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Electrical activity of external oblique and multifidus muscles during the hip flexion-extension exercise performed in the Cadillac with different adjustments of springs and individual positions

Atividade elétrica dos músculos oblíquos externos e multífidos durante o exercício de flexoextensão do quadril realizado no Cadillac com diferentes regulagens de mola e posições do indivíduo

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Abstract

Background: Despite of the widepread use of Pilates in Physical Therapy, there are few studies that have assessed the muscle electrical activation during Pilates exercises. **Objective:** Verify the influence of different spring adjustments and individual positions on the electrical activation of multifidus (MU) and oblique external (OE) muscles during hip flexion-extension (HFE) exercise on the Cadillac. **Methods:** Eight women practicing Pilates exercises for at least six months performed 10 repetitions of HFE in the following situations: Lower Spring, spring fixed at 30 cm in relation to level which the individuals were positioned. Higher Spring, spring fixed at 90 cm in relation to level which the individuals were positioned. Near Position, distance of 10 cm from the fixed spring. Distant Position, distance of 30 cm from the fixed spring. Kinematic and eletromyographic data (EMG) were collected simultaneously and the MU and OE muscles were monitored. Each movement of HFE was splitted in two phases (extension and flexion). The EMG signal was calculated and normalized using the maximal voluntary contraction (MVC). The Wilcoxon test was used to investigate differences between the situations ($p \leq 0.05$). **Results:** MU muscle presented muscle activation values ranging from 10 to 20 % MVC, and the highest muscle activation in the lower spring and in the near position. OE muscles presented muscle activation values ranging from 20 to 45% MVC, and the highest values in the higher spring and in the distant position. **Conclusion:** MU and OE muscles presented a distinct electrical activation during different available spring adjustments and individual positions.

Keywords: Posture; pilates; biomechanics; eletromyography; rehabilitation; low back pain.

Resumo

Contextualização: Apesar do amplo uso do Pilates na Fisioterapia, há poucos estudos que avaliaram a ativação elétrica dos músculos nos exercícios. **Objetivo:** Verificar a influência de diferentes regulagens de mola e posições do indivíduo sobre a ativação elétrica dos multífidos (MU) e oblíquos externos (OE) durante a flexoextensão do quadril (FEQ) no Cadillac. **Métodos:** Oito mulheres praticantes de Pilates por seis meses realizaram 10 repetições de FEQ nas situações: mola baixa (MB), mola fixada a 30 cm do nível em que estava o indivíduo; mola alta (MA), mola fixada a 90 cm do nível em que estava o indivíduo; posição próxima (PP), distância de 10 cm da fixação da mola; posição distante (PD), distância de 30 cm da fixação da mola. Dados cinemáticos e de eletromiografia (EMG) foram coletados sincronizadamente, e os músculos monitorados bilateralmente foram os OE e os MU. Cada movimento de FEQ foi recortado em duas fases (extensão e flexão). O sinal de EMG foi calculado e normalizado usando a contração voluntária máxima (CVM). O Wilcoxon test foi usado para investigar diferenças entre as situações ($p \leq 0,05$). **Resultado:** Os músculos MU apresentaram valores de ativação muscular de 10 a 20% da CVM, sendo os maiores valores observados na MA e na PD. Para os OE, valores de ativação de 20 a 45% da CVM foram encontrados, com os maiores valores obtidos na MB e na PP. **Conclusão:** Os músculos OE e MU apresentaram uma ativação elétrica distinta durante as diferentes regulagens de mola e posições dos indivíduos avaliados.

Palavras-chave: postura; Pilates; biomecânica; eletromiografia; reabilitação; dor lombar.

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Introduction

The emergence of Pilates as a method for rehabilitation occurred during the First World War, when Joseph Hubertus Pilates used his knowledge to rehabilitate the war injured individuals, however this method became popular only in the 80's[1,2]. More recently, Pilates has been used by health professionals, with the purpose to integrate mind and body, providing an improvement in physical fitness (flexibility, strength and balance) and body consciousness[2]. To obtain these benefits, the method counts with exercises performed on the ground and in equipment created by Joseph Pilates[1-4]. For the Pilates practicing, it is recommended the use of six key principles, which are: concentration, control, precision, movement fluidity, breathing and center of strength[1,3,5].

The center of strength, also called as the *powerhouse,* refers to a region of a specific muscle groups (anterior abdominal wall muscles, spine extensors, hip extensors, hip flexors and deep pelvic muscles)[3,4]. In Pilates rehabilitation programmes, such as in the treatment of low back pain, it is common for physical therapists to emphasize the strengthening of the powerhouse's muscles[6], with the purpose to obtain trunk stabilization. In this case, the Pilates method considers that these muscles have a single and integrated action towards a better center of balance and that these activation patterns may help on pain relieve and in the restoration of muscle function of the affected muscles[3,6,7]. The therapeutic benefits of Pilates, associated with its widespread use, seem to have motivated the emergence of studies that investigated the program's effects on different outcomes of interest, such as the isokinetic torque production[4], levels of obesity[5], pain[6,7], range of motion and flexibility[8,9]. Although such studies have investigated the effectiveness of Pilates, i.e., the method's ability to accomplish what it proposes to do, what is observed is the diffuculty of finding information in the literature with respect to muscle activation patterns generated by different exercises. Few studies were identified that evaluated the electrical activation of the trunk stabilizing muscles during exercises in Pilates equipment[10].

In physical therapy programs using Pilates method[10], a movement commonly used for strenghtening the muscles associated to the powerhouse[11] is the hip flexion-extension (HFE), with the knees extended, which can be performed on the Cadillac (Trapeze Cadillac, Physio Pilates). This device allows the performance of a variety of patterns of movements and postures. When the HFE exercise is performed in supine position, it is possible to vary the horizontal position of the individual (approaching or moving the individual away from the device's edge), the spring used (and, consequently, the elastic constant used) and the vertical adjustment of the spring (the spring attachment point on the equipment, or its fixation heigth). Each of these variations can lead to different mechanical overloads on the muscles acting during movement performance and, consequently, different patterns of muscle electrical activity[12]. Although only one study that investigated the activation of agonist and antagonist muscles during the movement of hip extension in the Cadillac had been identified in the databases consulted[13], to date, we found no studies that have evaluated the electrical activation of trunk stabilizing musculature during this exercise. This fact, in addition to the widespread use of Pilates method by therapists and fitness trainers in different populations, with the intense marketing of equipment and professional training justify the development of studies attempting to quantify the electrical activation of the stabilizers muscles during the exercises in the practice of Pilates.

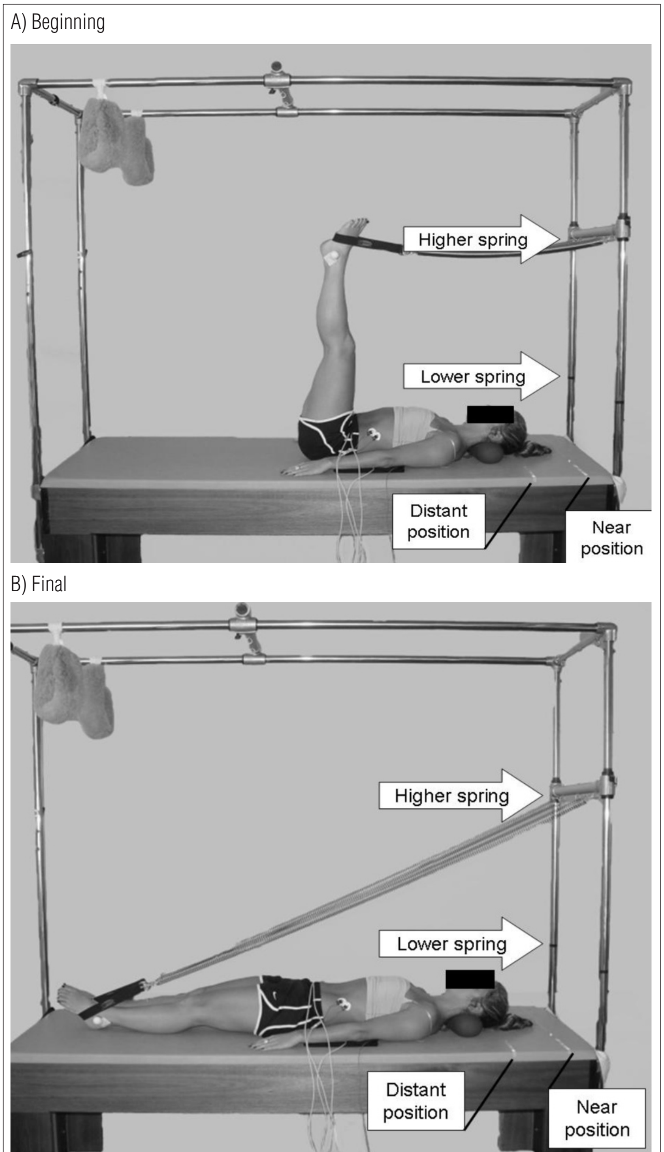
According to Silva et al.[13], when the Cadillac is used during a rehabilitation program, choosing the position of individuals on the equipment and the heigth of the spring is usually based upon subjective criteria. Moreover, it is common, in clinical practice, the assumption that the stabilizing muscles are activated homogeneously, without the prevalence of one group over another[14,6]. Identify and knowing the possible changes in muscle activation of stabilizing muscles arising from variations of the same exercise (the individuals' position and height of the spring) can be helpful for physical therapists to determine, more objectively, the selection of the exercises in a rehabilitation program. With these data, the physical therapist can, for example, avoid the use of adjustments or exercise positions that activate undesirable muscles in the recovery period, or even, to select exercises' conditions that priviledge the activation of specific muscle groups, according to the program purpose.

Considering the use of the HFE exercise focusing on the trunk stabilizing muscles during therapy[6], the objective of this study was to investigate the influence of the diverse spring adjustments and individuals positions in the activation of multifidus (MU) and obliques external (OE) during the HFE exercise peformed in the Cadillac equipment.

Methods

Sample

Participated in this study eight women, with a mean heigth of 160.0±6.0 cm, mean weigth of 55.6±5.7 kg, mean age of 27.7±1.8 years-old. The sample size calculation was performed using the WinPepi software, version 1.45, from the variability found in the studies of Escamila et al.[15] and Arokoski et al.[16], with an expected difference of 20% of the maximum voluntary contraction (MVC) and a statistical power of 80%. The inclusion criteria were that the subjects were healthy, without history of lumbar musculoskeletal injury, without trunk and lower limb asymmetries visually identifiable, and whom had attended at least six months (twice a week, 1h session) Pilates before the beggining of the study. All participants signed an informed consent form and were informed about the right to stop participating in data collection at any time, if they desired. This study was approved by the Ethics Committee of Research of the Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil, under the protocol nº 2007996.



A) Start position of the exercise; B) Final position of the exercise.

Figure 1. Cadillac equipment used in the study showing different spring adjustments and individual positions.

Data acquisition

Assessment protocol: The assessment protocol was performed in the Cadillac equipment, which allows that a single movement be performed under diverse external mechanic overloads, ranging, for example, from the spring adjustments and the positioning of the subjects (Figure 1). One of the equipment adjustments is the variation of the spring height, which is conducted through a mobile transverse bar that slides by the two lateral bars of the equipment. Moreover, the variation in the distance where the subject is positioned in relation to the fixation point of the spring characterizes another manner used on the Cadillac equipment to modify the external stimulus. Thus, in the present study, we evaluated two different positions (near position (NP) and distant position (DP)) and two spring adjustments (lower spring (LS) and higher spring (HS)) (Figure 1). In the NP and DP, subjects were positioned in supine on the equipment, in distances of 10 cm and 30 cm of the beginning of the equipment upholstered, respectively. On LS and HS heights, the springs were fixed at 30 cm and 90 cm of the level where the subject was, respectively. The assessments order was determined by drawing lots. Each subject performed 10 repetitions of the HFE movement, from 90º to 0º of hip flexion and this movement was recorded by a webcam (25 frames/s) for further analysis. In addition, to ensure the quality of all executions, i.e. the desired range of motion was performed and that the pelvis and trunk remained in isometry during the exercise, each repetition was monitored by an assessor. None of the repetitions was excluded after verification of the range of movement and inspection of the positioning of the pelvis and the trunk during the exercise. To standardize the exercise, during extension, the subjects were asked to breathe out , and during flexion, to breathe in. The repetitions were performed in a mean angular velocity of 30º/s. A 2-minute interval was used between each series of 10 repetitions. Springs classified by the manufacturer (METALIFE) by the yellow collor and the long length (45 cm) were previously callibrated[17], and an elastic constant (K) of 0,082 kgf/cm was found.

Electromyography: Muscle activation data were collected through an Electromyograph Miotool 400 (Miotec Biomedical Equipments Ltd, Porto Alegre, Brazil). The sampling rate used was of 2000 Hz per channel. To capture the electromyographic signal (EMG signal), all procedures recommended by Hermens et al.[18] were strictly observed, being the impedance verified and accepted when it was less than 5KΩ. The reference electrode was positioned over the spinous process of the seventh cervical vertebra (C7). The muscles monitored were the MU and the left and right OE. Pairs of disposable surface electrodes were used, from the brand Kendall (Meditrace

– 100; Ag/AgCl; diameter of 2.2 cm, with adhesive fixation, bipolar configuration). The electrodes were positioned over the muscle belly, parallel to the muscle fibers, in a way that they were 2 cm apart from each other[19]. For the MU, the electrodes were placed bilaterally at the level of L5 and aligned parallel between the line of the posterior-superior iliac spine (PSIS) and the interspinous space of L1 and L2[20]; for the OE, the electrodes were positioned at a mean point distance between the iliac crest and the lowest point of the costal margin (up to the third lumbar vertebra)[21]. For comparison, the EMG signals were normalized based on the maximal voluntary isometric contraction (MVIC) of the MU and OE muscles. To obtain this parameter, before the start of the assessment protocol described above, all participants were submitted to a test of the MVIC, which consisted of the performance of two MVIC, lasting five seconds each, with a 2-minute interval between them. For the MVIC of the OE muscles, the individuals were positioned sitting in a chair, with back supported, with the arms extended beside the body and holding on to the seat. From the established position, the subjects were instructed to flex and rotate the trunk to the left and then to the right, against a manual resistance imposed on the shoulders in the direction opposite to flexion and rotation[16]. This procedure was performed twice on each side. For the MU muscles, subjects were positioned in prone[20], with the arms extended beside the body and the thighs and legs fixed on the ground with the assistance of manual resistance imposed by two assessors. Meanwhile, another assessor applied a resistance in the upper torso, in the opposite direction to the trunk extension movement performed by the subject[16]. The root mean square (RMS) of the three central seconds of each MVIC was calculated. The highest value was used as reference for normalization. To ascertain the reliability of the test and also to provide some information about the validity, an analysis of the intraclass correlation coefficient (ICC) was performed, which revealed that there was a high degree of consistency between the MVIC. The ICC for the right and left OE muscles was 0.998 e 0.990 respectively. To the right and left MU muscles, the ICC was of 0.997 and 0.999, respectively.

Data analysis

The EMG signals were submitted to a process of digital filtering with the support of the software SAD32 (School of Engineering – UFRGS), version 2.61. A Butterworth bandpass filter, third order, with a cutoff frequency between 20 and 500 Hz was used. The EMG curves were divided according to the flexion and extension phases of each repetition, based on visual information provided by the webcam connected via USB to the same computer where the eletromyograph was connected.

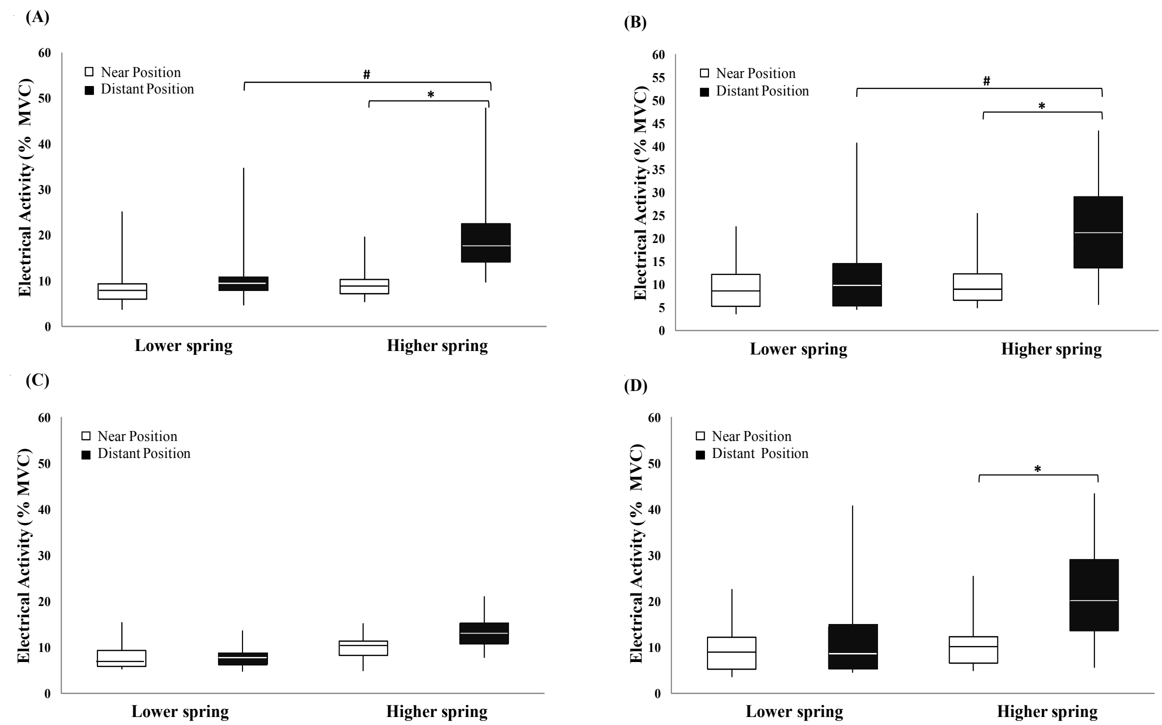
The camera images were also used to assess the mean angular velocity of the repetitions, calculated by the quotient between the range of motion in degrees and the duration of the execution. The RMS value of each phase cut from each repetition was calculated, and then, the average of these values was computed, normalized and used for statistical analysis.

Statistical analysis

The data were analyzed using the SPSS 17.0 software. Data normality was evaluated using the Shapiro-Wilk test, and the equivalence of variances was evaluated by the Levene test. Since there was no adherence to the normal model, it was attempted to transform the data through the logarithmic, exponential and secant process. As the normality was not verified through these methods, and considering the small number of participants, a non-parametric test was chosen. In order to verify the differences between the influence of the adjustments and positions used on the EMG of the muscles evaluated in each movement phase separately, multiple comparisons were performed using the Wilcoxon test. The level of significance chosen for all tests was of $p \leq 0.05$.

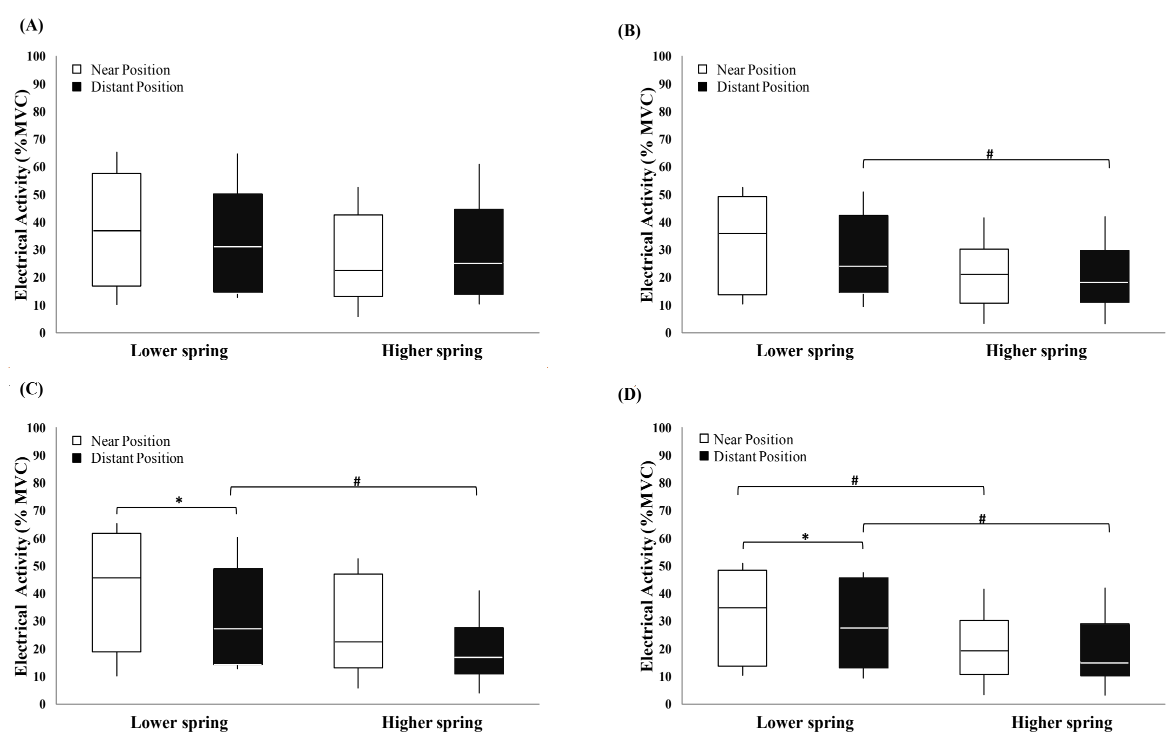
Results

Overall, the results indicated that the electrical activation of the muscles evaluated was significantly influenced by the diferent spring height adjustments and subjects' positions. As shown on Figure 2A and 2B, during the hip extension phase, the right and left MU presented significant differences in the comparison between the spring heigths in DP and also in the comparison between the positions in the HS. On the other hand, during the hip flexion phase, significant differences were only observed for the right side and in the comparison between the positions in the HS (Figure 2C and 2D). In both phases of the movement, the highest percentages of EMG for the MU muscles were obtained in the combination HS and DP. When the OE were evaluated in the extension phase, significant differences were observed only for the rigth side in the comparison between the heigths in DP (Figures 3A and 3B). For the flexion phase, both the right and left OE presented significant differences in the comparisons between the positions of the subjects in the LS and in the comparison between the spring heigths, with the subjects placed in DP (Figures 3C and 3D). As opposite from the MU, the largest percentange of electrical activation of the OE muscles were found in the LS with NP.



Left side (A) and rigth side (B) in the extension phase. Left side (C) and rigth side (D) in the flexion phase. * significant differences between positions in the same height. # significant differences between height in the same position.

Figure 2. Maximal, minimum and median values of the normalized electromyographic activity of multifidus muscles in evaluated positions and height.



Left side (A) and rigth side (B) in the extension phase. Left side (C) and rigth side (D) in the flexion phase. * significant differences between positions in the same height; # significant differences between height in the same position.

Figura 3. Maximal, minimum and median values of the normalized electromyographic activity of external obliques muscles in evaluated positions and height.

Discussion

The results showed that the variations of subjects' positions and springs' adjustments produced changes in the flexion phase different from the extension phase in the muscle activation of the anterior and posterior muscles of the trunk, in the same movement.

During the phase of hip extension, it was observed an activation of the MU 10% higher when the spring height changed from low to high (with the subject in the DP). These findings suggest that the MU activity is related to the resistance torque (RT) (product of the active external forces and their perpendicular distances[22]) offered by the exercise in this situation. Using two spring fixations similar to those used in the present study, Silva et al.[13] quantified the reaction time during the performance of the HFE in the Cadillac and observed that the mechanical overload was greater when the spring was fixed in the high adjustment. Thus, considering this situation of a higher overload, the dificulty of maintaining the pelvis in a neutral position, as requested, it is possible to admit that it may have happened an anteversion of the pelvis, which would justify an increase in the MU activity. These ideas corroborate to the findings reported by Queiroz et al.[10] regarding to the increase in the MU activation observed in the modification from the pelvis position from neutral to anteversion during an exercise of stabilization in the quadruped position of Pilates. Furthermore, although statistical differences have been observed only on the rigth side, the hypothesis that an undesirable movement of anteversion have influenced the results of the MU is considered by observing that, in the same situations assessed, the OE muscles, responsible for the maintenance of the pelvis in neutral position during hip extension performed in supine[23] had shown an apparent decrease of the electrical activation (Figure 3).

According to Silva et al.[13], when the spring is placed in LS position, the weigth of the thigh and leg contributes more for the composition of the RT than the spring torque itself. From a mechanical point of view, in this situation, the RT will be in the extension direction, even with the spring pulling in order to flex the hip. Considering, thus, the action of the hip flexors during the flexion phase, there would be a higher tendency to anteverted the pelvis, with a subsequent increase on lumbar lordosis[23]. It is possible that the highest challenge to maintain the pelvis in the relative neutral position, avoiding the anteversion, explains the significant increase of OE activation in 20% of the MVC in HS and NP to 40% of MVC observed in the situations LS and DP (Figure 3). The OE action for the maintenance of the pelvis position in supine, as the hip is flexed, had been previously descibed by Calais-Germain and Lamotte[23] and is consistent with its function of global muscle documented by Bergmark[24].

Studies that investigated specifically the electrical activation of the OE and MU muscles during the performance of the HFE exercise of Pilates, performed in supine were not found in the literature. However, it is possible to establish a comparison with other studies which evaluated the activation of the trunk muscles during exercises conventionally known as stabilizers, aiming to support physical therapists to choose the exercise more adequated to the clinical objectives established.

Considering the MU muscles, the literature has documented that they are involved in the production of the extensor torque and in the spine stabilization[25]. Besides this, the MU has been targeted of therapeutic exercises, specially in cases of chronic low back pain associated to the atrophy of this musculature[16,25]. In this context, Arokoski et al.[16] interested in the activation of the MU during different therapeutic exercises, recorded surface and deep EMG signals of the MU in the level of L2 of five men and four women and found percentages that variated, in average, ranging from 4% to 20% of the MVC in isometric and dynamic therapeutic exercises. These results are similar to those found in the present study, in which the levels of electrical activation for the MU had shown a range from 10% to 20% of the MVC.

Considering these results and the recommendations done by McGill[25], which states that an activation of 10% of MVC or less is enough for stabilization purposes during the activities of daily living, the HFE exercise on the Cadillac is recommended as one more option of stabilizing exercise, especially in the initial phase of rehabilitation. On the other hand, according to Souza, Baker and Powers[26], activation levels below 40% of MVC, observed for abdominal and spinal erectors muscles, produced during stabilizing exercises including the unilateral HFE exercise performed in supine, may not be enough for muscle strengthening of healthy subjects. In this context, our suggestion is that physical therapists use other types of therapeutic exercises when the aim of the program is a higher performance of the spinal erectors, since the levels of activation obtained for MU during HFE were equal or lower than 20% of MVC.

The OE muscles have also been object of attention by several studies which made comparisons among different abdominals exercises, in addition to studies which investigated the muscle patterns among stabilizing exercises. In this scenario (but outside the Pilates context), McGill and Karpowicz[27] analyzed exercises performed on the ground without equipments in the supine and four-point kneeling positions and obtained activation values of 20 to 40% of the MVC for the OE muscles. In addition, Queiroz et al.[10] found percentages of activation for the OE ranging from 27 to 43% of MVC when comparing the activity of the stabilizing muscles of trunk and hip. In a similar way, in the present study, activation values of the OE muscles (20 to 45% of MVC) were obtained bilaterally during the hip flexion phase. In special, the higher percentages were obtained when the spring was fixed in the lower position and the subjects were placed in the NP.

Considering the similarity observed in the comparison between the electrical activation values obtained for the OE in the studies from Queiroz et al.[10], McGill and Karpowicz[27] and those found in the present study, it may be suggested that if the objective of the training is the muscle strengthening of healthy subjects, all three exercises investigated in the studies compared in the paragraph above can be used. However, some clinical situations require more caution in the correct selection of the therapeutic exercise for the strengthening of the abdominal muscles. In studies developed with animals, performed by Callaghan and McGill[28] support the idea that exercises performed with repetitions of spine flexion can cause disc herniation. Moreover, exercises with abdominals that actively flex the pelvis and trunk can represent a problem for persons with disc pathologies, since this posture can generate an increase in intra discal pressure[29] and a compression in lumbar spine[30].

Given these considerations, the therapeutic use of the HFE exercises on the Cadillac with active abdominals while resisting to trunk extension and maintaining the pelvis and spine in a relative neutral position, can be one of the safest and asymptomatic options for persons with disc pathologies in comparison to the exercises performed with the trunk and pelvis in flexion. However, generalizations must be avoided, especially when considering weak muscles and special populations[26], such as the older adults, being the professional responsible to evaluate the patient's initial condition regarding the muscle strength or the coordination capacity and to decide which is the HFE condition most adequated to the individual capacity of each patient or client.

It is still important to highlight that the prescription of the HFE exercises for individuals with spondilolysthesis or stenosis in the vertebral foramen should be performed carefully, since some studies warn that individuals with these conditions may not tolerate the movements of trunk extension[15], which may happen in the HFE, when they are extremely weak or unable to stabilize the pelvis and spine when there is an increase of external loads.

Regarding to the methodological limitations, the absence of a quantitative control of the maintenance of the stability of the positioning of the pelvis and the trunk during the execution of the exercises may have influenced directly the activation of the muscles evaluated. Nevertheless, the results presented here are interesting and deserve appreciation, since the relative stability of this region had been monitored by an evaluator placed beside the participant and that, in adittion, gave feedback of the quality of movement, a situation common in Pilates rehabilitation programmes, which, consequently, can approximate the results to the clinical reality. Another important aspect that may be considered is the fact that only the trunk and lower legs assymetries visually identifiable were excluded. Thus, scoliosis of lower degrees or small discrepancies of the lower limbs may had influenced the results.

This is a possible explanation for the results obtained only for the rigth side, specifically for the OE in the flexion phase and for the MU in the extension phase. However, the limitations proper to the use of EMG[19], regarding the greater proportion of fat tissue in the anterior region of the trunk shall also be considered as possible causes of the discrepancies results for the rigth and left sides.

In an ultimate analysis, the small number of participants may have been a limitation since the sample may be easily contaminated by a single case of postural deviation. The consequence of this fact is that the statistical analysis may not have found a difference that existed indeed (type error II), therefore, our recommendation in that future studies should use a relative greater number of individuals than that indicated by sample size calculation, while considering the ethical aspects related to some types of evaluations and the public costs. However, it is valuable to highligth that the statistical power of 80% reached with the number of subjects evaluted in the present study is an indicator of the capacity of the test used to verify real differences, considering their existence. The scientific scarcity of studies in this field, considering the electrical evaluation of trunk musculature during the performance of Pilates exercises and the widespread use of this method for rehabilitation, were the motivation for the development of this study. In addition, the voluntary contraction of the powerhouse muscles advocated by the Pilates method, might be considered a limiting factor, since it could affect significantly the electrical activity of the muscles studied. However, this would be a systematic bias since all the exercise's variants analyzed would be susceptible to the same individual initiative.

Conclusion

It was possible to identify differences between the levels of activation of the MU and OE muscles in the different spring adjustments and subjects' positions inthe HFE movement assessed on the Cadillac. The main findings showed that, for the MU muscles, the higher percentages of muscle activation occurred in HS with DP, both for the flexion and extension phases. However, for the OE muscles, the higher percentages of EMG were observed in LS with NP, in the flexion phase. These results suggest that the muscles which compose the powerhouse are not always activated as a single group and in the same intensity.

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