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Electromyographic activity of vastus medialis obliquus and vastus lateralis muscles during functional activities in subjects with patellofemoral pain syndrome

Atividade eletromiográfica do vasto medial oblíquo e vasto lateral durante atividades funcionais em sujeitos com síndrome da dor patelofemural

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Abstract

Objective: The purpose of this study was to evaluate the amplitude and onset of electrical activation of the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) and vastus lateralis obliquus (VLO) during functional activities in individuals with patellofemoral pain syndrome (PFPS). **Methods:** Twenty women participated in the study: ten in a control group and ten in the group with PFPS. The electromyographic signal of the quadriceps muscle was detected using simple active differential surface electrodes and a four-channel electromyography system, during open kinetic chain activities (using an isokinetic dynamometer) and closed kinetic chain activities (step and squat maneuvers). For the statistical analysis, Student's t test and ANOVA with Tukey's post-hoc method were used, with a significance level of $p \leq 0.05$. **Results:** The results suggested that the electrical activation of the VMO was less intense than in the VLO (p=0.04) and that there was greater delay in VMO onset (p=0.0023) in the group with PFPS, with regard to all of the functional activities evaluated. There was a significant difference between the VMO and VLO in relation to the activities of isokinetic extension at 30°/s (p=0.042) and step down with knee flexion at 75° (p=0.038) in the group with SDPF, and in the activities of rising from a bench (p=0.041), single-leg hop (p=0.046) and heel raising (p=0.004) in the control group. **Conclusions:** Under the experimental conditions used, this study suggests that there is an imbalance in the electric activity and abnormal recruitment patterns among the VMO, VLL and VLO muscles in individuals with PFPS, with greater delay and lower amplitude of activation of the VMO in this group.

Key words: electromyography; quadriceps muscle; functional activities; patellofemoral pain syndrome.

Resumo

Objetivo: O propósito deste estudo foi avaliar a amplitude e o tempo de ativação elétrica do vasto medial oblíquo (VMO), vasto lateral longo (VLL) e vasto lateral oblíquo (VLO) durante atividades funcionais em portadoras da síndrome da dor patelofemural (SDPF). **Métodos:** Participaram do estudo 20 mulheres, sendo dez do grupo controle e dez do grupo com SDPF. O sinal eletromiográfico do quadríceps foi detectado por eletrodos ativos diferenciais simples de superfície e um eletromiógrafo de quatro canais, durante atividades em cadeia cinética aberta (em um dinamômetro isocinético) e fechada (através de um step e durante o agachamento). Na análise estatística foram utilizados o teste *t* de *student* e uma análise de variância (ANOVA), com método pos-hoc de Tukey, com nível de significância de $p \leq 0{,}05$. **Resultados:** Os resultados sugerem uma menor intensidade na atividade elétrica do VMO em relação ao VLO (p=0,04) e maior retardo no tempo de ativação do VMO (p=0,0023) no grupo com SDPF considerando todas as atividades avaliadas. Houve diferença significativa do VMO em relação ao VLO nas atividades de extensão isocinética à 30°/s (p=0,042) e descida do step com 75° de flexão de joelho (p=0,038) no grupo com SDPF, e nas atividades de levantar-se de um banco (p=0,041), salto unipodal (p=0,046) e elevação dos calcanhares (p=0,004) no grupo controle. **Conclusões:** Nas condições experimentais realizadas, o estudo sugere um desequilíbrio na atividade elétrica e um padrão de recrutamento anormal entre os músculos VMO, VLL e VLO em sujeitos com SDPF, com maior retardo e menor amplitude de ativação do VMO neste grupo de sujeitos.

Palavras-chave: eletromiografia; músculo quadríceps; atividades funcionais; síndrome da dor patelofemural.

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Introduction

The knee is considered to be one of the joints that is most injured in sport activities[1]. Because it is incapable of dissipating excessive forces, it becomes susceptible to injuries and the development of infirmities resulting from the absorption of these forces[2]. Among the large variety of pathological conditions affecting this joint, the patellofemoral pain syndrome (PFPS) is the most common[3]. It accounts for 25% of the diagnoses in orthopedic clinics[4,5] and 30 to 33% of the cases within sports medicine and at rehabilitation centers[2,6]. These disorders involve the extensor mechanism of the knee and are characterized by diffuse anterior or retropatellar pain. Such pain is commonly reported after performing activities like going up or down stairs, kneeling, squatting and remaining seated for a long time, and during sport activities[2,7,8]. It affects one in every four individuals[9] and most commonly affects adolescents and young adults aged between 15 and 35 years[9,10], especially female athletes[3,5,11].

Even though the etiological factors are not clear, some researchers have correlated the appearance of patellofemoral dysfunctions to anatomical and biomechanical abnormalities of the lower limb or soft tissue restrictions (static imbalance), along with knee muscle disorders (dynamic imbalance)[3,12]. Among these abnormalities, dynamic imbalance has been studied by several authors, who have reported the appearance of abnormal patterns of patellar alignment with changes in the activity of the medial and lateral stabilizers of the patellofemoral joint and the vastus medialis obliquus (VMO), vastus lateralis longus (VLL)[13,14] and vastus lateralis obliquus (VLO)[2,4,5,15] muscles. Other studies have shown the influence of hip rotation on the recruitment patterns of the VMO and VL (vastus lateralis) muscles[16,17].

The electromyographic activity of the VMO and VL among individuals with PFPS has been thoroughly investigated through open kinetic chain (OKC) and closed kinetic chain (CKC) exercises. However, few studies have observed the intensity and the time required to achieve muscular activation in functional activities. Some authors have suggested that there are no spatial (activation amplitude)[18-22] or temporal alterations (beginning time of activation)[7,9,19-21] in the electromyographic femoral quadriceps muscle (m.) patterns during functional tasks. On the other hand, studies comparing subjects with and without patellofemoral dysfunctions have found spatial VMO and/or VL abnormalities in step activities or going up and down steps[2,12,23], walking on a treadmill[24] or tapping of the patellar tendon[25], along with asynchrony in the muscular activation patterns in step tasks[2], step tasks associated with therapeutic patellar tapping[22,26], standing on tiptoes and on the heels[27] and walking on treadmills in the horizontal and inclined surface activities[24,28].

Although studies have investigated the myoelectric activity of the femoral quadriceps muscle of subjects with and without PFPS in functional tasks, there is no consensus in the literature regarding changes in the activation patterns of the three portions of this muscle. Moreover, there is a scarcity of scientific studies evaluating the role of the VLO in patellar stabilization.

In this light, the purpose of this study was to investigate the recruitment patterns of the VMO, VLL and VLO in relation to patellar control among individuals with PFPS, analyzing the intensity and start time (onset) of electric activity when functional activities are performed.

Materials and methods

Characterization of the study

This study was a randomized blind controlled clinical trial, conducted between December 2006 and April 2007 in the electromyography laboratory of a local hospital.

Subjects

Twenty sedentary women, or who did not practice regular physical activity (over three times a week), took part in the study. The volunteers were divided into two groups, composed of ten clinically asymptomatic individuals (22.4±1.65 years; 51.3±6.77kg; 1.60±0.06m) and ten individuals with a clinical diagnosis of PFPS (24.7±4.35 years; 61.6±12.27kg; 1.66±0.05m). The statistical tests did not reveal any anthropometric differences between these two groups. Only women were evaluated in this study, in view of the biomechanical differences between the genders and the greater incidence of this pathological condition among women[4]. Among subjects who demonstrated bilateral knee pain, the knee in which the greatest pain was reported was evaluated.

The healthy volunteers were selected from among students attending the physical therapy course at a public university, by means of a physical evaluation consisting of clinical tests. The volunteers with PFPS were recruited from a university hospital and three local rehabilitation centers, and they performed a clinical diagnosis carried out by their orthopedist. For both groups, there was an identifying evaluation and an analysis of whether they were in a condition to take part in the study, in accordance with the inclusion and exclusion criteria.

The subjects in the PFPS group were included if they showed pain in the anterior or retropatellar region of the patellofemoral joint, reported in at least two of the following functional activities: squatting for a long period of time, going up and/or down stairs, remaining seated for a long time, kneeling, running, isometrically contracting the quadriceps and practicing sports[7]. Furthermore, they had to report pain of at least 2 on the Visual Analog Scale (VAS) in the patellofemoral joint in the week before the evaluation[2].

These subjects did not demonstrate a history of surgery in the knee joint, subluxation or patellar dislodgment, clinical evidence of meniscal injury, acute inflammatory processes, trauma or pain in other evaluated joints of the lower limb, ligament instability, pathological condition of the patellar tendon, chondral injuries, osteoarthritis[7], use of medications or previous physical therapy consultations within the last semester.

Subjects who did not report any histories of knee pain, diseases, surgery, trauma or injury of the osteomyoarticular system of the lower limb evaluated were included in the control group[2]. The volunteers also had to have indicated a VAS pain score of zero in relation to the patellofemoral articulation on the evaluation day and during the preceding week[2].

All subjects were previously informed of the objectives of the study and were asked to sign an informed consent statement, in accordance with the guidelines of resolution 196/96 of the National Health Council. The study had previously been approved by the Research Ethics Committee of the Onofre Lopes University Hospital (HUOL, protocol 017/06).

Instruments

For the study, a four-channel conditioner module was used (EMG System do Brasil Ltda), interfaced with a microcomputer that received the electromyographic signals and filed them, along with the AqDados version 5.0 software for digital signal analysis. To capture the electrical activity of the muscles, simple differential active surface electrodes were used (EMG System do Brasil Ltda), composed of two rectangular parallel bars of Ag\AgCl. One claw type reference electrode was used to eliminate external interference. The signal gain was 1.000x (20 on the active electrode and 50 on the A/D converter). The signal acquisition rate was 1.000Hz, with a filtering of between 20 and 500Hz. The signal was normalized in accordance with the maximum voluntary isometric contraction (MVIC), with the knee at 60º flexion.

To determine the muscle activity onset, initially the subject was instructed to remain in a state of absolute muscular relaxation, and the RMS value was taken as the reference. After asking the subject to initiate the exercise, the beginning of muscle activity was found when the reference values exceeded three standard deviations (sd) of the mean baseline value that had been found while the subject was resting. When the values exceeded this limit, the time immediately before this point (in ms) was considered to be the beginning of muscular activity. The duration of data collection was set at seven seconds, from which four seconds were reserved to record the activity levels while resting. The magnitude of the muscle activity was recorded as the area under the linear envelope (the integral) during muscular activity. The linear envelope has been shown to be reliable for determining the muscular activation magnitude during functional activities. The EMG activity magnitude during the activities was calculated as percentages of MVIC.

The knee joint movement amplitude was measured using a universal goniometer, positioned with the fixed arm aligned with the greater trochanter of the femur and the axis in the region of the knee joint interline. An isokinetic dynamometer (Medina®, Spain) was used for the OKC exercises. To simulate going up and down stairs, a wooden step was used and its height could be regulated at angles of 45 and 75º of knee flexion[2]. To simulate the activity of getting up from a chair, a bench of a height that favored a 90º angle of hip and knee flexion was used.

Procedures

Initially, the subjects warmed up on a stationary bicycle for five minutes with the saddle positioned at the height of the greater trochanter of the femur. Soon afterwards, they performed sustained passive stretching of the hamstrings, leg triceps, thigh adductors and femoral quadriceps: two series of 30 seconds with an interval of 30 seconds.

After these initial procedures, the volunteers were positioned on the isokinetic dynamometer (trunk and hip at 90º flexion) and were stabilized by pelvic and axillary belts, secured using Velcro. The subjects' skin was duly prepared at the electrode locations, involving shaving the area and cleaning using 70% alcohol, with the aim of reducing the tissue impedance. The electrodes were covered with an electrically conducting gel; were positioned over the VMO, VLL and VLO of the lower limb under evaluation; and were attached using adhesive tape. The electrodes for the VMO and VLL were positioned in accordance with the Seniam[29] standards. For the VLO electrode, an imaginary line was traced out from the antero-superior iliac spine to the center of the patella. It was attached at the center of the venter of the VLO, approximately 2.2cm from the femur lateral epicondyle, at a 50º inclination[4]. The reference electrode was positioned over the medial malleolus of the non-evaluated, contralateral limb. Two velcro bands were placed over the electrode region to avoid dislodging them during the activities. The evaluated activities were:

1. Maximum isometric extension on the isokinetic dynamometer, with 60º of knee flexion;
2. Isokinetic extension with the equipment adjusted to 30º/s, going from 60 to 0º;
3. Squatting on the limb under evaluation, from standing up to 45º of knee flexion;

4. Going up onto the step with 45º of knee flexion, starting with the limb under evaluation;
5. Going down from the step with 45º of knee flexion, starting with the non-evaluated, contralateral limb;
6. Mounting the step with 75º of knee flexion, starting with the limb under evaluation;
7. Descending from the step with 75º of knee flexion, starting with the non-evaluated, contralateral limb;
8. Standing up from a bench without support, up to a standing position;
9. Unipedal jump, starting from a doorstop (24cm in height) and landing on the ground;
10. Heel elevation from the ground;
11. Maintaining the body vertical while standing on the heels.

The activities were administered in a random sequence that was drawn for each subject. The subjects were familiarized with all of the tasks and instructed to perform them in a natural manner. Each task was performed once, with a one minute interval between them. The OKC activities followed a standardized verbal command, in which the subjects were instructed to perform a maximum voluntary muscular contraction. For the other activities, they were asked to start and end the movements upon the investigator's command. The data gathering for all the activities took place over a five second period.

Statistical analyses

The normalization of the data was investigated through descriptive statistical procedures using the Shapiro-Wilks test. This analysis was done by means of parametric tests. The differences between the vastus muscles were assessed using ANOVA with normalized RMS values, followed by Tukey's test, when indicated. To investigate the onset among the quadriceps muscles, between each of the exercises, the Student's t-test for independent samples was used. The data were analyzed using the Statistical Package for Social Sciences (SPSS) software (version 14.0). In all of the analyses, a significance level of $p \leq 0.05$ was used.

Results

Comparing the groups, the results showed significant differences in the ratios of VMO/VLO electric activity, such that the control group demonstrated a mean of 0.79 and the group with PFPS showed a mean of 0.66 (p=0.04). Thus, the individuals with PFPS showed decreased VMO intensity in relation to VLO (Figure 1). The data did not show any significant differences in the VMO/VLL ratios between the groups ($p \geq 0.05$).

Comparing the muscles in the control group for each activity, the data showed differences in the VMO/VLO ratios during the activities 8 (p=0.041), 9 (p=0.046) and 10 (p=0.004) (Figure 2). On the other hand, among the individuals with PFPS, the data showed differences in the activities 2 and 7 (p=0.042 and p=0.038, respectively), (Figure 3). All of these activities demonstrated significant differences with greater activation of VLO.

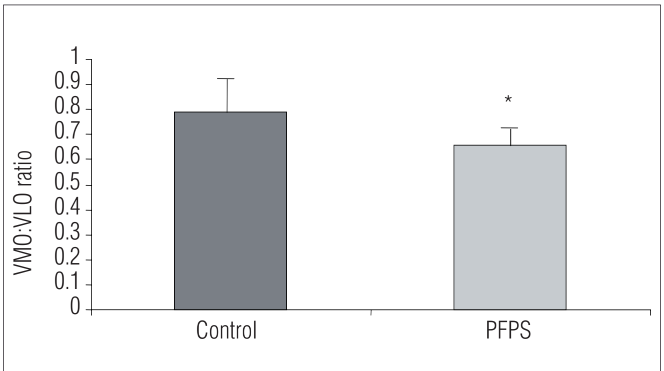
Considering the subjects in all the functional tasks, the results showed a significant differences in the relative onset of VMO-VLO between the groups (p=0.0023). This reveals a greater delay in the time taken to activate the VMO in relation to the VLO, among individuals with PFPS (Figure 4).

However, no significant differences in the VMO-VLL onset ($p \geq 0.05$) were observed in any of the activities, between the two groups. Although no significant differences were found when considering each activity in isolation, the subjects with PFPS showed a delay in VMO onset in relation to VLO, and anticipation of the VLL in most evaluated activities.

Discussion

Electromyographic activity ratios

The results showed a significantly lower VMO/VLO ratios in the PFPS group and VMO/VLL ratios that were similar to that of the control group. This suggested differentiated activation between the VLL and VLO muscles, in subjects with patellofemoral dysfunctions. These results concurred with the study by Pulzatto[2], who studied the influences of the activities of going up and down a step with 45 and 75º knee flexions, on the electrical activity of the VMO, VLL and VLO muscles. They reported lower values for the VMO/VLO ratios and no differences between the VMO/VLL ratios among individuals with PFPS.



*decreased intensity in the VMO in relation to the VLO; significantly greater in the PFPS group than in the control group ($p \leq 0.05$).

Figure 1. Means and standard deviations of the vastus medialis obliquus (VMO)/ vastus lateralis obliquus (VLO) ratios during the functional activities evaluated in the control and patellofemoral pain syndrome (PFPS) groups.

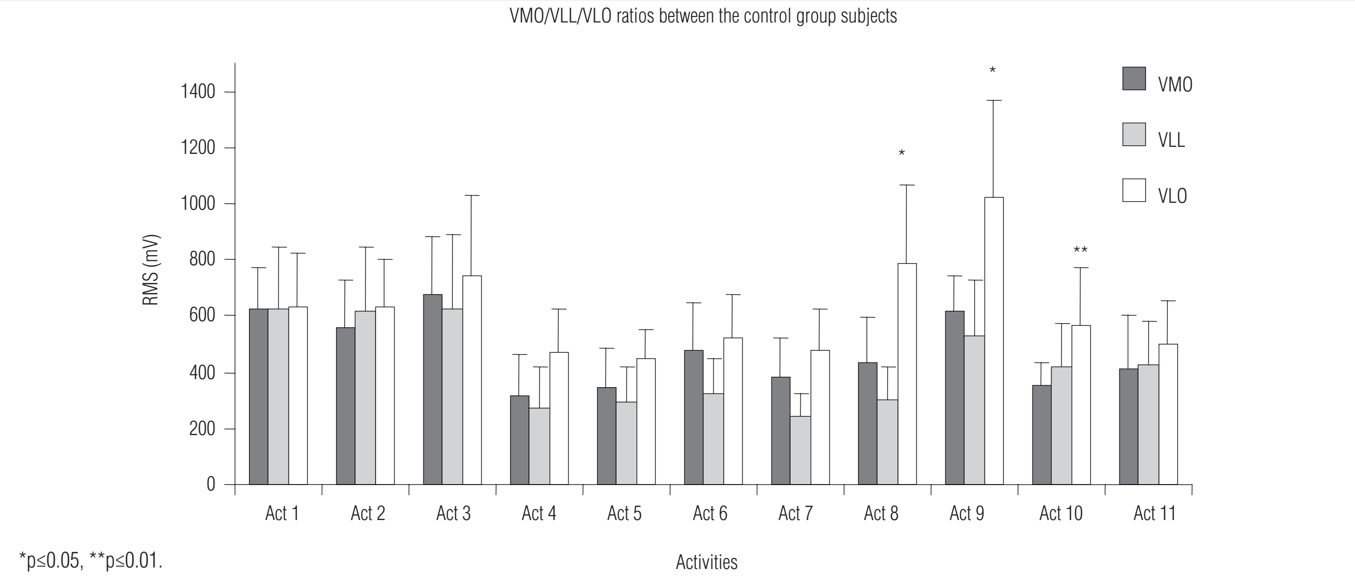


Figure 2. Amplitude of electromyographic activity in the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) and vastus lateralis obliquus (VLO) muscles (mV) during the functional activities performed by the control group.

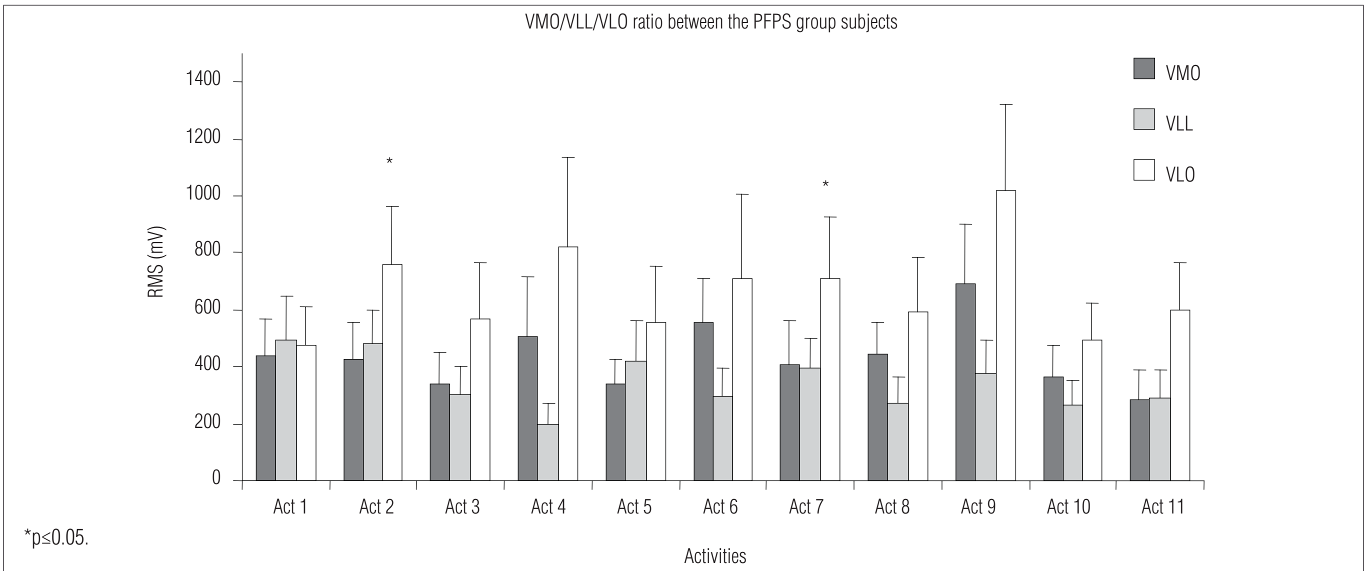
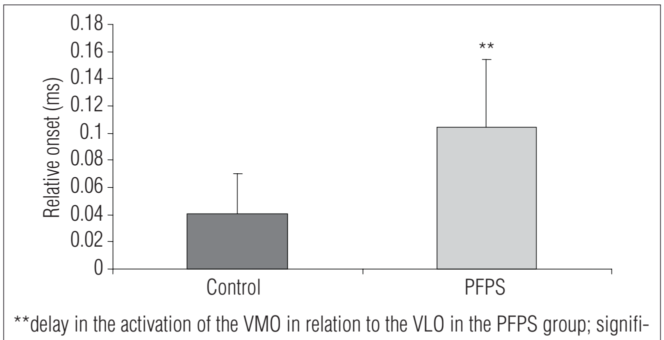


Figure 3. Amplitude of electromyographic activity in the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) and vastus lateralis obliquus (VLO) muscles (mV) during the functional activities performed in the patellofemoral pain syndrome (PFPS) group.



**delay in the activation of the VMO in relation to the VLO in the PFPS group; significantly greater than in the control group (p≤0.01).

Figure 4. Means and standard deviations of the vastus medialis obliquus (VMO)-vastus lateralis obliquus (VLO) relative onset (millisecs) during the functional activities in the control and patellofemoral pain syndrome (PFPS) groups.

In addition to the absence of activity prioritizing the VMO muscle shown in the literature or in this study[8], these results suggested that the electrical activity in the VLO muscle was boosted[2], *id est*, this muscle participated more actively in patella lateralization among individuals with PFPS. Although some authors disagree with these results[3,8,24], this finding demonstrated that significant imbalances of the medial and lateral stabilizers of the patella were associated with individuals with PFPS.

In agreement with the data of the present study, Bevilaqua-Grossi, Monteiro-Pedro and Bérzin[4] showed that not only are VLL and VLO muscles physiologically different[15], but also they demonstrated differences in recruitment patterns in the static knee extension exercises at 15º. Likewise, in an electromyographic study on activities of mounting onto a step backwards, Pulzatto et al.[12] found greater recruitment of the VLO than of the VLL as the knee flexed. This corroborated the present findings that during 30% isokinetic extension and eccentric activity on the step at 75º among the subjects with PFPS. According to Owings and Grabiner[10], the performance of eccentric actions may cause changes to the normal myoelectric patterns of the quadriceps and contribute towards lateral dislodgement of the patella.

In a similar manner, healthy individuals demonstrated different activation intensities between the VMO and VLO muscles, as observed in the activities of getting up from the bench, unipedal jumping and rising on the heels. To our knowledge, no previous study has evaluated these activities in regards to differences in activation amplitudes between these muscles. This study suggested that performing these functional tasks may favor patella lateralization and predispose these subjects towards developing patellofemoral disorders.

Therefore, the results from this study reinforced the notion that the VLO had an antagonistic function in relation to the VMO, given that in most activities for both groups, the activation observed in the VMO and VLL muscles was no greater than in the VLO. On the other hand, greater activation was observed in the VLO than in the other muscles of subjects with PFPS, thus possibly making this muscle the main agent responsible for the patellar dynamic imbalance.

Electrical activation onsets

The results from the present study showed that there was a delay in VMO activation in relation to the VLO in both groups, considering all the activities. The control group demonstrated a mean delay in the VMO of around 4ms in relation to the VLO. By implementing experimental models, Neptune, Wright and Bogert[30] showed that a delay of 5ms in VMO muscular activation, in relation to the VL, resulted in significantly greater lateral loading of the patellofemoral joint. This corroborates with what was found in the present study, in which a delay of 10ms in the VMO, in relation to the VLO, was recorded among individuals with PFPS. According to Souza and Gross[23], neuromuscular synchronism is an important factor in normal movement, thus implying that strength is not the only criterion for determining precise movements. Therefore, asynchrony in the activation time of the quadriceps may contribute towards lateral patella contact with the trochlear groove, which suggests that there may be an imbalance in the neuromuscular control in subjects with PFPS.

It must emphasize that, to our knowledge, this has been the only study that observed earlier activation of the VLO in relation to the other portions of the quadriceps, followed by the VMO and then the VLL in the PFPS group. These results do not corroborate the findings of Santos et al.[24], who studied treadmill walking on a horizontal surface and at an inclination of 5º between subjects with and without PFPS. They showed that the electrical activity of the VLL preceded the activation of the VMO and VLO in individuals with PFPS. Similarly, Pulzatto[2] showed VLL activation preceding VMO and, finally VLO activation in step activities at 45 and 75º among individuals with PFPS. In addition to these methodological differences, the divergences of these findings from the present study may have been due to the sample size and the fact that the studies evaluated specific functional tasks.

Although there is no consensus between the recent studies on PFPS, the present study showed that there were differences in this group of subjects regarding the amplitude and onset of femoral quadriceps muscle activity while performing functional activities. Thus, it is suggested that there is an imbalance of electrical activity and abnormal recruitment patterns between the VMO, VLL and VLO muscles, with greater delays and lower activation amplitudes of the VMO in the group with PFPS. However, more studies need to be conducted to investigate possible changes of the three superficial components of the femoral quadriceps muscle in activities that simulate functional tasks, and to investigate the real function of the parts of this muscle in the dynamic behavior of the patella.

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