

EMG Analysis of a Pilates Exercise

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1. Introduction

The Pilates method was originally developed by Joseph Pilates in Germany during the First World War and introduced in the United States in 1923 (Latey, 2001; Muscolino & Cipriani, 2004; Rydeard et al., 2006). The method assembles movements from gymnastics, martial arts, yoga and dance with philosophic ideas (Self et al., 1996; Latey, 2001; Rydeard et al., 2006). After the 1980's, new elements were incorporated aiming to improve both physical conditioning and rehabilitation programs. When considering physical conditioning increases in joint flexibility, muscle strength, balance and whole body conditioning were observed in Pilates' practitioners (Bertolla F, 2007; Jago et al., 2006; Segal et al., 2004). For rehabilitation, Pilates exercises have been used for joint function restoration, lumbar-pelvic stabilization, fibromyalgia control and low back pain treatment (Blum, 2002; Kolyniak et al., 2004; Donzelli et al., 2006).

In order to achieve the program goals, the health professionals can choose between mat or apparatus exercises. The apparatus, such as the reformer or the Cadillac, were designed specifically for the Pilates method. These apparatus uses springs in order to generate external load for the musculoskeletal structure. In general, each spring presents a different elastic constant and has more than one attachment possibility in the different apparatus, reflecting in the external load (Self et al., 1996; Rydeard et al., 2006). Regardless of the objectives, it is recommended that the training program uses exercises with progressive external load, according to each individual's needs. However, what have been observed is that the determination of external load in Pilates' exercises is based on subjective information, such as changing a less resistance for a higher resistance spring, without realizing how high is the difference in each situation. When this is follower, intensity is only determined based on patient's feedback and the instructor's experience (Blum, 2002), what may affect negatively the Pilates training program success.

Attentive to this situation, the Mechanics of Movement Investigation Group (*BIOMECH - Grupo de Investigação em Mecânica do Movimento*) has been using biomechanical analysis of human movement, in order to identify the resistance moments curve shape in a quantitative analysis of Pilates exercises (Silva et al., 2009; Loss et al., 2010; Melo et al., 2011). Thus, besides using load cells for measuring spring's strength (Self et al., 1996), resistance moment may be estimated in different subjects positioning and spring setups (Silva et al., 2009).

Using this kind of analysis it is possible, for example, to identify the angles where external load is maximum or internal moment is higher, what may help developing a workout with specific objectives. Although direct measurement of spring force or resistance moment analysis provides quantitative data of Pilates exercise intensity, this kind of analysis does not allow evaluating muscle activation levels during exercise.

Identifying and learning the possible changes in muscle activation arising from variations of the same exercise (such as in spring setup) can help health professionals determining, more objectively, the exercises for a Pilates training program. This way it is possible, for example, to avoid using spring adjustments or exercise positions that activate undesirable muscles during an injury recovery period, or even selecting exercises conditions that privileges the activation of specific muscle groups, according to the program's objective.

For this reason, it is believed that evaluating muscle response for imposed loads during an exercise using surface electromyography (EMG) may subsidize in an important way Pilates exercise prescription (Silva et al., 2009; Loss et al., 2010; Queiroz et al., 2010). Among several possibilities, analysis may compare different situations in the same exercise, such as changes in spring setup or in the practitioner's position. In the context that scientific studies that investigated electric activation during Pilates exercises is extremely limited, the BIOMECH group decided to analyse one of the exercises commonly used for strengthening the muscles associated to the powerhouse, performed on the Cadillac. In general this exercise may be characterized as a hip flexion-extension exercise performed in supine position with the possibility of varying subject's horizontal position (moving the subject closer or further to the apparatus edge), the spring used (the elastic constant used) and the spring's setup (the spring's vertical attachment point on the equipment, or its fixation height). Furthermore, depending of the Pilates method system followed the same exercise may be performed in different speeds. Each one of these variations may lead to different mechanical overloads on the active muscles during movement and, consequently, different patterns of muscle electrical activity (Silva et al., 2009).

Considering the importance of scientific information that may subsidize Pilates exercise prescription, this chapter will unite information from three studies on muscular activation during hip flexion-extension exercise performed in the Cadillac, including two studies already published about the use of agonist/antagonist muscle groups and trunk stabilizer muscles during the exercise. Thus, the first study aimed to compare the electrical activation of the Rectus Femoris (RF), long head of the Biceps Femoris (BF) and Semitendinosus (ST) with two spring adjustments. The second study aimed to compare the electrical activation of the Multifidus (MU) and the External Oblique (OE) adjusting spring setup and subject position. And the third study aimed to compare the electrical activation of the Multifidus (MU), the External Oblique (OE), the gluteus maximum (GM) and the Rectus Femoris (RF) performed with three different speeds.

2. General procedures

Each study sample was composed by 8 to 12 female subjects, that trained Pilates at least twice a week for a minimum of six months. The hip flexion-extension movement evaluated started at 90° of hip flexion with the subjects extending the hip until 0° of hip flexion, with two springs attached to the executioners feet and fixed to the Cadillac.

All studies collected electromyography and kinematic data. Electromyography signal was collected using a Miotool 400 (*Miotec Equipamentos Biomédicos Ltda*) equipment. Sample rate

was 2000 Hz for each muscle, and all procedures recommended by the International Society of Electrophysiology and Kinesiology were strictly followed, such as shaving, sanitizing with alcohol electrode positioning and impedance verification (accepted when lower than $10K\Omega$). Pairs of disposable surface electrodes were used (Kendall, Meditrace - 100; Ag/AgCl; self-adhesive 22 mm diameter, in bipolar configuration) for each muscle, following the placing location from the SENIAM project, unless otherwise informed. Electrodes were positioned over the muscle belly, parallel to the muscle fibres, separated in 2 cm from each other.

Besides the data from the hip flexion-extension exercise, signal from maximum isometric voluntary contractions (MVC) were collected in specific positions for each muscle of interest. All tests were repeated twice with 5 minutes intervals between each repetition. Electromyography signal was processed using a third order Butterworth digital filter in band pass configuration, with cut frequencies between 20 and 500 Hz. Root mean square (RMS) values from each MVC signal was calculated with a 2000 points moving-window. The highest value obtained for each muscle was used for normalization.

Kinematics used either video analysis or electronic goniometer in order to identify hip joint angle dividing the gesture in extension and flexion phases. For each set of data RMS value was calculated and normalized by the RMS value from the respective muscle MVC.

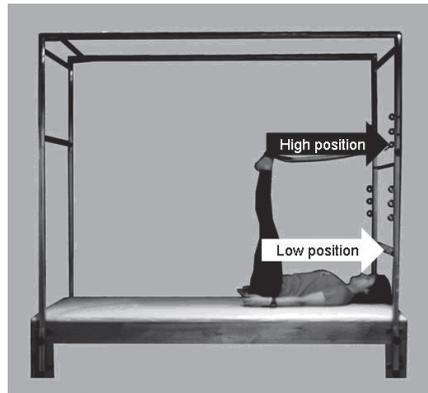
3. Study 1 – Movement agonist and antagonist muscle evaluation

Twelve subjects took part in this study. Rectos Femoris, Biceps Femoris (long head) and Semitendinosus muscles were evaluated. Rectos Femoris electrodes were positioned in the middle of a line going from anterior superior iliac spine and the patella superior part; Biceps Femoris electrodes were positioned in the middle of the line going from the ischial tuberosity and the lateral epicondyle; and Semitendinosus electrodes were positioned in the middle of the line between ischial tuberosity and medial epicondyle. Reference electrode was positioned in the right knee over the Fibula's styloideus process. Maximum isometric voluntary contraction was collected for the Rectos Femoris with the subject in supine lying position with the trunk kept still while they were instructed to try flexing the hip against manual resistance in the ankle. For Biceps Femoris and Semitendinosus subjects were in probe lying position, with the superior part of the trunk kept still in a gurney and the legs hanging with a 90° hip flexion, while they were instructed to extend the hip against manual resistance in the ankle.

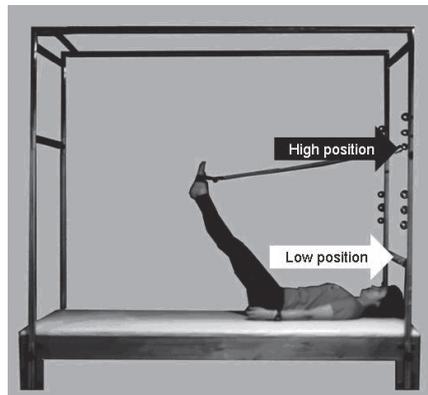
The hip joint angular positions were registered during the evaluation protocol by means of an electronic goniometer (*Miotec Equipamentos Biomédicos Ltda, Porto Alegre, Brazil*). Each subject performed 2 series of 5 repetitions each of the hip flexion-extension movement using two different spring setups: i) higher position (90 cm higher than the subjects level) e ii) lower position (20 cm higher than the subjects level), as is shown in Figure 1. An interval of 1 minute was kept between positions. The spring used had been previously calibrated, and had an elastic constant of 0.013 kg/cm.

For analysis, the hip extension phase was divided in two parts: from 90° of flexion to approximately 45° of flexion and from 45° of flexion to full extension. Multiple one way ANOVA were used to verify differences in each muscle's electric activation in the following comparisons:

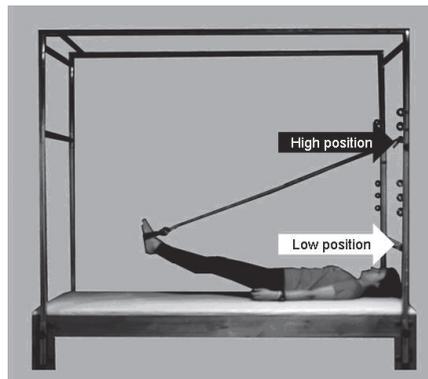
1. between higher and lower spring setup during the whole hip extension;
2. between higher and lower spring setup in the first half of the hip extension;
3. between higher and lower spring setup in the second half of the hip extension;
4. between first and second half of the hip extension using the higher spring setup;
5. between first and second half of the hip extension using the lower spring setup.



(a)



(b)



(c)

Fig. 1. Hip extension position on the Cadillac: a) near to initial position, b) intermediate position, c) near to final position. The black arrow indicates the higher spring setup and the white arrow indicates the lower spring setup. Extracted from the Brazilian Journal of Physiotherapy with permission.

Figures 2 and 3 show a typical EMG response obtained during one hip extension in only one subject. Each point in the graphic represents the RMS value of 40 consecutive points normalized by the respective muscle MVC value. It may be observed that EMG presented higher activation percentages for Biceps Femoris and Semitendinosus when compared to Rectos Femoris in the higher spring setup (Figure 2) and higher Semitendinosus values when compared to Biceps Femoris and Rectos Femoris in the lower spring setup (Figure 3). Comparing first and second halves of the hip extension subjectively in Figure 2, it may be assumed that activation is crescent and is higher during the second half, while in Figure 3 it may be assumed that Semitendinosus activation is higher than the activation of others muscles analysed, especially in the first half of the hip extension.

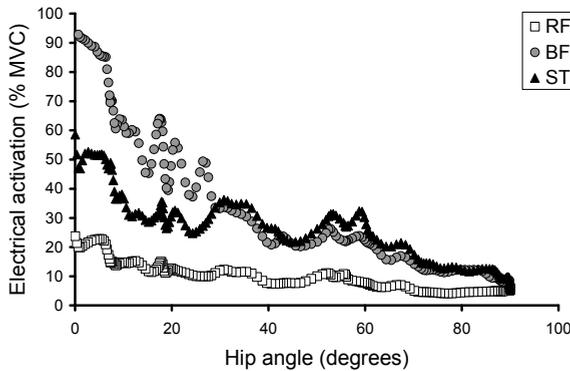


Fig. 2. Typical normalized EMG behaviour for one sample representative subject during hip extension performed on Cadillac with spring attached to the higher position.

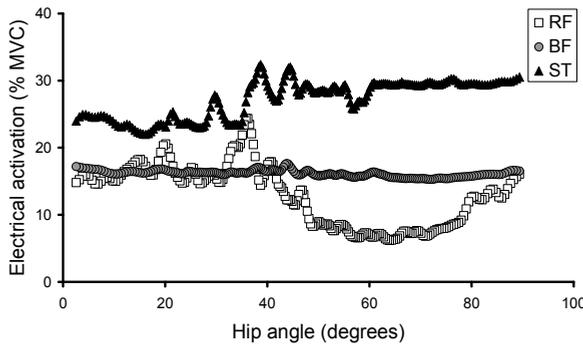


Fig. 3. Typical normalized EMG behaviour for one sample representative subject during hip extension performed on Cadillac with spring attached to the lower position.

The behaviour assumed in Figures 2 and 3 were confirmed by statistic analysis. Table 1 shows partial results of EMG divided between each half (HALF1 represents first half and HALF2 represents second half of the hip extension) of the muscles evaluated. This table show results of position comparison between positions, for the same half of the same muscle, are presented in the intermediate rows, while comparison of results between halves, for a same position of the same muscle, are presented in the last column.

Muscle	Spring setup	HALF1	HALF2	<i>p</i>
Rectos Femoris	Higher	10,8±3,8	15,2±9,4	0,038 *
	Lower	13,4±5,3	17,6±7,5	0,023 *
	<i>p</i>	0,015 *	0,295	
Biceps Femoris	Higher	47,5±19,4	115,1±61,7	0,003 *
	Lower	16,1±8,9	15,9±7,2	0,865
	<i>p</i>	0,000 *	0,000 *	
Semitendinosus	Higher	54,3±21,7	92,6±35,0	0,000 *
	Lower	28,3±15,1	20,7±4,7	0,088
	<i>p</i>	0,000 *	0,000 *	

Table 1. Each muscles EMG values expressed in MVC percentage, evaluated by half, separately: first half (HALF1) and second half (HALF2) of the hip extension. Intermediate lines *p* values refer to comparison between spring setup for the same half of each muscle. The last column *p* values refer to comparison between half, for the same spring setup of each muscle. * significant differences ($p < 0.05$).

3.1 Practical applications

The findings in study one suggests that altering spring positions during hip extension exercise in the Cadillac as is usually prescribed in Pilates exercises, does not change only exercise intensity magnitude, but also interferes in the kineisological function that the muscles assume during exercise.

In summary, it may be observed that the agonist muscles of the hip extension movement, represented by the Biceps Femoris and Semitendinosus muscles, were significantly more active when using the higher spring setup during the second half of the evaluated exercise. Considering that the external load in Cadillac is larger using the higher spring setup when compared to the lower spring setup (Melo et al., 2011; Silva et al., 2009), this results probably reflect the increase in motor unit recruitment due to the larger load acting on the muscle in the higher spring setup. This pattern of increased hip extensors activation was observed, mainly, in the movement's final angles; a region in which the progressive tension offered by the spring is larger than in the initial angles.

As expected, antagonist muscles in the hip extension movement, represented by Rectus Femoris muscle, presented lower values then the agonists, especially when the exercise was performed with the higher spring setup. However, co-activation values registered for Rectos Femoris show an important magnitude when compared to other studies reported in literature, even though, in this study, sample was composed by subjects with at least six months of Pilates practice. It is possible that unwanted pelvic anterior tilt occurred in extension or lowering phase due to insufficient activation of paravertebral muscles and also of trunk flexors. Because Rectos Femoris also acts on hip anterior tilt, it would justify the activation levels observed in the present study. However, since pelvic movement was not controlled, this hypothesis could not be confirmed. Regardless, one aspect to be noted when the exercise is performed with the lower spring setup is that muscle activation pattern of the movement's agonist and antagonists that was observed is the opposite of that of the higher spring setup; in other words, as hip extension movement agonists electric activation decreases through the entire hip extension movement, antagonists

muscles present increases in electric activity values, including during the second half of the movement.

Previous studies showed (Melo et al., 2011; Silva et al., 2009) that when spring is positioned in the lower setup, inferior limb weight (thighs, lower legs and feet) may contribute more in resistance moment composition than the spring moment itself. When this occurs, an inversion in the direction of external moment happens, meaning that the moment occurring in the flexion direction and demanding from the extensor muscles may be happening in the opposite direction and demanding larger activation of the flexor muscles. This situation would explain the increase of Rectus Femoris activation, which will probably assume the function of movement agonist and contract eccentrically to keep the extension movement slow and controlled as it approached the 0° angle. Nevertheless, Biceps Femoris and Semitendinosus higher values during the movement's second half using the lower spring (as the legs approach the horizontal) indicates that the hip extensor muscles have acted not only as co-activator, but have also helped in the pelvic neutral positions maintenance by avoiding hip anterior tilt in the attempt to keep the pelvic-lumbar region supported to the ground.

The different muscle recruitment strategies used by the central nervous system to perform hip extension movement in Pilates are a direct consequence of the external load behaviour that should *a priori* be chosen consistently by the health professional. By prescribing hip extension exercise with the higher spring setup, extensor muscles are demanded concentrically, with higher demands as the movement amplitude increases, while antagonistic muscle activation is expected to be above the levels of co-contraction due to the necessity of maintaining pelvic position. When opting for the same movement with the lower spring, hip flexor muscles may be demanded eccentrically as the movement agonists, meaning that there will be a higher contribution of passive components for the muscle force production. It is the Pilates professional that has the responsibility to choose the spring position that is more appropriate for one or another clinical objective. From this results it is considered a mistake prescribing hip flexion-extension exercise using the lower spring setup for a beginner followed by the higher spring setup as the training progresses, expecting that this change will only echoes in the intensity of the exercise, as the results presented here show that another changes will also occur influencing significantly the exercise.

4. Study 2 – Evaluation of trunk stabilizing musculature

Eight subjects took part in this study. Multifidus and External Oblique muscles were evaluated. Multifidus electrodes were positioned bilaterally in the level of the fifth lumbar vertebrae, aligned in parallel between the posterior-superior iliac spines and the first and second lumbar vertebrae interspine space. The External Oblique electrodes were positioned bilaterally in the middle of the line between the iliac crest and the most inferior point of the costal margin (same high as the third lumbar vertebrae), according to Ng (2002). Reference electrode was positioned over the seventh cervical vertebrae spinal process. Maximum isometric voluntary contractions were collected for the External Oblique with the subject positioned in a sitting position on a chair, leaning on the backrest, with the arms in the side of the body, holding himself in the chair's seat. They were instructed to flex and rotate the trunk to the left and then to the right, against a manual resistance imposed to the shoulders in the opposite direction (Arokoski et al., 1999). For Multifidus, subjects were positioned in prone lying, with thighs and legs fixed,

and were asked to perform trunk extension against manual resistance applied to the superior dorsal region (Arokoski et al., 1999).

The hip joint angular positions were registered by means of a webcam (25 frames/s). Each subject performed 4 series of 10 repetitions each of the hip flexion-extension movement combining two different spring setups: higher position (90 cm higher than the subjects level) and lower position (30 cm higher than the subjects level); and two different subject positions: near position (distant 10 cm from the apparatus edge) and distant position (distant 30 cm from the apparatus edge) (Figure 4) in random order. An interval of 2 minutes was kept between series. The two springs used had been previously calibrated, and had an elastic constant of 0.082 kg/cm. For standardization it was requested that subjects expire during extension and inspire during flexion.

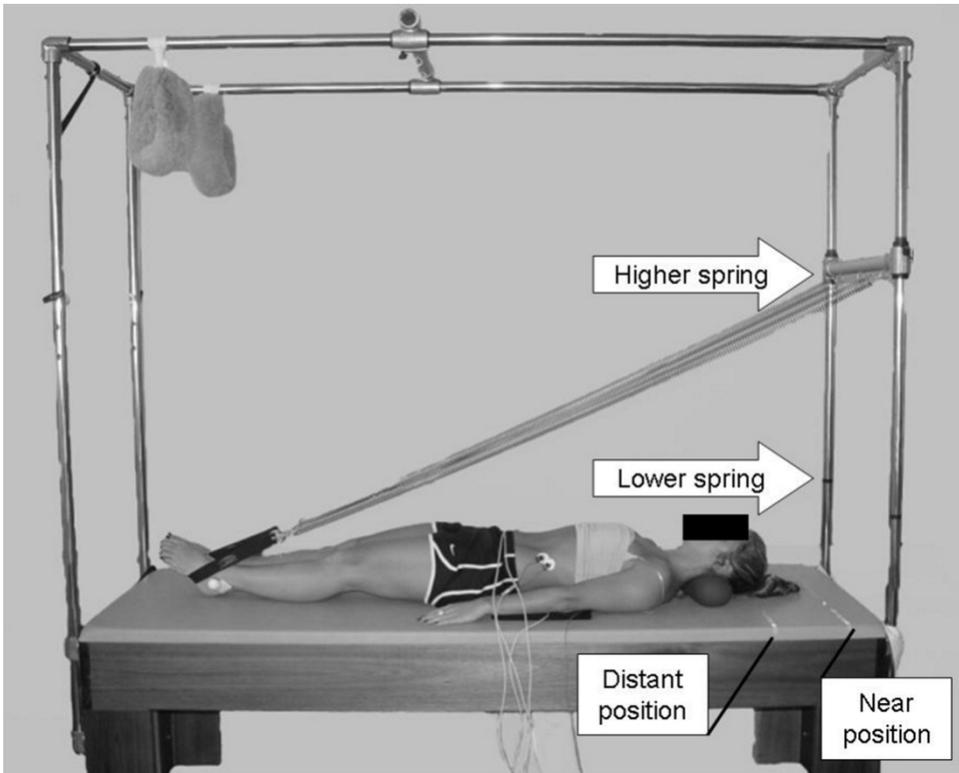


Fig. 4. Cadillac apparatus used in the study, showing different spring regulations and subjects positioning. Extracted from the Brazilian Journal of Physiotherapy with permission.

To verify electromyography differences between the distinct spring setup and subject position combinations, multiple comparisons were made using Wilcoxon test for each muscle and each phase separated. Significance level adopted for all tests was $p \leq 0.05$.

In Figures 5A and 5B is shown that during hip extension phase, right and left Multifidus presented significant differences in two situation: i) in the distant position when compared between higher and lower spring setup, and ii) in the higher spring setup, when compared

between distant and near position. Figures 5C and 5D show that during the hip flexion phase significant differences occurred only in the right side of the trunk in the higher spring setup when compared distant and near positioning. Considering both phases, higher Multifidus electric activation was found in the combination higher spring setup and distant position. In figures 6A e 6B is shown that during hip extension phase significant differences occurred only in the right side of the trunk in the distant position when compared higher and lower spring setups, for the External Oblique muscle. Figures 6C and 6D show that during the hip flexion phase, right and left external oblique presented significant differences in two situation: (i) in the distant position when compared between higher and lower spring setups, and (ii) in the lower spring setup, when compared between distant and near subject positions. When both phases are considered, External Oblique electric activity was higher in the lower spring setup in the near position.

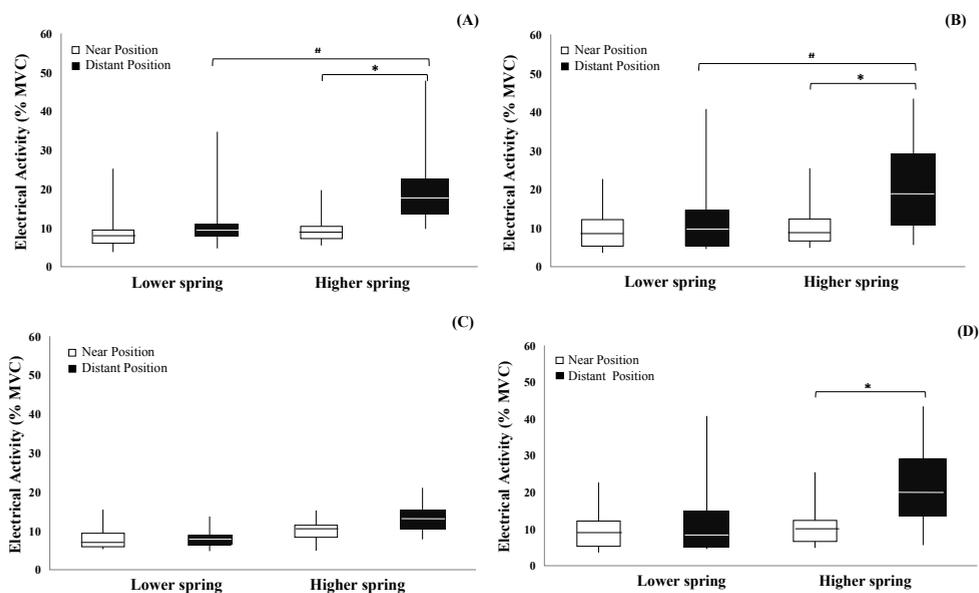


Fig. 5. Normalized electromyographic activation maximum, minimum and median values of right and left muscle Multifidus on the evaluated spring positions and subjects positioning. (A) and (B) represent extension phase for left and right sides, respectively. (C) and (D) represent flexion phase for left and right sides, respectively. Extracted from Brazilian Journal of Physiotherapy with permission.

4.1 Practical applications

When investigating activation pattern of muscles recognized by the Pilates method as trunk stabilizers, important effects on electromyographical activation of selected muscles were found in the choice of spring setup and subjects positioning while performing hip flexion-extension exercise. Results show that during hip extension phase a 10% enhance in Multifidus activation appeared when spring setup was modified from lower to higher and subject was kept in the distant position. In the same situations, though significant difference was only found in the right side, External Oblique muscles presented an apparent decrease

in the electric activation values. External Oblique are muscles responsible for maintaining the pelvic in the neutral position during hip extension performed in supine-lying (Calais-Germain & Lamotte, 2005). These results may indicate that a possible unwanted pelvic anterior tilt may have influenced the Multifidus muscles results. This hypothesis appears to be supported by previous studies that found higher Multifidus activation when pelvic posture changed from neutral to anterior tilt during the performance of a stabilizing Pilates exercise in the quadruped position (Queiroz et al., 2010).

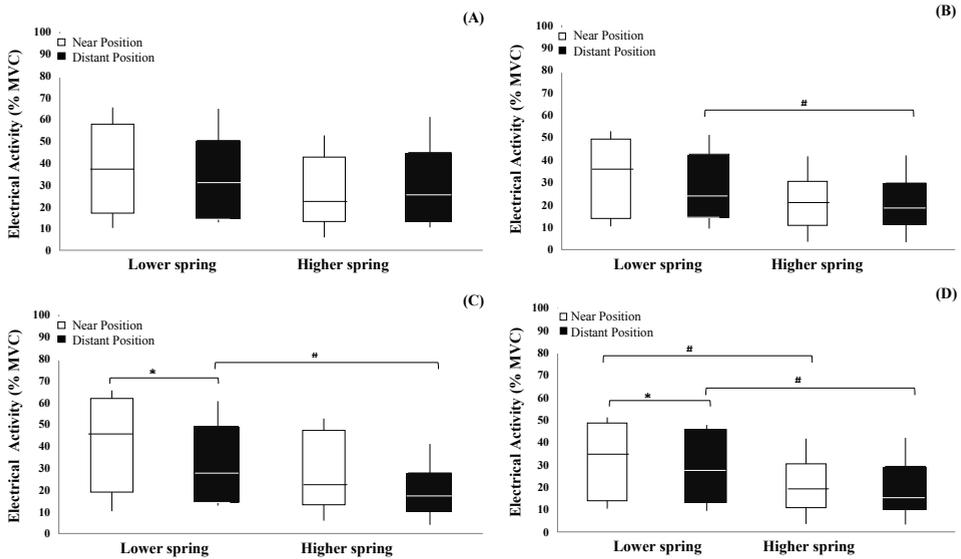


Fig. 6. Normalized electromyographical activation maximum, minimum and median values of right and left muscle external oblique on the evaluated spring positions and subjects positioning. (A) and (B) represent extension phase for left and right sides, respectively. (C) and (D) represent flexion phase for left and right sides, respectively. Extracted from Brazilian Journal of Physiotherapy with permission.

During the hip flexion phase, there was a significant increase in External Oblique activation of about 20% in the lower spring setup and distant position when compared to the higher spring setup and near position (Figure 6), probably due to a more challenging situation for keeping the pelvis in a relative neutral position and avoiding anterior tilt. The External Oblique muscle actions for maintaining the pelvis in place as the hip is flexed in a lying position was previously described by Calais-Germain and Lamotte (2005) and is consistent with global function documented by Bergmark (1989). Furthermore it should be remembered that when the spring is used in the lower position the thigh and lower leg weight may have a higher contribution in the resistance moment composition than the actual spring moment. In the mechanical point of view, in this situation the resistance moment will happen in the extension direction, even with the spring acting in the hip flexion direction. Considering this configuration of hip flexors actuation during flexion phase, there may be a higher tendency for pelvis anterior tilt with a consequent increase in lumbar lordosis (Calais-Germain & Lamotte, 2005). This idea seems to

corroborate with the results in study 1, where a higher Rectus Femoris activation in the hip extension phase using the lower spring was found.

Based in the results, the hip flexion-extension exercise in the Cadillac with higher spring setup and variations in subject's position is recommended as an option of paravertebral muscles stabilization exercise. This may be the case especially in the initial rehabilitation phase, because the electric activation levels found for Multifidos (10 to 20% of MVC) are in accordance with McGill's (2007) suggestion that an activation of 10% or less is sufficient for means of stabilization during everyday life activities. On the other side, there are studies suggesting that observed low activation levels (under 40% of MVC) for abdominal and erector spine muscles during trunk stabilization exercises, may not be enough for muscular strengthening in healthy subjects (Souza et al., 2001). Thereby, when the exercise program objective is the high performance of the trunk stabilization muscles, it is suggested that the health professional make use of other types of exercise, once activation levels obtained for Multifidos during hip flexion-extension were equal or lower than 20% of MVC.

In addition, the same hip flexion extension exercise in the Cadillac with lower spring setup and near position may be indicated as another option of exercise for trunk flexors strengthening, once the External Oblique electric activation levels obtained were similar to those found by previous studies performed outside (McGill & Karpowicz, 2009) and inside (Queiroz et al., 2010) the Pilates environment. Therapeutic use of hip flexion-extension exercise in the Cadillac is preferable to exercises where the abdominal actively flex the pelvis and trunk. This is because this exercises may represent a problem for individuals with disc pathologies due to the increase of intradiscal pressure (Nachemson, 1987) and lumbar spine compression (Axler & McGill, 1997). Nevertheless, caution is recommended when using the exercise evaluated in this study, especially for individuals with weak muscles or incapable of stabilizing pelvis and trunk against an increase in external load (Souza et al., 2001), like may be the case of elderly people.

5. Study 3 – Speed performance evaluation

Nine subjects took part in this study. External oblique, Multifidus, Rectos Femoris and Gluteus Maximum muscles were evaluated in the right side. External oblique, Multifidus, Rectos Femoris electrodes were positioned in accordance to the previous studies. Gluteus Maximums electrodes were positioned in the middle of the line between the sacral vertebrae and the greater trochanter. Reference electrode was positioned in the spine process of the seventh cervical vertebrae. Maximum isometric voluntary contraction was collected for the Gluteus maximum following the same procedure as the isquiotibialis muscles.

The hip joint angular positions were registered by means of a webcam (25 frames/s). Each subject performed 3 series of 10 repetitions each of the hip flexion-extension movement in three different speeds. First, all subjects performed the movement at self selected speed. The execution speed average was 30 degrees/s, with a very low variability. The low variability found was probably because all subjects trained at the same place and with the same instructor, having learned to perform the exercise in the same way. Then, in random order subjects performed the movement in slower speed (15 degrees/s) and in faster speed (45 degrees/s), having a digital metronome dictating the rhythm. An interval of 2 minute was kept between series. The two spring used were fixed at the higher spring setup, 90 cm high, and had been previously calibrated, having an elastic constant of 0.082 kg/cm. For standardization it was requested that subjects expire during extension and inspire during flexion.

Multiple two factors ANOVA, one for each muscle, with a Bonferroni post hoc were used to evaluate speed influence in each phase. Significance level adopted was $p < 0.05$.

For the trunk stabilizers muscle, Multifidus and External Oblique, no speed influence was found, while for Rectos Femoris and Gluteus Maximum a difference between the higher speed and the other two speeds was found, as may be seen in Figures 7 to 10. In the phase analysis, difference was only found for the External Oblique muscle, when RMS value was higher in the extension phase when compared to the flexion phase (Figure 11).

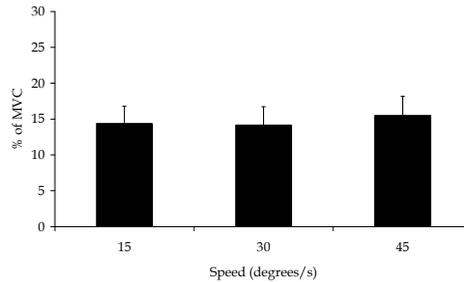


Fig. 7. External oblique muscle electric activation comparison in three angular speeds during hip flexion-extension movement in Cadillac.

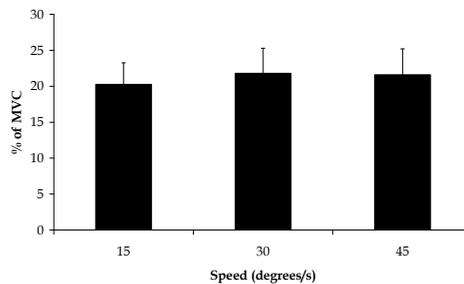


Fig. 8. Multifidus muscle electric activation comparison in three angular speeds during hip flexion-extension movement in Cadillac.

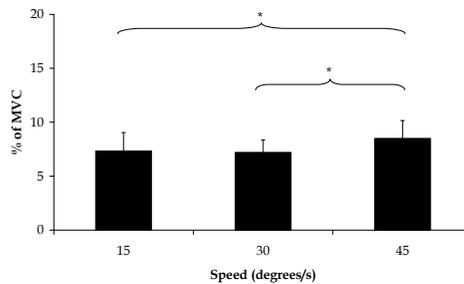


Fig. 9. Rectus Femoris muscle electric activation comparison in three angular speeds during hip flexion-extension movement in Cadillac.

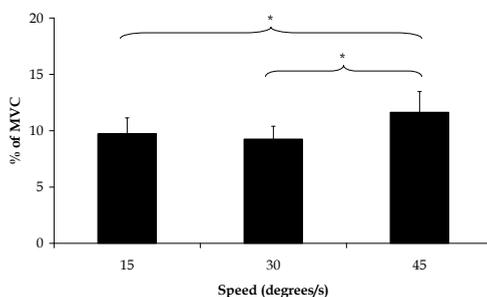


Fig. 10. Gluteus Maximum muscle electric activation comparison in three angular speeds during hip flexion-extension movement in Cadillac.

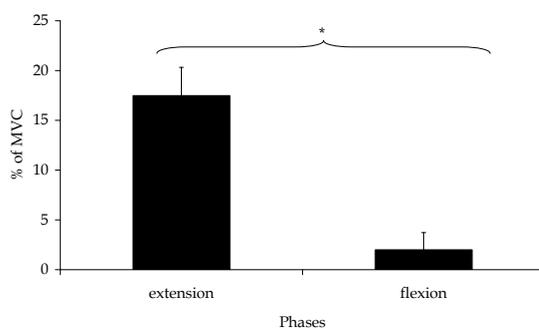


Fig. 11. External oblique muscle electric activation comparison between flexion and extension phases during hip flexion-extension movement in Cadillac.

5.1 Practical application

When verifying speed effect on the electrical activation of External Oblique, Multifidus, Rectos Femoris and Gluteus Maximum muscles during hip flexion extension movement in the Cadillac, it may be observed that only extension movement agonist and antagonist muscles were influenced by speed, showing increases in electrical activity as speed increased. Gluteus Maximum is considered by literature as the main hip extensor, having the biggest cross sectional and muscle perpendicular distance (Oatis, 2009) and Rectus Femoris (a biarticular muscle), is an important knee extensor and hip flexor (Oatis, 2009). Both muscles are fundamental in performing the analysed movement (Silva et al., 2009). Based in the force-velocity relation, that determines that in slower velocities there is a higher capability of force production (Babault et al., 2003; Hill, 1938), it is possible to speculate that using the same absolute spring load, there is a better neuromuscular efficiency in slower velocities, meaning that the muscle is capable of producing more force with a slower muscle recruitment necessity, reflecting in smaller EMG values. It may also be considered that as execution speed increases, the inertial effect is each time more significant. The inertial effect is due to the movement with variable speed of the lower limbs' mass and is part of the resistance moment. In this perspective, agonist muscles become more required to rapidly start while antagonist muscles become more required to abruptly stop faster movements.

It may also be remarked, when considering the faster speed versus the self-selected speed, that these results corroborate with those found by Hatfield et al. (Hatfield et al., 2006) that verified that execution speed exerted influence in strength training variables during squat exercise, where the self-selected speed showed better performance for the exercise. According to Purves et al (2008) when performing fast tasks and with certain time limitations, the central nervous system seems to choose speed dependent strategies, while when the individual is free to choose movement speed, the central nervous system chooses speed independent strategies (adjusting electric impulse intensity with adequate duration for complete execution of the gesture). The preferred speed used by the subject during Pilates training sections represents the necessary neural strategy to perform the hip flexion extension exercise, this being an important specific adaptation to training. Considering that execution speeds different from the self-selected may interfere in individuals muscle recruitment pattern (Germain et al., 1996; Hatfield et al., 2006; Bottaro et al., 2007), it is suggested that future studies about Pilates, also consider execution speed as a variable that may intervene significantly in the muscle electrical activity pattern.

One fundamental principle of the Pilates Method is the core musculature recruitment, having the External Oblique as a representative muscle of the anterior superficial muscle group (Bergmark, 1989) and the Multifidus a representative of the posterior deep muscle group (Rosatelli et al., 2008). Thus, another important result is that in the hip extension phase, External Oblique was significantly more active than in the hip flexion phase, regardless of execution speed. This results corroborate with anterior studies (Loss et al., 2010; Rydeard et al., 2006) and indicates that stabilizer muscles are higher influenced by pelvic positioning, that seems to vary according to the movement's phase and its association to external overload and not according to speed variation. As discussed in studies 1 and 2, it may be speculated that in the hip extension phase there is a higher external overload that increases the necessity of activation of the muscles responsible for preventing pelvis anterior tilt.

6. Conclusion

In spite of the popularity of the exercises performed on the Cadillac equipment, there is a lack of scientific research focusing on muscle electrical activity during Pilates exercise. Aiming to contribute with a step to fill the gap between science research and practical application, the present chapter presented a summary of knowledge produced by *BIOMECH* Group on EMG analysis of Pilates exercises in three studies on the hip extension movement performed on the Cadillac equipment. The first study compared the electrical activation of the Rectus Femoris, Biceps Femoris long head and Semitendinosus between two spring setups. The second study compared the electrical activation of the Multifidus and the External Oblique between two spring setup and two subjects positions. The third study compared the electrical activation of the Multifidus, the External Oblique, the Gluteus Maximum and the Rectus Femoris between three different execution speed. Together, the results of all studies showed that spring setup, subjects positioning and execution speed changes interfere in electrical activity pattern of movement agonist and antagonist muscles and muscles considered stabilizers for the Pilates methodology. In one side, the exercise performed with higher spring setup may generate larger activation levels of the hip extension movement agonists and of the Multifidus (on distant position). On the other side the exercise performed using the lower spring setup may increase the electrical activity of the hip flexors and external oblique muscles. The stabilization muscles activation pattern seems to be kept even when speed execution varies,

however the same does not occur for movement agonist and antagonist muscles. In faster speeds extra motor unit recruitment appears to be necessary in front of the new motor challenge, reflecting in higher activation levels for agonist and antagonist muscles.

7. References

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