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ORIGINAL ARTICLE

Analysis of electromyographic patterns during standard and declined squats

Análise do padrão eletromiográfico durante os agachamentos padrão e declinado

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Abstract

Objective: To identify and compare the electromyographic (EMG) pattern of the main muscles of the lower limbs with bilateral support during standard and declined squats. **Methods:** Eight healthy subjects were recruited (three men and five women), all right-handed and weekend athletes (means: 20.57 years; 69.5±15kg; 1.73±0.15m). Electromyographic (EMG) signals from the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), soleus (SO), tibialis anterior (TA) and erector spinae (ES) muscles were recorded during the ascending (70°-0°) and descending (0°-70°) phases of the standard squat (horizontal plane) and declined squat (at 25°). The integral of the EMG activity for each muscle was calculated over an interval between 300 ms before the start of the movement and its end. The mean for each muscle for each subject was analyzed using analysis of variance for repeated measurements (ANOVA) to investigate the effect of the squatting task. **Results:** Qualitative analysis revealed that the muscle activity patterns during standard and declined squats were similar, and quantitative analysis did not reveal any differences in EMG activity. **Conclusion:** The results demonstrated that the EMG activity of the muscles studied was similar in these tasks.

Key words: electromyography; knee joint; motor activity; exercise therapy.

Resumo

Objetivo: Identificar e comparar o padrão eletromiográfico (EMG) dos principais músculos do membro inferior com apoio bilateral durante o agachamento padrão e declinado. **Métodos:** Foram recrutados oito sujeitos (três homens e cinco mulheres), todos destros, atletas de final de semana e saudáveis (médias: 20,57 anos; 69,5±15kg; 1,73±0,15m). Foram registrados os sinais eletromiográficos dos músculos vasto medial oblíquo (VMO), vasto lateral (VL), bíceps femoral (BF), sóleo (SO), tibial anterior (TA) e eretor espinhal (EE) durante a fase ascendente (70°-0°) e descendente (0°-70°) dos agachamentos padrão (plano horizontal) e declinado (a 25°). A integral da atividade EMG de cada músculo foi calculada no intervalo de 300 milisegundos (ms) antes do início e do final do movimento. A média de cada músculo para cada sujeito foi analisada pelo teste de análise de variância para medidas repetidas (ANOVA) para verificar o efeito da tarefa de agachar. **Resultados:** A análise qualitativa revelou que o padrão de atividade muscular durante os agachamentos padrão e declinado foram similares, e a análise quantitativa não revelou diferenças na atividade EMG. **Conclusão:** Os resultados demonstram que a atividade EMG dos músculos estudados foi similar entre as tarefas propostas.

Palavras-chave: eletromiografia; articulação do joelho; atividade motora; terapia por exercício.

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Introduction

Patellofemoral Pain Syndrome (PFPS) comprises several lesions that affect the knee-extensor muscle group, such as patellar tendinopathy, tendinitis in patellar tendon insertion, patellar tendinitis, patellar tendinosis, jumper's knee and patellofemoral dysfunction[1]. It is a common condition that predominantly affects individuals between 10 and 35 years of age, especially women[2]. Patellofemoral dysfunction causes great stress to joint cartilage and has the potential to increase stress to the subchondral bone, which is a plausible explanation for the pain in that joint[3].

Although the patellar instability is the main cause for that syndrome[4], there are many factors that can cause this instability[5]. The antagonism between the activity of the vastus medialis obliquus (VMO) and of the vastus lateralis (VL) stabilizes the patella. Thus, when there is imbalance between the forces generated by these parts of the quadriceps, instability ensues, causing the onset of pain in the patellofemoral joint[2], especially when that joint is overloaded.

Closed kinetic chain exercises have been employed in many rehabilitation programs, including those for PFPS patients[6,7]. Squatting is a good example of a closed kinetic chain exercise[8] and is part of any gymnastics or workout program[9], as well as rehabilitation programs[10]. The main goal is to develop strength in the main lower-limb muscles[10], although there may be a difference in the EMG activity of those muscles[11]. More recently, Purdam et al.[12] and Young et al.[13] suggested that the declined squat (DS) at 25° is a good recovery strategy for patients suffering from patellar tendinitis, if compared to the standard squat (SS), which is done horizontally.

Nevertheless, the motor strategies (muscle recruitment patterns) involved in the squatting have not been fully investigated. Cheron et al.[14] and Hase et al.[15] focused on the motor strategy for the initial phase of squatting, and there may be more than one strategy for that phase[15]. Other studies observed the motor strategy in sports movements, which focused mainly on the knee joint[8,10,11]. More recently, Dionísio et al.[16] identified and described a single strategy for squatting when trunk movements are limited in the sagittal plane.

However, these studies where designed for the SS, and the effects of the DS on motor strategy are still unknown. Kongsgaard et al.[17] pointed out that, in the unilateral DS, the EMG activity of the quadriceps and plantar flexors was greater than that of other muscles, and that the patellar tendon suffered greater tension than during the SS. This extra strain on the patellar tendon produces a biopositive effect, which could justify the improvement in patients with patellar tendinitis. However, the author did not discuss the pattern of muscle recruitment used in this kind of squat compared to the standard type. Therefore, the objective of the present study was to identify and compare the electromyographic pattern during the ascending and descending phases of SS and DS.

Methods

Sample

Eight healthy, young adults (three males and five females) were selected. They were all right-handed and did not exercise on a regular basis (weekend athletes). Age varied from18 to 25 (mean 20.57 years), weight from 50 to 90Kg (mean 69.5±15kg), and height from 1.60 to 1.90m (mean 1.73±0.15m). Exclusion criteria were history of pain, surgery or bone, joint and muscle disorders in the lower limbs. The subject had the right to quit the research at any time, as stated in the consent form previously signed by them and approved by the Research Ethics Committee of Centro Universitário do Triângulo (Unitri), under protocol number 624842 on June 27, 2007.

Data recording

After shaving and asepsis with alcohol, simple differential active surface electrodes were fixed on the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), soleus (SO), tibialis anterior (TA), and erector spinae (EE). For the VMO, the electrode was placed on the muscle belly, according to the direction of the fibers (about 54º) and 2cm distal from the motor point[18]. To find the motor point, the subject was asked to perform an isometric contraction of the quadriceps so that the VMO activity could be observed. The electrode was then placed as close as possible to the retinaculum. For the other muscles, the electrodes were placed according to the guidelines of the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) from the Biomedical Health and Research Program (BIOMED II) of the European Union[19]. The electrodes were not disposable, and each one consisted of two parallel silver plates measuring 1cm long and 1mm wide each, placed 1cm apart. The electrodes had a 20-time gain and were connected to the computer-aided electromyograph manufactured by DataHominis Tecnologia Ltda with a 100-time gain (2000-time total gain), 15Hz to 1kHz band pass filter, with an acquisition frequency of 2000Hz. A 3cm^2 ground electrode was also attached to the lateral malleolus and daubed with electroconductive gel to improve signal transfer and eliminate any occasional external interferences. An auxiliary channel was also used with a DataHominis electrogoniometer with flexible poles and 360° rotation. It was placed on the knee joint, with its axis attached to the lateral epicondyle of the femur, and the arms aligned with the femur and the tibia. Before the assessment started, the electromyographic channels were calibrated to determine the total knee extension (0º) and flexion (180º).

Task

The subjects were positioned with feet parallel and shoulder-width apart. They were also advised to keep arms folded across the chest, so that each hand touched the opposite shoulder. The electromyographic signals were recorded from the dominant limb (right-hand side) only. The electrical activity of these muscles was captured during the SS (Figure 1A) and the DS at 25º (Figure 1B), in the descending phase (0º to 70º) and in the ascending phase (70º to 0º). An adjustable support was placed on the subject's back to restrain the final movement of the descending phase and to mark the onset of the ascending phase movement.

The subject was allowed 2 practice repetitions in order to learn the movement, and to verify if any wires would limit movement and if signal-recording was adequate, i.e. noise-free. The subjects then performed 10 SS repetitions, divided into descending repetitions and ascending repetitions. After that, they performed the same number of repetitions, in the same sequence, for the DS.

The onset of each movement was signaled by the researcher's oral command. The subjects were instructed to perform the movements as quickly as possible and to maintain the final position until the end of the data collection, which lasted 2 seconds. Between each repetition, there was an interval of about one minute, necessary to save the data obtained and also to avoid muscle fatigue. Between each series of 5 repetitions, there was a 3-minute rest period intended, once again, to avoid muscle fatigue.

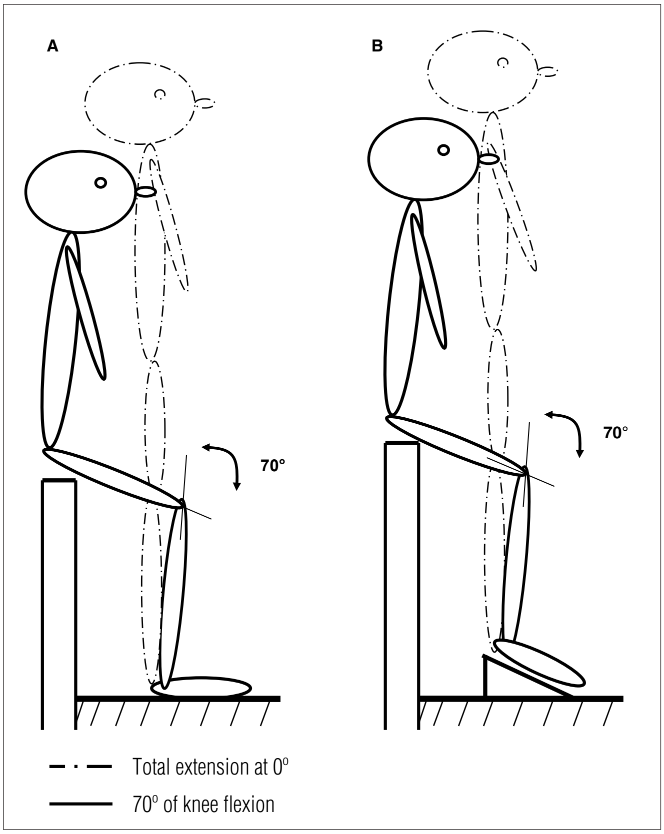

Figure 1. Standard Squat (A) and Declined Squat at 25º (B) Model. The descending phase of the movement was from 0° to 70° of knee flexion, and the ascending phase of the movement was from 70° to 0° of knee flexion.

Data processing

The EMG signals, obtained in microvolts (μV), were rectified (*full wave*), filtered (low pass at 25Hz, using a second-order *Butterworth* filter) and normalized by the maximal voluntary isometric contraction (MVIC). The EMG signals were analyzed from the onset of the movement minus 300 milliseconds (ms) set from the beginning of the angle displacement, captured by the electrogoniometer. The mean of the 5 repetitions of each subject for each task was obtained. Based on that mean, the integral (area of the rectified curve) of each muscle until the end of the movement was calculated. These procedures were carried out in *Excel* (*Microsoft, Office* XP 2003) and *KaleidaGraph* (*Synergy software*, version 3.08).

Statistical analysis

Student's t-distribution was used for the sample calculation based on the standard deviation observed in pilot studies. In order to evaluate the effect of the task, we used *two-way* factorial ANOVA for repeated measures [task (SS and DS) X muscles (curve integral of six muscles)]. As a *post hoc* test, we used the *Least-significant difference* (LSD) method. The data were analyzed in a personal computer using the statistical software *Statistica for Windows* (Statsoft, Inc. version 5.0). For all evaluations, the significance level (α) was set at 0.05 and β at 0.2, with 80% power.

Results

Descending phase of squat (eccentric activity)

Through a qualitative analysis of the time series of a squat repetition in the descending phase (Figure 2), it was noted that all of the muscles had a basal activity before the onset of the squatting movement. Only the EE had some additional activity. This occurred for both squat modes

(Figures 2E and 2F). In the beginning of the squat, the SO and the EE increased their activity in the DS, suggesting that they were involved at the onset of the movement. For the SS, the TA was also activated, suggesting that it was recruited to start the movement (Figure 2A). The TA would be needed to generate a postural disturbance in the knee joint and to begin the movement.

In both squats (DS and SS), the electric activity of the VMO and VL muscles began after the onset of the movement (Figures 2C and 2D). These muscles try to decelerate to the movement to control the flexion speed, which increases with gravity as the knee flexes. This would explain the increased EMG activity when knee flexion is greater. The BF muscle was the last to be activated in the DS (Figure 2E), but in the SS its activation was concomitant with the VMO and the VL (Figure 2F). This activation may be necessary to control the rotation of the pelvis, keeping it stabilized and aiding the EE in the control of the squat. It may also contribute to knee stability during the movement in conjunction with the quadriceps heads.

After the onset of the movement, the EMG activity of all muscles being studied increased in both groups; but

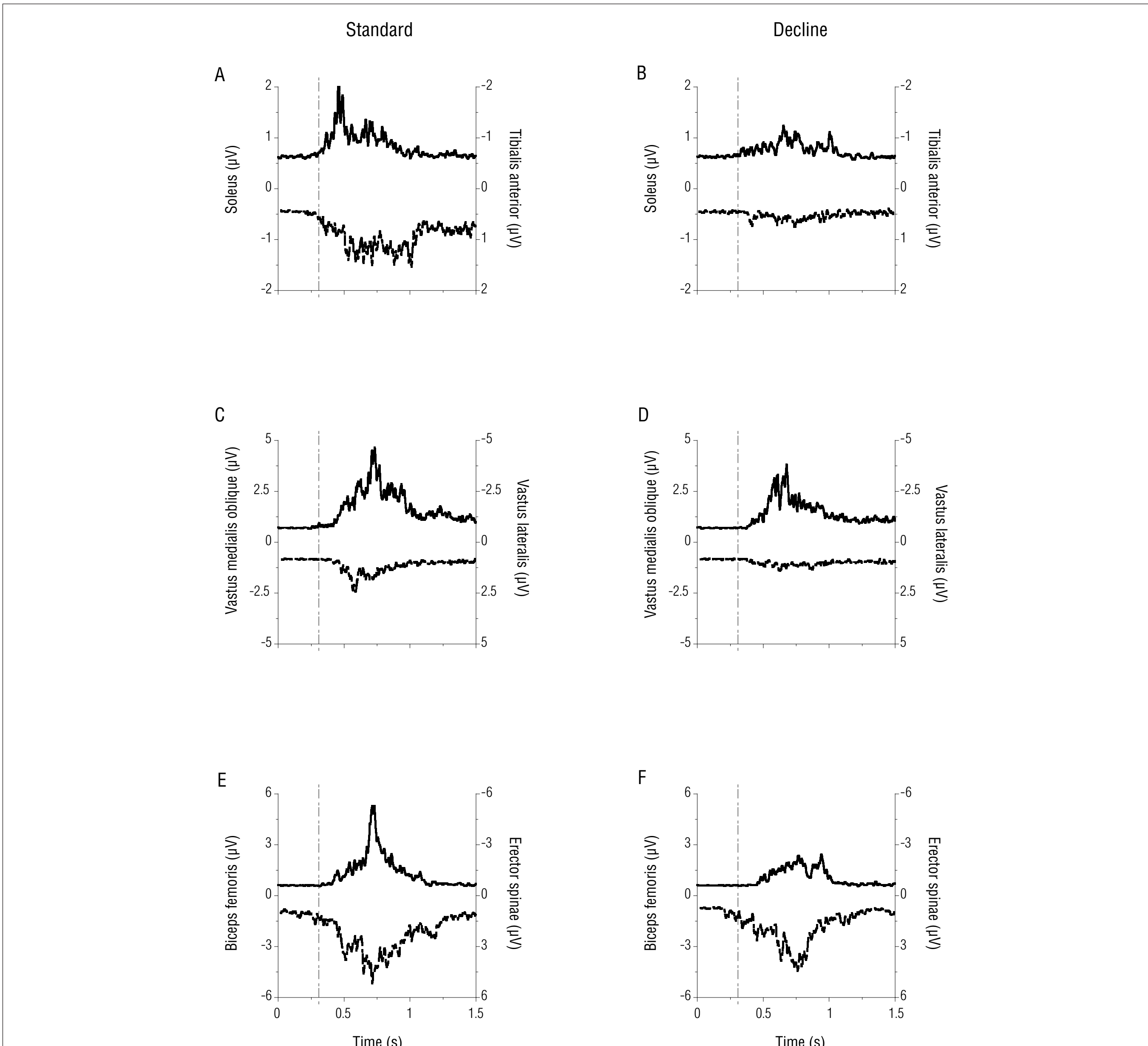

Figure 2. Time series of normalized EMG activity (microvolts) of the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), soleus (SO), tibialis anterior (TA) and erector spinae (EE) in the descending phase of the standard (left) and declined (right) squats. The dotted line represents the onset of the movement.

qualitatively the EMG activity of these muscles was greater in the SS task. However, when the mean of the integral for each one of the muscles was calculated for the entire movement (Figure 3A) and statistically analyzed, the analysis of variance did not reveal any effect of the tasks ($F_{(1.14)}$=2.54 p<0.1332) nor of the interaction ($F_{(5.70)}$=0.10 p<0.9926); in spite of that, as expected, there were effects of the muscles ($F_{(5.70)}$=5.34 p<0.003). The *post hoc* did not reveal any effect of the task for each one of the muscles (p>0.33).

Ascending phase of squat (concentric activity)

The qualitative analysis of the time series of a squat repetition in the ascending phase (Figure 4) shows that all the muscles studied were activated before the onset of the movement, both in the DS and in the SS. This is necessary to maintain the initial position (squat at 70°). Nevertheless, the magnitude seemed greater in the SS, when compared with the DS. In order to start the movement in the ascending phase, it is necessary to increase the activity of the muscles responsible for overcoming inertia and gravity (VMO, VL, and EE) in both squats (Figures 4C and 4D). These muscles remained active throughout the movement until the upright position was reached. Activity was then reduced to a minimum required to maintain the posture.

The TA muscle was concentrically activated to produce ankle joint stabilization and anterior tibial displacement in the SS, but during the DS its activity was reduced (Figures 4A and 4B). The BF behaved differently between the squats. In the DS, its activity remained low before the onset of the movement; but as soon as the movement started, it was slightly more noticeable, moving concentrically and generating a posterior pelvic tilt to aid in the ascent (Figure 4F). In the SS, the BF had a greater activation than in the DS even before the onset of the movement, and this activity increased during the movement (Figure 4E).

After the onset of the movement, the EMG activity of all muscles increased in both groups, but qualitatively the EMG activity of these muscles was greater in the SS task. However, in spite of these observations (Figure 3B), the analysis of variance did not reveal any effects of the tasks ($F_{(1.14)}$=1.03 p<0.3280) or interaction ($F_{(5.70)}$=0.16 p<0.9769), but there were effects of the muscles ($F_{(5.70)}$=6.54 p<0.001). In the same way, the *post hoc* did not show effects of the tasks for each of the muscles (p>0.27).

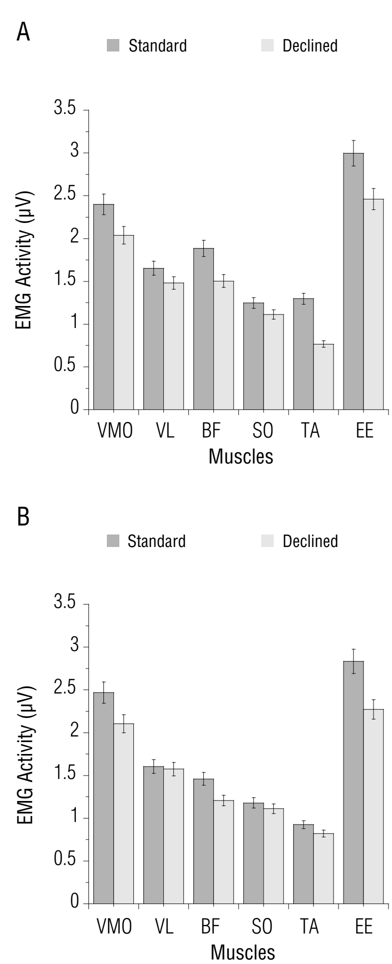

Figure 3. Mean across all subjects for the integral of the EMG activity (μV) and standard deviation for the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), soleus (SO), tibialis anterior (TA) and erector spinae (EE) in the descending (A) and ascending (B) phases of the standard (hatched bar) and declined (dotted bar) squats.

Discussion

The main objective of the present study was to identify and compare the motor strategy (motor recruitment pattern) and the electromyographic activity in the ascending and descending phases of the SS and DS. All subjects were able to perform the tasks adequately.

According to Hase et al.[15], the EE, gastrocnemius, and medial ischiotibial muscles are the first to be activated to enable the trunk and the knees, respectively, to begin the descending movement during the squat. The authors noted a brief deactivation of the EE after the onset of the movement, and the magnitude of the activity increased gradually as the squat was being performed. In contrast, TA activity was only observed in part of the subjects. This pattern was reflected from the displacement of the pressure center as the squat began[15].

For the descending phase of the squat, the results of the present study showed that the EE muscle was one of the first to be activated to generate a postural disturbance in the trunk, increasing its activity as trunk flexion occurred. There was no deactivation of the EMG activity of the EE, but there was TA activity throughout the SS. The TA muscle was activated at the onset of the movement to produce a postural disturbance in the knee joint as a pre-programmed reaction[15,16]. However, TA activation was not observed in the DS. To produce postural disturbance, the subjects may have used the EE[15] or another muscle which was not being examined. The popliteus muscle is considered a primary knee flexor and an external rotator of the femur when the foot is not free to move[20,21]. Stensdotter et al.[22] observed that the popliteus was the first to be activated during isometric contractions of the quadriceps in both closed and open kinetic chain regardless of the range of motion. The subjects of the present study probably used the strategy of primary activation of the popliteus to produce postural disturbance, since the TA was at mechanical disadvantage during the DS. Further studies must be carried out to confirm this hypothesis.

In addition to greater EMG activity of the EE in the descending phase to control the anterior displacement of the center of mass and maintain an adequate position[23,24],

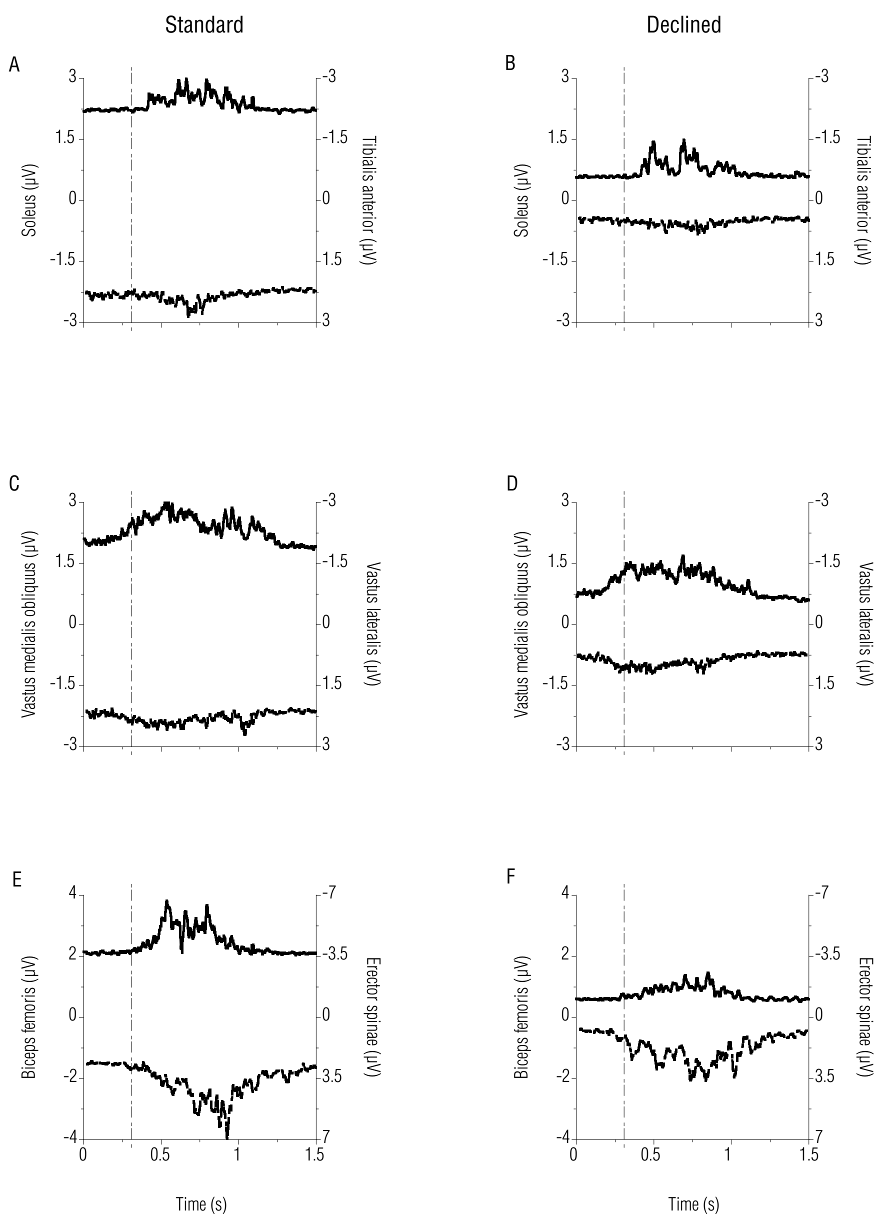

Figure 4. Time series of the normalized EMG activity (microvolts) of the vastus medialis obliquus (VMO), vastus lateralis (VL), biceps femoris (BF), soleus (SO), tibialis anterior (TA) and erector spinae (EE) in the ascending phase of the standard (left) and declined (right) squats. The dotted line represents the onset of the movement.

the BF was also activated. Ohkoshi et al.[25] described a great activation of the posterior thigh muscles in the descending phase of the squat with trunk flexion, which corroborates the findings of the present study. As the trunk flexes, an effective action of the BF is necessary to stabilize the hip. This action reduces anterior pelvic tilt during trunk flexion, thus preventing the center of mass from moving forward and aiding the EE. In the SS, this synergy appeared to be greater (Figure 2E), possibly because it requires greater hip flexion than in the DS.

The TA activity was important at the onset of the SS movement, but it was also relevant during the ankle stabilization movement in the medial-lateral direction[16]. The TA is also important in anterior-posterior stabilization and tibial control to maintain balance. This stabilization of the tibia is also attained through the synergetic action of the SO, whose main function is to decelerate the tibia during the descending phase of the squat. The importance of the SO in tibial control has been noted by other authors during gait[26] because it contributes to knee extension, thus being an agonist of the quadriceps. In the SS, the SO is well activated during the movement and tends to be greater than in the DS (Figures 2A and 2B). This probably happened because, during the descending phase of SS, there is an increment in the anterior displacement of the tibia and a consequent increase in ankle torque[16]. In the DS, however, the ankle is positioned in plantar flexion, and the anterior displacement of the tibia is more discreet, not requiring much SO activation. However, data analysis showed no statistical difference. The SO muscle has an activation pattern similar to that of the TA, being its antagonist, and performs a co-activation during the descending phase of the squat. Together they promote the stabilization of the ankle in the anterior-posterior direction.

Dionísio et al.[16] showed that the quadriceps muscles and the posterior thigh muscles do not change their EMG activity at the onset and in the acceleration phase of the movement. They argue that gravity produces free fall and eliminates the need for any extra EMG activity. The present study corroborates these findings. These muscles (VMO, VL, and BF) are activated during the movement in an attempt to decelerate it by contracting eccentrically. The VMO muscle activation is qualitatively greater than that of the VL, although the analysis of variance did not reveal the effect of the task.

In the ascending phase of the squat, the subjects were already in a squatting position before the onset of the movement, therefore all muscles displayed EMG activity with the aim of sustaining the initial position. Even before the onset of the movement, there was an increase in the EMG activity of the VMO and VL muscles in order to execute the movement. This is in agreement with the study by Isear et al.[11]. The EE is also activated before the movement, contributing to the extension of the trunk so that the ascending movement can be performed efficiently.

After the onset of the movement, these muscles maintained great EMG activity and other muscles were activated, such as the SO, TA, and BF. The BF contributed with the hip extension, with a posterior pelvic traction[25], whereas the TA and the SO were activated to maintain ankle stability[10]. However, the SO was more active to pull the tibia backwards, producing the plantar flexion needed for the ascending phase of the squat. These observations of the ascending phase were similar for both squat modes (Figures 4A and 4B).

The most noteworthy result in both the ascending and descending phases was the tendency, although not statistically significant, for greater EMG activation of all muscles in the SS (Figures 2 and 4). This result does not agree with the study by Kongsgaard et al.[17]. These authors detected the electric activity of the VMO and VL muscles, which was significantly greater in the eccentric phase of the DS than in the SS. The task performed in this study was the unilateral squat in the eccentric phase (0º to 95º). The mechanical demand imposed by this activity is enhanced by the need to decelerate in the descending phase. The fact that the task was performed unilaterally also maximizes this demand and is reflected in the EMG findings. In the present study, however, the squat was bilateral without trunk control, thus minimizing the difficulties in performing the task. The great trunk flexion causes anterior displacement of the center of mass, which generates less knee torque and therefore less EMG activity in the quadriceps. These methodological differences partly justify the contrasts between the studies. These contrasts may also be related to the samples. Kongsgaard et al.[17] used a sample that consisted of seven men and six women, whereas in the present study, the sample consisted of three men and five women. The gender differences may have contributed to the difference in the activation of the EMG activity. Several studies have shown gender differences in various activities, such as greater strength of the knee extensor muscles[27] and in the contact and pressure area of the patellofemoral joint[28] in favor of the men. In contrast, the sliding and rolling between the femur and the tibia during the closed kinetic chain are greater in women[29]. Based on those studies, it is speculated that these differences could generate different torques in the knee and ankle joints[30], which may, in turn, influence EMG activity. Further studies must be carried out in order to confirm these hypotheses related to trunk control and gender differences.

Given the size and composition of the sample, and considering the possibility of gender differences, the results of the present study must be carefully assessed. Nonetheless, it is correct to say that both squat modes are effective for quadriceps strengthening, a common situation in clinical practice, including in PFPS rehabilitation.

Conclusion

According to the methodology, sample and results of this paper, it can be concluded that the pattern of EMG activity of the muscles studied is similar in the standard and declined squats.

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