefully controlled. In this way, it is possible to suggest that different strategies may have been used in different foot positions on the Reformer bar, contributing to the absence of differences in muscle activation of some groups.

In relation to the BF muscle, there was no significant difference in its activation in the different positions, showing that the muscle in question may not be influenced by variations in foot positioning on the Reformer bar during the Footwork exercise. Bi-articular muscles have their muscle length differentiated during multi-articular exercises.

> “One study reports that during the concentric phase of the squat exercise, the biceps femoris varies its muscle excursion in a range of 116° to 128° of knee flexion, with the influence of both the hip and knee joints [23].”

Which indicates that, as already well described, according to Lombard's paradox, biarticular muscles, such as the hamstrings, act together as agonists, in hip extension, and antagonists in knee extension during movements such as squatting. [24]

The PL muscle, in turn, was more activated on tiptoe; its recruitment may be associated with stabilization of the foot position in isometry. A limitation of the present study was not considering the foot postures (flat and hollow of the volunteers). This may interfere with the overload and plantar pressure that is placed on the foot, as well as in the shortening of muscle fibers, resulting in a reduced capacity to develop contractile force. [25]

CONCLUSION

Surface electromyography is a gold standard technique for quantifying muscle activity and allows us to understand the differences in average muscle activation during exercises. Pilates professionals can better manage the results of Footwork in their patients if they take into account that the support position of the feet on the Reformer can alter muscle activation in the lower limbs.

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