Altered Vastii Recruitment When People With Patellofemoral Pain Syndrome Complete a Postural Task

Sallie M. Cowan, BAppSci, Paul W. Hodges, PhD, Kim L. Bennell, PhD, Kay M. Crossley, BAppSci


Objectives: To investigate the recruitment of the vastus medialis obliquus (VMO) and vastus lateralis during voluntary tasks that challenge the stability of the knee and to evaluate whether there is a change in the coordination of the postural response by the central nervous system in subjects with patellofemoral pain syndrome (PFPS).

Design: Cross-sectional.

Setting: University laboratory in Australia.

Participants: Thirty-seven subjects with PFPS and 37 asymptomatic sex-matched controls.

Interventions: Not applicable.

Main Outcome Measures: Recordings of electromyographic activity of the VMO, vastus lateralis, tibialis anterior, and soleus were made by using surface electrodes. Subjects rose onto their toes (rise task) or rocked back on their heels (rock task) in a visual choice-reaction time task. Electromyographic onsets were determined by using a computer algorithm and were verified visually.

Results: Our results confirm that, in asymptomatic subjects, contraction of the VMO and vastus lateralis occurs as part of the feed-forward postural response associated with ankle movements in standing, and the contraction of these separate heads of the quadriceps group occurs simultaneously. However, when subjects with PFPS perform identical tasks, the electromyographic onset of the vastus lateralis occurs before that of the VMO.

Conclusion: These findings indicate a difference in motor control in subjects with PFPS. They also support the hypothesis that changes in the timing of activity of the vasti and PFPS and provide the theoretic rationale to support physiotherapy treatment commonly used in the management of PFPS.

Key Words: Electromyography; Muscles; Pain; Posture; Rehabilitation.

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Accepted August 28, 2001.

Supported in part by the Physiotherapy Research Foundation and the National Health and Medical Research Council.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

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ARCH PHYS MED REHAB Vol 83, July 2002

PATELLOFEMORAL PAIN SYNDROME (PFPS) is a common complaint in athletes and the general populations, particularly in tasks that involve repetitive loading of the lower limb.1 PFPS is defined as anterior or retropatella pain in the absence of other pathology. Clinically, the condition presents as diffuse pain that is exacerbated by activities such as stair climbing, prolonged sitting, squatting, and kneeling.2,3 Although the development of PFPS is multifactorial, abnormal lateral tracking of the patella is the most commonly accepted hypothesis.4,4 Such tracking may result from poor coordination between the medial and lateral forces produced by the vastus medialis obliquus (VMO) and vastus lateralis.7-13 However, controversy exists in the literature as to the normal relationship between the onsets of electromyographic activity of the VMO and vastus lateralis in the asymptomatic population and indeed whether this differs in the PFPS population.8,11-17 Studies of recruitment of the quadriceps muscles in subjects with PFPS during functional movements have reported the simultaneous recruitment of both the VMO and vastus lateralis8,14-16 and activation of the vastus lateralis before the VMO.13 Investigation of controlled tasks that limit the variability associated with functional movements is likely to provide more consistent data and to provide an ideal method to evaluate whether the recruitment of the VMO and vastus lateralis is altered in people with PFPS. A paradigm that has been used in experimental situations to investigate the strategies used by the central nervous system (CNS) to control stability of body segments is to investigate the recruitment of muscles in association with voluntary movements that challenge the stability of adjacent segments of the body. Numerous studies19-23 have reported activation of muscles of the adjacent segments before the movement. This activity is thought to prepare the adjacent segment for the reactive movements resulting from movement and thus must be planned by the CNS (ie, anticipatory or feed forward because they occur before the afferent feedback from the movement).

The response of the quadriceps muscles has been studied in association with voluntary ankle movements in standing.24,25 These studies report activity of the quadriceps either at the same time24,26 or up to 100ms25 before the activation of the muscle responsible for the movement, depending on the specific task and the biomechanical challenge that these tasks present to the postural stability of the body. However, these studies only investigated the component of the quadriceps.

In a previous study,27 we investigated the coordination of the VMO and vastus lateralis in ankle movement tasks in people with no history of knee pathology. The results showed that when the CNS predicts that a movement will challenge the stability of the knee, an anticipatory postural adjustment is initiated that coactivates the medial and lateral muscles that guide the movement of the patella in the femoral groove. The current experiment compared the recruitment (time of onset of electromyographic activity) of a medial (VMO) and lateral (vastus lateralis) component of the quadriceps group, in people with and without PFPS during voluntary ankle movements that challenge the stability of the knee and thus determine whether
there is a change in coordination of the postural response in people with PFPS.

**METHODS**

**Participants**

Thirty-seven subjects (23 women, 14 men) diagnosed with PFPS on the basis of clinical examination by an experienced physiotherapist and an equal number of sex-matched asymptomatic control subjects participated in the study. The inclusion and exclusion criteria were based on criteria used in other studies of PFPS. Subjects in the PFPS group were included if they had anterior or retropatellar knee pain while engaged in at least 2 of the following activities: prolonged sitting, climbing stairs, squatting, running, kneeling, and hopping and jumping. In addition, they were to have had pain on patellar palpation, have had symptoms for at least 1 month, have had an average pain level of 3cm on a 10-cm visual analog scale, and have had an insidious onset of symptoms unrelated to a traumatic incident. All subjects had to be aged 40 years or less to reduce the likelihood of osteoarthritic changes in the patellofemoral joint. Subjects were excluded if they had a recent history (within 3mo) of knee surgery; a history of patellar dislocation or subluxation; or clinical evidence of meniscal lesion, ligamentous instability, traction apophysitis around the patellofemoral complex, patellar tendon pathology, chondral damage, osteoarthritis, or spinal referred pain. The pain characteristics of the PFPS subjects are presented in table 1.

Asymptomatic control subjects were recruited from the School of Physiotherapy at the University of Melbourne and were matched for sex. Control subjects were excluded if they had a history of lower-limb pathology or other disorders that might interfere with the kinetics or kinematics of knee motion.

The mean age, height, and weight ± standard deviation (SD) of the PFPS subjects were 28.5 ± 7.3 years, 170.7 ± 8.9 cm, and 71.8 ± 12.8kg, respectively. The mean age, height, and weight of the control subjects were 24.4 ± 5.8 years, 171.9 ± 12.0cm, and 64.5 ± 11.5kg, respectively. An independent t-test showed no difference in height between the 2 groups (t_{12}=4.9, P>.05), although the PFPS subjects were older and heavier than the controls (t_{12}=2.7, P<.05; t_{12}=2.58, P<.05, respectively).

The study was approved by the University of Melbourne Human Research Ethics Committee. All subjects provided written informed consent.

**Electromyographic Recordings**

Electromyographic recordings of the VMO, vastus lateralis, tibialis anterior, and soleus were made by using surface electrodes. Pairs of Ag-AgCl electrodes were placed over the muscle bellies of the VMO and vastus lateralis with an inter-electrode distance of 22mm. The electrode placements were based on previous studies. The electrode for the VMO was placed approximately 4cm superior to and 3cm medial to the superomedial patella border and orientated 55° to the vertical, the electrode for the vastus lateralis was placed 10cm superior and 6 to 8cm lateral to the superior border of the patella and orientated 15° to the vertical, the electrode for the soleus was placed at the midpoint of the back of the leg just medial to the gastrocnemius tendon, and the electrode for the tibialis anterior was placed 3cm lateral and 3cm inferior to the tibial tubercle. The ground electrode was placed over the tibial tubercle. Before electrode placement, the skin was shaved, swabbed with alcohol, and gently abraded with sandpaper to reduce the electric impedance to less than 5kΩ.

Electromyographic data were preamplified (10×), band-pass filtered between 20 to 500Hz, sampled at 1000Hz, and 12-bit analog-to-digital converted.

**Procedure**

Subjects stood unsupported with their arms by their side, their feet placed approximately 20cm apart, and with equal weight on each foot. They were instructed to rise onto their toes by contracting their triceps surae muscle (rise task) or to rock on to their heels by lifting their toes and contracting their tibialis anterior muscle (rock task) as quickly as possible in response to a light fixed at eye level. Two different colored lights were used to indicate the movement to be performed; a yellow light signaled the subject to perform the rock task, and a red light signaled the rise task. The trial was performed as a visual choice reaction-time task in which the order of movements was randomized and no indication of specific task to be performed was given before the stimulus to move. Subjects were instructed not to remain balanced on their toes or heels at the completion of the task nor to attempt to return to the exact initial position. If an increase in electromyographic activity was noted while the subject was standing at rest between movements, he/she was told to relax. Data were collected for 10 repetitions of each of the rock and rise tasks. Subjects experienced no pain during the testing procedure, which has been found reliable in both the rock and rise tasks in asymptomatic subjects (relative difference electromyographic onset vastus lateralis – VMO: ICC3,5 = .76 rock, ICC3,5 = .87 rise).27

**Data Analysis**

Electromyographic data were full-wave rectified and digitally low-pass filtered at 50Hz (6th-order Butterworth filter). The onset of electromyographic activity was identified as the point at which the electromyographic amplitude increased by more than 3 SDs for a minimum of 25ms from the baseline level (taken 200ms before the stimulus began). The electromyographic onsets identified by the computer were checked against the electromyographic onsets identified visually from rectified unfiltered electromyographic data to ensure that the onset was not obscured by movement artifact or an electrocardiogram (<5% of trials). Before data analysis, 50 traces were randomly selected in which the onset was not obscured by movement artifact or noise and several different algorithms were compared with visually identified electromyographic onsets. The 25ms/3 SD combination had the greatest agreement with the onsets that were identified visually (r=.998, y intercept=1.30ms, P<.001) and thus were the most accurate for the present experiment.

The onsets of electromyographic activity were expressed relative to the electromyographic onset of the prime mover (ie, electromyographic onset of the VMO or vastus lateralis minus onset of the tibialis anterior or soleus) and averaged over the 10 trials. The relative difference in time of onset of electromyographic activity of the VMO and vastus lateralis was quantified by subtracting the onset of the VMO from that of the vastus lateralis (VL – VMO electromyographic onset timing difference). Reaction time for the rock and rise tasks was defined as

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**Table 1: PFPS Group Pain and Disability Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since onset of symptoms (mo)</td>
<td>10.9</td>
<td>22.3</td>
<td>1–120</td>
</tr>
<tr>
<td>Worst pain in last week (VAS) (cm)</td>
<td>1.5</td>
<td>1.0</td>
<td>3.5–10</td>
</tr>
<tr>
<td>Average pain in last week (VAS) (cm)</td>
<td>7.2</td>
<td>1.5</td>
<td>3–7</td>
</tr>
</tbody>
</table>

Abbreviation: VAS, visual analog scale.
the latency between the movement stimulus and electromyographic onset of the muscle responsible for ankle movement (ie, tibialis anterior or soleus).

Statistical Analysis

All data were analyzed by using Statistical Package for Social Sciences. For the rock and rise tasks, separate unpaired t tests were used to identify statistically significant differences between PFPS and control groups for the vastus lateralis (VL)-VMO electromyographic onset timing and reaction times. Separate 2-way mixed analyses of variance (muscle × group) were used for the rock and rise tasks to determine if there was a difference between PFPS and control groups for the times of electromyographic onset of the VMO and vastus lateralis expressed relative to the prime mover for each task (tibialis anterior for rock task, soleus for the rise task). Post hoc unpaired t tests were used to determine specific differences. A Bonferroni correction was applied and the α level was adjusted to P less than .0125 for these post hoc tests. To assess whether the VL-VMO onset timing difference differed from zero (ie, Was the onset of the VMO and vastus lateralis simultaneous?), separate independent 1 group t tests were used in the 2 groups. Because as weight and age differed between groups, the data were reanalyzed with age and weight as covariates, but this did not affect the results. The α level was set at P less than .05.

RESULTS

Although there was large variation in individual electromyographic onset times, there was a difference in the latency between the onsets of the VMO and vastus lateralis (ie, electromyographic onset VL — onset VMO [VL — VMO onset timing difference]) between the PFPS and control groups in both tasks (rock, P < .001; rise, P < .01). When subjects with no history of PFPS rose onto their toes (rise task) or rocked onto their heels (rock task), there were no differences in the electromyographic onsets of the VMO and vastus lateralis (rock, P = .31; rise, P = .33) (figs 1A, 2B). In contrast, when the identical tasks were performed by the subjects with PFPS, the onset of the vastus lateralis preceded that of the VMO (rock, P < .005; rise, P < .005) (figs 1B, 2B). The means and standard errors of the mean (SEMs) of the relative difference in time of onset of electromyographic activity of the VMO and vastus lateralis in all subjects in both tasks are presented in figure 3.

In both the rock and rise tasks, the latency between the electromyographic onsets of the VMO and vastus lateralis and the prime mover (tibialis anterior or soleus) were different between groups (rock, P < .01; rise, P < .05). In the rock task, the onset of the VMO was delayed in the PFPS group (ie, electromyographic onset VMO — onset tibialis anterior) (P < .0125), whereas there were no differences between groups for the onset of the vastus lateralis (ie, electromyographic onset vastus lateralis — onset tibialis anterior) (P = .91) (fig 4). In contrast, in the rise task, the onset of the vastus lateralis occurred earlier in the PFPS group (ie, electromyographic onset vastus lateralis — onset of soleus) (P < .01), whereas there were no differences between groups for the onset of the VMO (ie, electromyographic onset VMO — onset soleus) (P = .07) (fig 4).
When the PFPS and control subjects completed the rock task, there was no difference in the reaction time of the prime mover tibialis anterior ($P = .66$). However, when subjects completed the rise task, there was a difference in reaction times of the prime mover (soleus) between groups ($P < .05$), with the onset of the soleus occurring later in the PFPS subjects. When both PFPS and control subjects completed the rise task, the majority (35/37 in the PFPS, 34/37 in controls) showed an initial activation of the tibialis anterior before the activation of the soleus (fig 5).

**DISCUSSION**

Our results confirm that contraction of the VMO and vastus lateralis occurs as part of the feed-forward postural response associated with movement of the lower limb. Our findings also indicate a change in the recruitment of the knee muscles in subjects with PFPS compared with non-PFPS subjects. When subjects with PFPS rock onto their heels or rise onto their toes, the electromyographic onset of the VMO occurs after that of the vastus lateralis, in contrast to the simultaneous activation of these muscles in control subjects. Theoretically, this change in relative timing could occur if the VMO was delayed or if the onset of activity of the vastus lateralis occurred earlier in symptomatic patients compared with controls. The present data provide evidence for both possibilities, depending on the specific task.

**The Onset of the Vastus Lateralis Occurred Before the VMO in PFPS Subjects**

The electromyographic onset of the VMO and vastus lateralis occurred in a manner consistent with a feed-forward postural response in the PFPS subjects (see later). However, the relative timing of these 2 components of the quadriceps group within the preprogrammed response differed from that of control subjects. This shows a change in the preplanned strategy used by the CNS to control the patella. These results contrast with those of several previous studies\textsuperscript{14,16,17} that did not find a difference between the onsets of the VMO and vastus lateralis in PFPS during other functional tasks. The reasons for this discrepancy may be due to task specificity or to technical reasons. For instance, previous studies have expressed electromyographic onset as a percentage of the gait cycle\textsuperscript{17} or in relation to force development,\textsuperscript{15,16} which may reduce the sensitivity of the electromyographic onset measurements. However, our results concur with research that showed a difference in the timing of electromyographic onset of VMO compared with vastus lateralis in PFPS subjects in other functional tasks\textsuperscript{13}.
and reflex responses.\textsuperscript{8,12} Theoretically, this difference in electromyographic onset may be because of delayed onset of the VMO or earlier onset of the vastus lateralis; however, previous functional studies have not been able to identify the specific component of the quadriceps affected.\textsuperscript{13} The current data provide evidence for both possibilities, depending on the task.

When PFPS subjects performed the rock task, the electromyographic onset of the VMO was delayed in comparison with that in the control subjects. Despite the hypothesis that the VMO may be selectively affected in PFPS\textsuperscript{3,11} and that treatment programs commonly focus on improving the timing of VMO activation,\textsuperscript{2} a specific delay in the onset of VMO activity in PFPS has not previously been demonstrated (although both the VMO and vastus lateralis have been found to be delayed in PFPS subjects).\textsuperscript{15-17} Similar delays in the onset of muscle activation have, however, been identified in association with other musculoskeletal pathologies. For example, the transversus abdominis has delayed recruitment in people with low back pain,\textsuperscript{36,37} and the peroneus longus and brevis are delayed in people with recurrent ankle sprains.\textsuperscript{38} Furthermore, changes on the latency of feed-forward postural responses have been identified in people with frontal lobe trauma\textsuperscript{39} and Parkinson’s disease.\textsuperscript{40,41}

The mechanism of the relative delay in VMO activation cannot be firmly established from our findings. One explanation is motoneuron inhibition. Reflex inhibition occurs as a result of effusion,\textsuperscript{42-44} pain,\textsuperscript{45} ligament stretch,\textsuperscript{46} and capsular compression.\textsuperscript{46} In this study, subjects were excluded if they had knee effusion; however, as little as 20mL of saline can inhibit VMO contraction,\textsuperscript{44} which may not be clinically detectable. Other factors such as changes in nerve conduction velocity\textsuperscript{47} and fatigue\textsuperscript{48,49} have been shown to alter recruitment in other regions of the body. Alternatively, the delayed contraction of the VMO could potentially be a protective mechanism to avoid provocation of pain. Although this study cannot rule that out, it seems unlikely because our subjects did not experience pain when they rocked onto their heels.

In contrast to the rock task, when subjects with PFPS rose onto their toes, the onset of the vastus lateralis electromyography occurred earlier than for control subjects, and the timing of the VMO was unchanged. This is consistent with the results of reflex studies by Voight and Weider\textsuperscript{8} and Witvrouw et al.\textsuperscript{12} which identified activity of the vastus lateralis with shorter latency in subjects with PFPS in response to a tap to the patella. However, in these studies the actual differences reported were very small (<1ms), and therefore the biomechanical significance of these results may be questioned.

Theoretically, it is possible that the earlier activation of the vastus lateralis in the rise task represents an attempt to increase stiffness at the knee that is required for efficient completion of the task. A finding that is consistent with this hypothesis is that the onset of activity of the soleus was delayed in the subjects with PFPS. Previous studies\textsuperscript{50} have reported delayed activation of the muscle responsible for limb movement in situations in which the requirements for postural control are increased to allow for increased time for postural preparation. Decreased latency of muscle contraction in association with pathologies has been rarely reported in the literature. Beckman and Buchanan\textsuperscript{31} found a decrease in the latency of hip muscle activation in subjects with hypermobile ankles and described this recruitment pattern as an injury-adaptive strategy in which the subjects attempt to recruit a hip strategy to compensate for the reduced afferent input from the ankle complex.

Theoretical Consequences of Asynchronous Activity of the VMO and Vastus Lateralis

Regardless of the mechanism for the change in relative timing of the VMO and vastus lateralis, the period of unopposed lateral forces may have detrimental consequences for patellofemoral mechanics. With asynchronous VMO and vastus lateralis activity, the contraction of the VMO may be unable to control the alignment of the patella, despite normal strength or endurance, and may compromise quadriceps function. Anatomic studies have shown that absent VMO contraction results in increased lateral patellar contact pressure,\textsuperscript{52} lateral shift and tilt of the patellar,\textsuperscript{53} and decreased efficiency of vastus lateralis contraction.\textsuperscript{54} More recently, Neptune et al.\textsuperscript{55} found that a 5-ms delay in VMO activation was associated with a significant increase in lateral patellofemoral joint loading.

Because of the cross-sectional design of our study, we cannot determine if changes in the recruitment of the vastii in PFPS subjects is a cause or an effect of the pain and dysfunction associated with PFPS. Another possibility is that the change in timing may be a consequence of a person’s biomechanic characteristics. Further longitudinal studies are required to answer these questions.

Simultaneous Activation of the VMO and Vastus Lateralis in Control Subjects

Our finding of simultaneous recruitment of the VMO and vastus lateralis in asymptomatic subjects in both the rock and rise tasks concurs with previous results.\textsuperscript{13,14,17,27,36,57} These results support the belief that the onset of activity of the VMO and vastus lateralis is relatively balanced in people with no history of patellofemoral pain. Although the VMO and vastus lateralis may have antagonistic actions for the mediolateral control of the patella, ultimately their recruitment must be appropriately timed for efficient biomechanic function of the knee, such that they can act synergistically with each other and the rest of the quadriceps in any functional task.\textsuperscript{58}

Anticipatory Activation of the VMO and Vastus Lateralis

Although there was a difference in the coordination of the response of the VMO and vastus lateralis in the PFPS subjects, our results also support earlier data that have shown anticipatory activity of individual muscles of the quadriceps group in association with a perturbation to the lower limb induced by voluntary ankle movement.\textsuperscript{24,25} In both tasks, the feed-forward action of the quadriceps is consistent with the requirement to counteract the flexion moment at the knee that would be predicted to result from the rapid contraction of the prime mover of the ankle.

In the rock task, the contraction of the prime mover tibialis anterior would be predicted to cause anterior translation of the tibia and thus quadriceps activity would be required to counteract this. In accord with earlier findings in asymptomatic subjects,\textsuperscript{24,27} the electromyographic activity of the VMO and vastus lateralis occurred at approximately the same time as the onset of the tibialis anterior in the rock task. In the rise task, the onset of electromyographic activity of the VMO and vastus lateralis occurred around 100ms before the activation of the soleus. This is consistent with some previous findings,\textsuperscript{25,27} but differs from those of Nardone and Schieppati,\textsuperscript{24} who found that the vastus lateralis acted approximately 15ms after the electromyographic onset of the soleus in the rise task. The difference may be because of subtle variations in the task. It has been consistently shown that muscle activity directed at the control of the body during voluntary movements is specifically matched to the demands of the task.\textsuperscript{36,59,60} Theoretically, con-
traction of the quadriceps femoris muscle in advance of the rise task may occur to counteract the knee flexion moment generated by the femoral attachments of gastrocnemius. However, before subjects can rise onto their toes, they must move their center of mass (COM) forward so that it lies over the new base of support (ie, forefoot). To achieve this, a subject may pull the tibia forward either by contraction of the tibialis anterior or by reduction of activity of the soleus. Thus, early recruitment of the quadriceps may also be necessary to control the knee position with anterior translation of the tibia. This pattern of muscle activation was found in the majority of both the PFPS and control subjects in our study (fig 5). In contrast, Nardone and Schieppati reported a faster reaction time of the soleus in the rise task, which suggests that their subjects may have remained with their COM further anteriorly, thus reducing the demand for COM displacement, and, correspondingly, no early activation of the vastii. Other factors that may have influenced temporal aspects of the results include differences in electrode placement (exact placement was not specified by Nardone and Schieppati) and abstruse differences in the nature of the task. In our rise task, we instructed subjects to rise fully onto their toes so that the ankle was in full (or near full) plantarflexion, which may have placed stronger postural constraints on subjects than in the similar task used by Nardone and Schieppati. Our task may have resulted in a larger flexion moment at the knee, thus requiring earlier activation of the quadriceps muscles to ensure postural stability.

CONCLUSIONS

Despite the significant differences in vastii onset, there was wide variation in the electromyographic onsets of the VMO and vastus lateralis in both the PFPS and control groups. This finding is consistent with our previous findings in a functional and vastus lateralis in both the PFPS and control groups. This wide variation in the electromyographic onsets of the VMO muscles moving the patella in normal subjects and in patients with chronic patellofemoral problems. Scand J Rehabil Med 1997;29:43-8.


Suppliers

a. Graphics Control Corp, c/o Medical Equipment Services Pty Ltd, 3121 Richmond, Australia.

b. Associate Measurement Pty Ltd, North Ryde, NSW, Australia.

c. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.