Association between increase in vertical ground reaction force loading rate and pain level in women with patellofemoral pain after a patellofemoral joint loading protocol

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Background: The etiology of patellofemoral pain (PFP) is thought to be the result of increased patellofemoral joint (PFJ) load and aberrant lower extremity mechanics, including altered vertical ground reaction forces (VGRF). However, few studies have investigated the association between an increase in pain and VGRF loading rates in the context of PFP. Thus, this study aimed to investigate the immediate effects of PFJ loading on pain and VGRF loading rate, and to see if there is a link between modification of both pain and VGRF loading rate during stair negotiation.

Methods: Thirty-four women with PFP underwent VGRF analysis during stair negotiation under two conditions: with (condition 2) and without (condition 1) being previously submitted to a PFJ loading protocol in order to or not to exacerbate their knee pain, respectively.

Results: The VGRF loading rates were significantly higher in condition 2 (Mean ± standard deviation (SD) = 4.0 ± 0.6 N/s) compared to condition 1 (Mean ± SD = 3.6 ± 0.5 N/s) during stair ascent and during stair descent (Mean ± SD: condition 1 = 6.3 ± 1.1 N/s; condition 2 = 7.0 ± 1.4 N/s). In addition, VGRF loading rates were higher during stair descent compared to stair ascent in both conditions. There were significant correlations between the increase in pain and VGRF loading rate during both tasks.

Conclusion: There seemed to be an important relation between the increase in pain and VGRF loading rates in women with PFP. Based on these findings, interventions aimed at reducing VGRF loading rates are important in the context of PFP.

Keywords: Ground reaction forces Loading rates Patellofemoral pain Stair negotiation

1. Introduction

Patellofemoral pain (PFP) is a common and costly musculoskeletal disorder that affects men, women and adolescents; women are 2.23 times more likely to develop PFP than men [1]. Previous studies have suggested that PFP may be a precursor to subsequent knee osteoarthritis in such populations [2,3]. Patellofemoral pain is characterized by pain around and behind the patella, and is aggravated by activities causing repetitive and high patellofemoral compressive forces such as stair ascent and descent, squatting and running [4,5]. Although this disorder accounts for 25–40% of all knee complaints in sports medicine [6], the underlying mechanisms remain unclear [7].
The etiology of PFP is thought to be the result of increased patellofemoral joint (PFJ) load and aberrant lower extremity mechanics [8], including altered vertical ground reaction forces (VGRF) [9–11]. The VGRF during heel strike in gait produce stress waves that are transmitted through the lower extremity up the kinetic chain [12]. These stress waves have been shown to be harmful when they are applied for short periods of time [13]. Since human tissue is viscoelastic, its loading response is time-dependent (loading rates) and more prone to injury at higher loading rates [14]. Previous studies have investigated and found an association between high VGRF loading rates and joint degenerative process [13,14]. It is of interest that the general population dependent (loading rates) and more prone to injury at higher loading rates [14]. Previous studies have investigated and found harmful when they are applied for short periods of time [13]. Since human tissue is viscoelastic, its loading response is time- waves that are transmitted through the lower extremity up the kinetic chain [12]. These stress waves have been shown to be harmful when they are applied for short periods of time [13]. Since human tissue is viscoelastic, its loading response is time-dependent (loading rates) and more prone to injury at higher loading rates [14]. Previous studies have investigated and found an association between high VGRF loading rates and joint degenerative process [13,14]. It is of interest that the general population dependent (loading rates) and more prone to injury at higher loading rates [14]. Previous studies have investigated and found harmful when they are applied for short periods of time [13]. Since human tissue is viscoelastic, its loading response is time- 

Higher VGRF loading rates in women with PFP compared to pain-free controls have been explained by altered knee kinematics [9]. Reduced knee flexion has been found in women with PFP and, although such a compensatory strategy is a logical approach to decreasing pain, it may hamper the lower extremity absorption mechanisms and, hence, may result in increased VGRF loading rates during negotiating stairs [9,10]. Therefore, there seems to be a direct relation between pain level and VGRF loading rates (i.e., the higher the pain, the higher the VGRF loading rates) [10]; however, such a novel approach has not previously been thoroughly investigated. In this line of reasoning, interventions aimed at reducing pain and VGRF loading rates may play an important role in reducing pain in the context of PFP [9,11].

One study has examined and found a relation between pain level and higher loading rates from the first peak of the VGRF in women with PFP compared to controls [10]. Nevertheless, the authors used a previous month of self-reported pain in the correlation model and, therefore, the immediate link between pain level and VGRF loading rates remains unknown. Given as such, there has not been an investigation into whether VGRF loading rates change immediately in the presence of pain, which could be an issue, as individuals with PFP tend to have intermittent pain characteristics [16]. Investigating whether individuals with PFP have different patterns of VGRF loading rates in the presence of pain would be important in the context of PFP. As a PFJ loading protocol has recently been shown to increase pain in women with PFP [16], its application could be used to overcome the aforementioned limitation.

Therefore, the aims of the current study were to investigate the immediate effects of PFJ loading on pain and VGRF loading rate, and to see if there is a link between the modification of both pain and VGRF loading rate during negotiating stairs. In addition, it aimed to determine the immediate effects of PFJ loading on the parameters that could influence and explain possible changes in the VGRF loading rate (i.e., VGRF first peak magnitude and stance time). It was hypothesized that there would be a mutual increase in pain level and VGRF loading rates, either in stair ascent or in stair descent, and that these two variables would be associated.

### 2. Methods

#### 2.1. Participants

Thirty-four women with PFP were recruited via advertisements placed at the university, parks and gyms (demographics are presented in Table 1). Only women were included, due to the high prevalence of PFP in this population [1]. In addition, it was assumed that including both sexes could be seen as a confounding factor, as women have been reported to exhibit different movement patterns to men [17]. Based on calculations made in the sample power using Statistical Software for Social Sciences (SPSS) Version 18.0 (SPSS Inc. Chicago, IL, USA) with data from De Oliveira Silva et al. [10], a minimum sample size of 29 women was indicated to an expected \( r = 0.56 \), with a statistical power of 80% and a significance level of five percent. Prior to data collection, all participants provided written informed consent and the experimental protocol was approved by the Institutional Review Board of the University of São Paulo State Human Ethics Committee (306.729).

Diagnosis of PFP was confirmed following consensus from two experienced clinicians (>5 years’ experience) and based on definitions used in previous studies [18–20]. The inclusion criteria were: (1) anterior knee pain during at least two of the following activities: prolonged sitting, squatting, kneeling, running, climbing stairs, and jumping; (2) pain during patellar palpation; (3) symptoms of insidious onset and duration of at least one month; (4) worst pain level in the previous month of at least three centimeters on a 10-cm visual analogue scale (VAS); and (5) two or more positive clinical signs in the following tests:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Age, years</th>
<th>Height, m</th>
<th>Mass, kg</th>
<th>Bilateral symptoms, n</th>
<th>Dominance, n</th>
<th>Physical activity, MET·min·wk.(^{-1})</th>
<th>Bilateral/unilateral symptoms, n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, height, mass and physical activity are presented as mean and standard deviation.</td>
<td>22.6 (2.1)</td>
<td>1.65 (0.10)</td>
<td>70.2 (7.7)</td>
<td>10</td>
<td>21 right/13 left</td>
<td>4281.6 (478.6)</td>
<td>5/29</td>
</tr>
</tbody>
</table>
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