

## **Alteration of Quadriceps Muscle Activity During Functional Step Tasks After Extended Sitting Session**

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9

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48 of the patellofemoral joint during stair ambulation [11]. During stair ascent and descent,  
49 people with PFPS had lower knee extension moments, quadriceps forces, and  
50 patellofemoral joint reaction force than healthy controls [12,13]. Moreover, Wilson et al  
51 showed gluteus muscle activity increased in female with PFPS during stair ambulation  
52 [14].

53 Prolonged sitting with high knee flexion is a common activity of daily living and  
54 is performed in various postures and knee flexion positions, which may affect  
55 patellofemoral joint compression and quadriceps muscle length [15]. Cross-legged sitting  
56 is the most common sitting position on the ground [16]. Immediate reductions in  
57 quadriceps muscle force and EMG activity are commonly observed after static stretching  
58 [17], which greatly affects patellar movement [18] and dynamic stability during stair  
59 ambulation [19], during which patellofemoral joint forces reach 3.3 times the force of an  
60 individual's body weight [20]. Prolonged sitting with high knee flexion may therefore  
61 contribute to the development of PFPS. Sitting with high knee flexion and deep squats  
62 can facilitate knee pain and, therefore, should be avoided in an individual's daily routine.  
63 Exploring the activation of quadriceps muscles following prolonged sitting with high  
64 knee flexion is interesting, as it may help to explain the mechanism of changes in the VM  
65 and VL muscles after sitting, as a result of which, PFPS may develop.

66 Several studies have evaluated the onset time, muscle activity duration, and  
67 quadriceps contraction ratio to determine dynamic stability during stair ambulation  
68 [10,19,21]. However, only few studies have elucidated the mechanism underlying the  
69 effect of prolonged sitting on the quadriceps muscle in a healthy population. Therefore,  
70 the present study aimed to investigate quadriceps activity during performing challenge  
71 task which was step-up and -down tests after prolonged periods of sitting in various

72 positions: cross-legged sitting, side-sitting, and sitting on a chair without back support.  
73 The findings of the present study could be implied in similar activities, such as stair  
74 ambulation and squatting which require high knee flexion with weight bearing. This  
75 would guide clinicians on how the quadriceps muscle changes after prolonged sitting and  
76 can help develop preventive strategies for knee pain. Therefore, improving one's  
77 understanding regarding the effect of prolonged sitting in different positions on the EMG  
78 activity of the quadriceps muscle during stair ambulation is important.

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## 80 **MATERIALS AND METHODS**

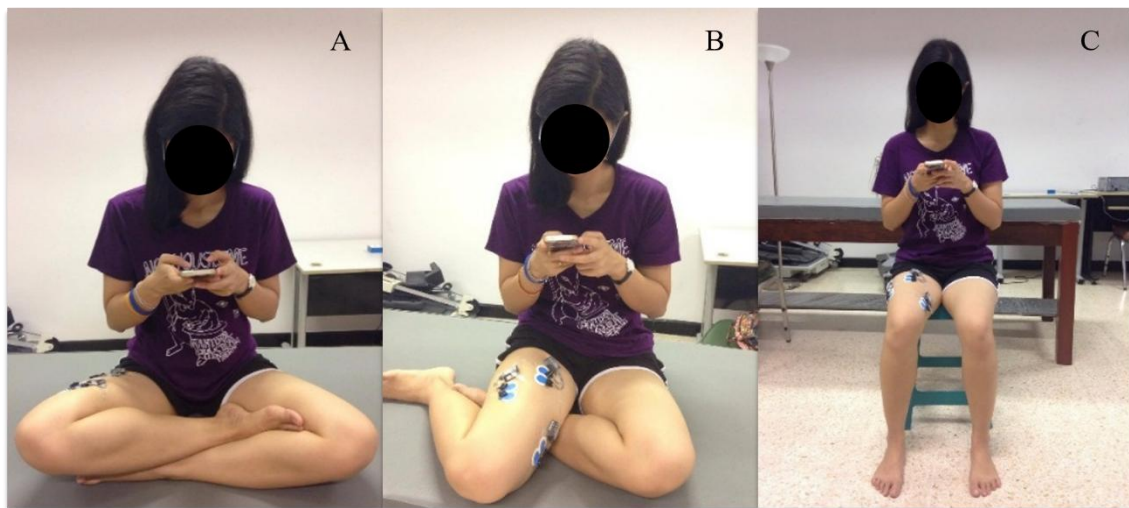
### 81 **Participants**

82 Thirty healthy females voluntarily participated in the present study and were  
83 randomly allocated into three groups: cross-legged sitting (n=10), side-sitting (n=10), and  
84 sitting on a chair (n=10) (Figure 1). Side and cross-legged sitting are common postures  
85 on the floor in daily living, while a high knee flexion posture is sustained. Sitting on a  
86 chair without back support is a common activity that causes knee flexion of approximately  
87 90°, which was used for the control group in this study. The participants were aged 18-  
88 24 years old, had no knee pain, and had no histories of severe injury or surgery in their  
89 lower extremities. All participants were right leg dominant, which was determined by  
90 asking them which leg they would use to kick a ball for a long distance?' [22]. Participants  
91 were excluded if they had flat feet, leg length discrepancies >2 cm [23], and Q-angles  
92 >20° [24]. The researcher explained the study protocol to all study participants, after  
93 which they signed a consent form. The study protocol was conducted according to the

94 declaration of Helsinki and was approved by the XXX University Central Institutional  
95 Review Board (COA 2017/XXX.XXXX).

96         Quadriceps muscle activity was assessed during step-up and step-down tasks,  
97 which included the RF, VM, and VL of the dominant side. Surface EMG was conducted  
98 using Trigno Avanti Delsys wireless sensors (Delsys Inc., USA) with a 2,000 Hz  
99 sampling rate. Before EMG sensors were placed, the skin was shaved and cleaned with  
100 alcohol to reduce skin impedance. Electrode placement was determined based on the  
101 European Recommendation for Surface Electromyography guidelines [25].

102



103

104 **Figure 1.** Prolonged sitting position. A, cross-legged sitting; B, side-sitting; C, sitting on  
105 a chair

106 **Procedures**

107         Participants were asked to perform three tests, which comprised stepping up and  
108 down randomly from a 20 cm-high box with the dominant leg. This height was selected  
109 based on the standard height of a stair step. Resting between step trials and step sessions

110 was allowed for 30 and 60 s, respectively, to prevent muscle fatigue. EMG data were  
111 recorded from three trials as baseline data.

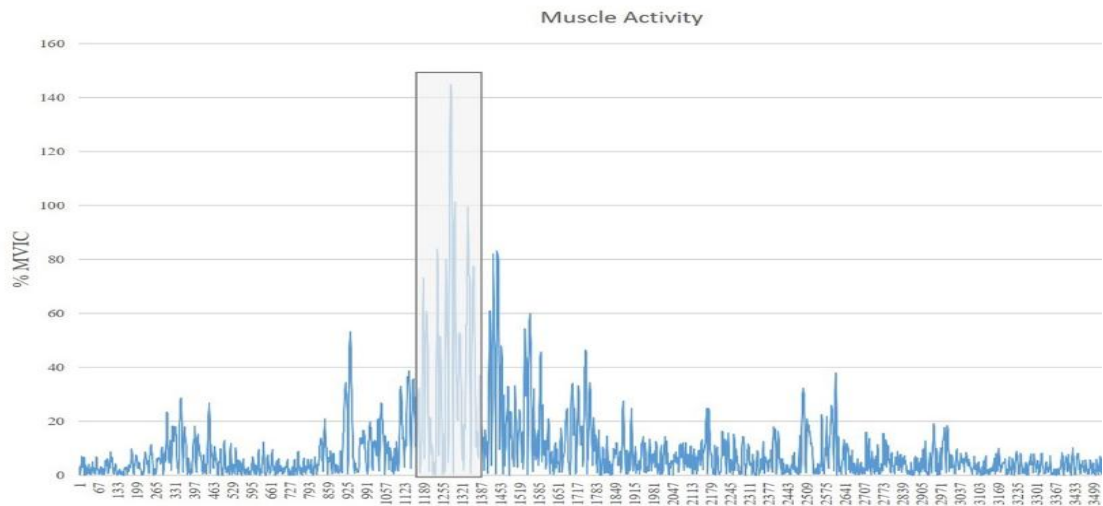
112 Participants were asked to sit and maintain lower limb postures according to the  
113 assigned posture for 15 min without any hand support. In conditions of side-sitting and  
114 cross-legged sitting, all participants were asked to sit with the right-leg on top (Figure 1).  
115 Playing cell phone was allowed during 15 min test to avoid hand support. After 15 min  
116 of sitting, participants were examined immediately to collect EMG data during the step-  
117 up and -down tasks after prolonged sitting.

118 Maximum voluntary isometric contraction (MVIC) was assessed and used to  
119 normalize EMG data for comparing between the sitting groups. Participants were asked  
120 to perform maximum quadriceps isometric contraction tests at 60° knee flexion [26] using  
121 a Biodex machine (Biodex Inc., USA). The average EMG in the present study was  
122 presented in terms of MVIC (%MVIC) [27,28].

### 123 **Data acquisition**

124 All EMG data analyses were performed using Delsys EMGworks® software  
125 (Delsys Inc., USA). Raw EMG signals from VM, VL, and RF muscles were filtered at  
126 20-450 Hz using a second-order band-pass Butterworth filter, after which full-wave  
127 rectification was performed [29].

128 During the step-up and step-down tasks, an average of 100 ms of EMG amplitude  
129 of each muscle was selected from 50 ms before and after the peak value time event (Figure  
130 2). The average EMG during step-up and step-down tasks was reported as %MVIC.  
131 Muscle activity of the VM, VL, and RF muscles was compared before and after prolonged  
132 sitting and within the sitting groups and compared among the three types of postures.



133 **Figure 1.** An example of EMG selection before 50 ms and after 50 ms to peak EMG  
 134 amplitude during step-up task

135

136 **Statistical analysis**

137 Participant characteristics (age, height, weight, and Q angle) are reported in  
 138 Table.1. EMG data with non-normal distribution were assessed using the Shapiro–Wilk  
 139 test and Kruskal-Wallis analysis of variance was used to analyze differences in muscle  
 140 activity among the prolonged sitting group. If statistically significant values were  
 141 observed, the least significant difference method was used with the significance level set  
 142 at  $p < 0.05$ . Furthermore, the Wilcoxon signed-rank test was used to compare muscle  
 143 activity before and after prolonged sitting within each group. All analyses were performed  
 144 using SPSS for Windows, version 23 (New York, NY, USA).

145

146

**RESULTS**

147 Thirty participants were female and right leg dominant, and their age, weight,  
 148 height, and Q angle are presented in Table 1. The participants' characteristics did not  
 149 differ significantly between the sitting groups. The postures used during prolonged sitting  
 150 significantly affected the %MVIC of the VL ( $p=0.02$ ) and VM ( $p=0.02$ ), but not the RF  
 151 ( $p=0.32$ ) during the step-up task. In contrast, postures used during prolonged sitting did  
 152 not significantly affect VL ( $p=0.45$ ), RF ( $p=0.10$ ), or VM activity ( $p=0.93$ ) during the  
 153 step-down task (Table 2). Furthermore, the cross-legged sitting position significantly  
 154 affected VM ( $p=0.01$ ) activity during the step-down task. However, other prolonged  
 155 sitting positions did not significantly affect the activity of all the quadriceps muscles  
 156 (Table 2).

157 **Table 1.** Characteristics of participants in three groups classified according to sitting  
 158 styles (mean (SD))

Characteristics	Cross-legged sitting (n=10)	Side-sitting (n=10)	Sitting on chair (n=10)	p-value
Age (years)	21.3 (1.8)	22.8 (1.4)	21.5 (2.0)	0.31
Weight (kg)	52.1 (4.3)	51.3 (5.1)	54.2 (4.0)	0.31
Height (m)	1.5 (0.04)	1.6 (0.05)	1.5 (0.04)	0.7
Q-Angle (degree)	18.2 (2.16)	18.2 (1.49)	17.6 (1.40)	0.43

159 SD: standard deviation

160 **Table 2.** Comparison of muscle activity (%MVIC) during step tests pre- and post-prolonged sitting sessions in various postures

Task	Muscle	Cross-legged sitting				P-value	Side-sitting				P-value	Sitting on a chair				P-value
		pre-sitting		post-sitting			pre-sitting		post-sitting			pre-sitting		post-sitting		
		Mean (SD)	Median	Mean (SD)	Median		Mean (SD)	Median	Mean (SD)	Median		Mean (SD)	Median	Mean (SD)	Median	
Step-up	VL	111.3 (44.8)	102.5	121.7 (46.9)	117.0	0.16	113.7 (47.7)	101.9	121.0 (49.4)	129.1	0.89	67.7 (11.3)	65.5	69.4 (12.4)	68.8	0.67
	RF	67.9 (33.0)	59.0	80.6 (45.3)	64.1	0.16	74.6 (30.2)	79.3	87.1 (35.8)	97.0	0.06	56.3 (19.8)	51.7	56.0 (26.5)	49.2	0.78

	VM	115.8 (66.0)	102.2	128.1 (71.4)	115.8	0.32	119.3 (49.1)	124.5	146.0 (90.2)	115.1	0.48	94.0 (42.9)	79.9	91.0 (33.6)	78.2	0.78
Step - down n	VL	78.8 (27.8)	77.6	82.5 (23.3)	86.0	0.48	70.6 (26.2)	69.5	68.3 (21.6)	76.8	0.89	42.0 (11.4)	39.2	37.3 (10.7)	38.1	0.89
	RF	63.0 (22.51)	60.8	58.2 (17.3)	59.6	0.40	47.6 (22.4)	39.7	48.7 (22.3)	41.4	0.40	30.9 (9.2)	28.9	28.3 (8.4)	27.0	0.67
	VM	75.4 (23.4)	80.5	88.1 (28.1)	89.7	0.01 *	89.3 (41.3)	76.0	79.5 (35.8)	79.8	0.26	49.5 (22.7)	46.7	44.6 (17.0)	43.1	0.40

161 \* Significant difference:  $p < 0.05$   
162 SD, standard deviation; VL, vastus lateralis; RF, rectus femoris; VM, vastus medialis  
163

164 **Table 3.** Comparison of muscle activity changes (%MVIC) during step tests after extended sitting sessions among three groups

Task	Muscle	Cross-legged sitting		Side-sitting		Sitting on a chair		P-value
		mean (SD)	median	mean (SD)	median	mean (SD)	median	
Step-up	VL	9.2 (22.3) <sup>a</sup>	14.8	-5.8 (24.5)	-3.4	1.3 (7.6)	0.4	0.02*
	RF	11.3 (21.7)	9.4	0.8 (16.7)	1.0	-0,3 (10.3)	1.6	0.32
	VM	10.9 (26.0) <sup>a</sup>	12.2	-7.8 (19.3)	-8.5	-2.4 (11.6)	0.7	0.02*
Step-down	VL	3.3 (18.2)	7.5	1.3 (16.2)	0.5	-3.6 (15.5)	0.7	0.45
	RF	-4.2 (14.3)	-1.7	-0.3 (11.2)	2.1	-2.0 (8.9)	-0.9	0.10
	VM	11.2 (13.3)	7.3	-2.3 (11.5)	-2.6	-3.8 (24.8)	3.1	0.93

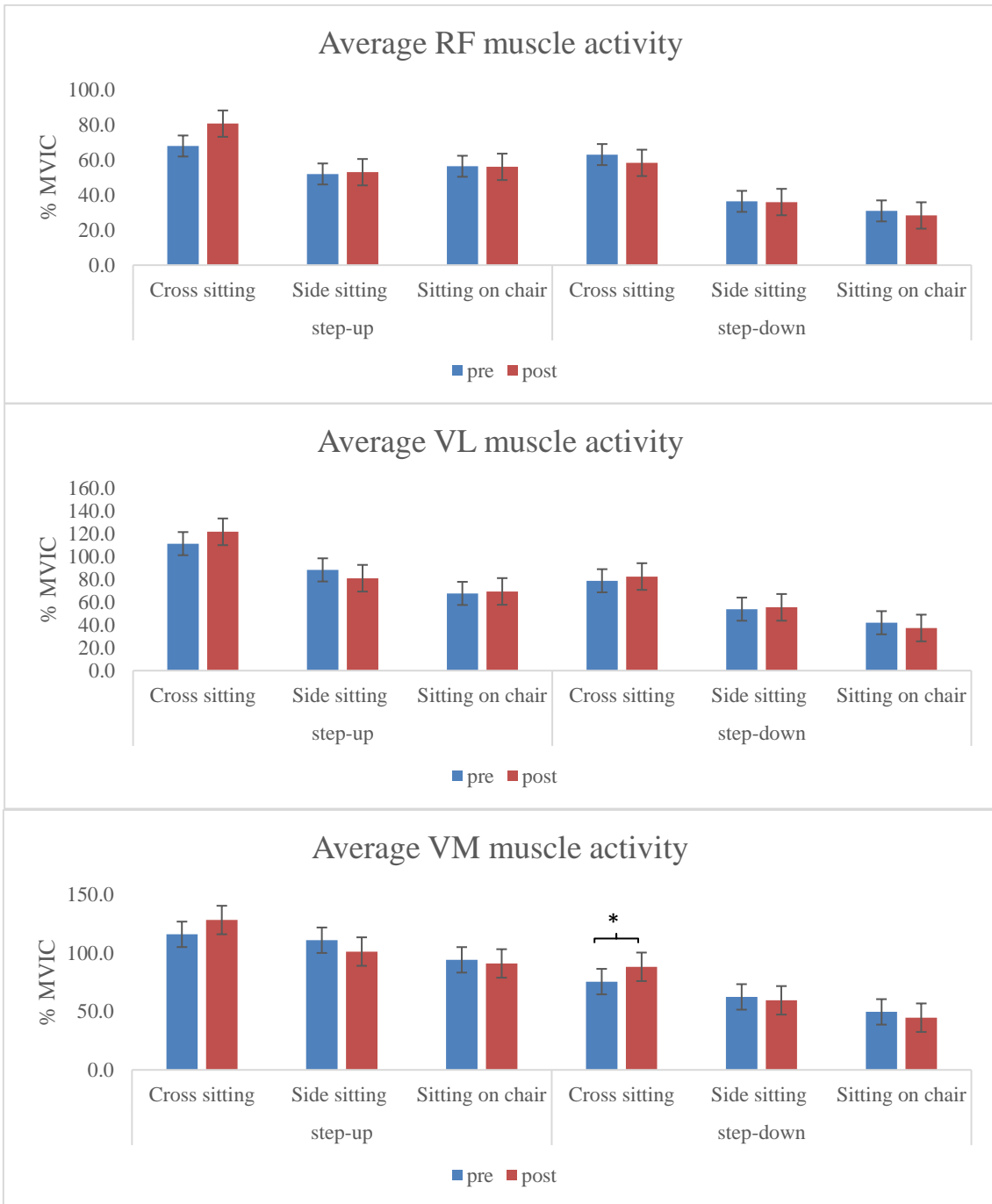
165 \* Significant difference: p<0.05

166 <sup>a</sup> Significant difference compared with the 'sitting on chair' group

167 SD, standard deviation; VL, vastus lateralis; RF, rectus femoris; VM, vastus medialis

168

169           Cross-legged sitting tended to increase muscle activity of all the quadriceps  
170 muscles during the step-up task, whereas VL and VM activity decreased slightly after  
171 participants sat in the side-sitting posture, and sitting on the chair did not affect the muscle  
172 activity of the quadriceps (Figure 3). However, VL, RF, and VM muscle activity did not  
173 differ significantly during the step-up task after prolonged sitting in various positions  
174 (Table 3).



175 **Figure 3.** Comparison of muscle activity pre and post prolonged sitting during step-up  
 176 and step-down tasks

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179

## DISCUSSION

180

181 Prolonged sitting is a common activity of daily life and is performed in various  
182 postures with different knee flexion positions that could affect quadriceps muscle  
183 function [15]. Cross-legged sitting is the most common sitting position on the ground,  
184 especially in Asian countries [16,30]. Therefore, this study evaluated the activity of the  
185 quadriceps muscle using EMG after a prolonged period of sitting in various positions  
186 (cross-legged sitting, side-sitting, and sitting on a chair without back support). The study  
187 findings showed that the EMG activity of the VM muscles increased significantly  
188 ( $p=0.01$ ) during the step-down test after prolonged sitting in the cross-legged sitting group  
189 (Table 2). Differences in sitting positions between the groups significantly influenced  
190 ( $p=0.02$ ) the VL and VM activity during the step-up test. A significant difference was  
191 noted in the pairwise comparison between the ‘cross-legged sitting’ and ‘sitting on a  
192 chair’ groups (Table 3).

193 No significant differences were noted in participants’ characteristics between the  
194 three groups (Table 1). After 15 min of prolonged sitting, muscle activation in the cross-  
195 legged sitting and side-sitting groups demonstrated an increasing trend of VM, VL, and  
196 RF activity during the step-up test compared with that noted in the ‘sitting on a chair’  
197 group. Muscle control of VM, VL, and RF appears to be similar during the step-up test  
198 before and after prolonged sitting on a chair. During the step-down task, significantly  
199 higher activation of the VM muscle was noted in the ‘cross-legged sitting’ group (Figure  
200 3). Different muscle functions could be attributed to differences in knee flexion and tibial  
201 rotation between the groups. A previous study demonstrated that immediate reductions in  
202 the quadriceps muscle force and EMG activity were observed after static stretching [17].  
203 In contrast, the VM and VL in the present study exhibited an increased EMG activity.

204 Differences in time, hip posture, and tibial rotation may have caused variations in tissue  
205 structure lengthening between the present and previous studies [17,18]. The VL exhibits  
206 greater muscle activity than the VM during isometric knee extension with medial tibial  
207 rotation [31]. Cross-legged sitting required high knee flexion and femur- and tibial  
208 rotation. However, no significant differences were noted in VL, RF, and VM muscle  
209 activity during the step-up task. The results of the present study indicate that VM muscle  
210 activity significantly increases during the step-down task. Increased muscle activity is  
211 associated with increased joint stiffness during eccentric contraction to reduce  
212 patellofemoral pressure [32]. This suggests that some changes in quadriceps muscle  
213 activation strategies occur during the step-down task after prolonged sitting. Moreover,  
214 reduced VL muscle activity indicates reduced control over the patellofemoral joint, which  
215 is associated with medial-lateral misalignment and frontal plane deviation [33]. However,  
216 this difference was not significant in the present study. A possible explanation for the  
217 significant difference between ascending and descending step was the characteristics of  
218 quadriceps muscle contraction. Quadriceps contracts concentrically and eccentrically  
219 during step-up and step down respectively. Pincivero et al [34] demonstrated increasing  
220 quadriceps muscle EMG in concentric phase, and decrease in eccentric during dynamic  
221 leg press exercise. Moreover, the %MVIC of the concentric phase is higher than eccentric  
222 during step task [35].

223

224 Different sitting postures significantly affected changes in VM and VL activation  
225 during the step-up task. A significant increase in VM and VL activation was observed in  
226 the cross-legged sitting group compared with that in the ‘sitting on a chair’ group.  
227 Differing degrees of knee flexion in a prolonged sitting position can affect muscle length

228 tension of the quadriceps muscles [8]. Mechanical factors affecting the muscle length  
229 tension relationship may reduce the contractile capacity of the muscle to produce force  
230 and affect motor unit recruitment [17]. Increasing the number of active motor units might  
231 be another response to perform the same task effectively after prolonged sitting.  
232 Prolonged sitting with different knee flexion magnitudes and femur rotations may also  
233 affect the VM and VL muscles, as shown in the present study. Rotations of the tibia and  
234 femur knee flexion position can affect the VL and VM [21]. Knee flexion with internal  
235 rotation of the femur was observed during side-sitting, whereas higher knee flexion with  
236 external rotation of the femur was noted during cross-legged sitting.

237         The present study demonstrated that 15 min of sitting in the cross- and side-sitting  
238 positions affected VL and VM control during step tests. Increased VM and VL activation  
239 possibly controls the patellofemoral joint. Therefore, the VM and VL muscles may  
240 become more easily fatigued when performing many step tasks or squatting exercises  
241 after prolonged cross-legged sitting, which might contribute to the development of PFPS.  
242 Therefore, individuals with knee pain should avoid cross-legged sitting. However,  
243 implications should be interpreted carefully because of the time of prolonged sitting.  
244 Individuals with PFPS should be recruited in future studies to better understand the  
245 mechanism of the role of prolonged sitting in various postures in PFPS.

## 246 **Conclusions**

247         VM and VL activity changes in healthy young women during step tasks after  
248 prolonged cross- and side-sitting. The VMs during descending controls exhibited a  
249 significantly increased activity after extended time periods of cross-legged sitting. The  
250 change in VM and VL activity after cross-legged sitting increased significantly during

251 the step-up task compared with that observed after sitting on chairs for extended time  
252 periods. Increased VM and VL activation may control the patellofemoral joint. The VM  
253 and VL muscles may therefore fatigue more easily when performing many step tasks or  
254 squatting exercises after prolonged cross-legged sitting, which might contribute to the  
255 development of PFPS.

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