No Difference in Gluteus Medius Activation in Women With Mild Patellofemoral Pain

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Context: The gluteus medius (Gmed) is proposed to consist of 3 functional subdivisions (anterior, middle, and posterior). Gmed weakness and dysfunction have been implicated in numerous lower extremity disorders, including patellofemoral pain syndrome (PFPS). PFPS is a knee condition that frequently occurs in females and is associated with activities such as squatting and stair climbing. There is a lack of evidence for the role of the subdivisions of the Gmed in females with and without PFPS. Objective: To compare muscle activation in the 3 Gmed subdivisions during 4 weight-bearing exercises in women with and without PFPS. Design: Single-session, repeated-measures observational study. Setting: University research laboratory. Participants: Convenience sample of 12 women with PFPS and 12 age- and gender-matched asymptomatic controls. Intervention: Participants performed 4 weight-bearing exercises (wall press, pelvic drop, step-up-and-over, and unilateral squat) 3 times while surface electromyography (sEMG) activity of the Gmed segments was recorded. Main Outcome Measures: sEMG muscle activity for each functional subdivision of the Gmed during each weight-bearing exercise was analyzed using a mixed between–within-subjects ANOVA (post hoc Bonferroni). Results: No statistically significant differences in muscle activation were found between the PFPS and healthy participants ($P = .97$). Furthermore, there were no statistically significant differences between the exercises ($P = .19$) or muscle fibers ($P = .36$) independent of group analyzed. However, the activation of the subdivisions varied according to the exercise performed ($P = .003$). Conclusions: Similar levels of muscle activation were recorded in the Gmed subdivisions of the PFPS and healthy participants during the different exercises. This is the first study to examine all 3 Gmed subdivisions in PFPS. Future studies using larger sample sizes should also investigate onset and duration of muscle activation in all Gmed subdivisions in both healthy individuals and those with PFPS.

Keywords: hip, exercise, electromyography

Although it has been implied that altered gluteus medius (Gmed) activity may negatively affect the knee joint, there is limited and conflicting evidence regarding the neuromuscular activity of the hip in patients with patellofemoral pain syndrome (PFPS). Electromyographical investigations and cadaver dissections have demonstrated that the Gmed consists of 3 subdivisions—anterior, middle, and posterior—each with separate nerve innervations and muscle-fiber orientations. Most previous studies examining Gmed activity in PFPS participants have used 1 or 2 electrodes and, therefore, did not evaluate all proposed functional subdivisions of the muscle. Considering that force is not generated homogeneously throughout muscles and different muscle subdivisions have different functional roles, analysis of muscle activity in all 3 subdivisions of Gmed is essential to provide accurate and comprehensive findings. Recently it was shown that the 3 Gmed subdivisions in pain-free individuals are activated differently by varying directions of isometric hip contraction and by different hip exercises. This has not yet been examined in individuals with PFPS. An awareness of how Gmed subdivision activation levels differ between PFPS and healthy individuals during functional weight-bearing activities could lead to a greater understanding of the proximal dysfunctions associated with PFPS and ultimately the development of optimal rehabilitation programs for such patients.

Although as a single muscle mass the Gmed acts primarily as a hip abductor and stabilizer of the pelvis, its subdivisions are also capable of selective and phasic activity. The exact role of these subdivisions, however, remains poorly understood. A recent study found that all 3 Gmed subdivisions have greater activation during both abduction and internal rotation than with external rotation. However, activation levels varied significantly between the different subdivisions during all the isometric contractions, with the anterior subdivision displaying higher levels of muscle activation than the middle and posterior fibers. In another study the posterior subdivision of the Gmed displayed significantly higher levels.
of activation than the anterior and middle subdivisions during weight-bearing activities. The results of such studies suggest that activation in 1 subdivision of Gmed may not necessarily be the same as that generated throughout the entire muscle during different activities.

PFPS is a common knee condition that is associated with activities that load the joint, such as squatting, running, and stair climbing. Research has linked gluteal dysfunction with PFPS.\(^{16,17}\) Weakness and dysfunction of the gluteal muscles, particularly the Gmed, have been implicated in numerous pelvic and lower extremity disorders including PFPS.\(^{18}\) It has been suggested that Gmed dysfunction may alter hip control\(^ {19,19}\) and cause contralateral pelvic drop,\(^ {2} \) allowing greater hip internal rotation and increased valgus forces at the knee,\(^ {1}\) contributing to PFPS. Furthermore, poor control of the Gmed has been implicated as a cause of lower extremity dynamic malalignment, which is strongly associated with PFPS.\(^ {2}\) Consequently, rehabilitation programs for PFPS commonly incorporate exercises focusing on gluteal control.\(^ {20–24}\) Despite the common use of gluteal exercises in PFPS rehabilitation programs, there are limited objective data regarding which exercises or hip movements recruit the gluteal muscles most effectively.\(^ {10,13,14,25,26}\)

Therefore, the primary aim of this study was to compare activation in the 3 subdivisions of the Gmed during 4 weight-bearing exercises in women with and without PFPS using surface electromyography (sEMG). The 4 exercises examined in the study were chosen based on their inclusion in previous similar studies examining Gmed activation—wall press,\(^ {27}\) pelvic drop,\(^ {28}\) step-up-and-over,\(^ {7}\) and unilateral squat.\(^ {7}\) We hypothesized that the PFPS group would demonstrate lower levels of muscle activation in all subdivisions of the Gmed during the different exercises than would the asymptomatic controls. The study also aimed to identify which exercises generate the greatest EMG activity in each of the different Gmed subdivisions for participants both with and without PFPS. We hypothesized, based on the findings of a previous study,\(^ {14}\) that the wall-press exercise would generate the greatest activation in all 3 Gmed subdivisions in both participant groups.

**Methods**

**Design**

Participants came to a university research laboratory for testing.

**Participants**

Approval for this study was granted by the local university research ethics committee. A convenience sample of 12 women with PFPS and 12 asymptomatic age- and gender-matched controls was recruited via word of mouth from the local community. The inclusion and exclusion criteria were based on previously published studies.\(^ {16,21,26,29–31}\) Specifically, the PFPS participants were women 18 to 35 years of age who were involved in at least 30 minutes of physical activity (including walking) 3 times per week. Participants had unilateral or bilateral knee pain located specifically around the patellofemoral articulation. The knee pain had been present for >3 months and was rated at a minimum of 3/10 on a numeric rating scale during at least 2 of the following activities: stair ascent or descent, squatting, kneeling, isometric quadriceps contraction, prolonged sitting or running, or sport activity. Participants were excluded if they were pregnant; if they had a history of previous hip, low back, ankle, or foot injury or surgery; or had had previous traumatic patellar dislocation or subluxation. Participants with any arthritis or inflammatory conditions affecting the foot, cognitive impairments, or neurologic impairments that may impair gait were also excluded.

All participants were screened for suitability for physical activity using a pretest physical activity readiness questionnaire\(^ {12}\) and provided written informed consent. Participants initially completed the Anterior Knee Pain Scale to record their subjective level of knee pain and disability before testing.\(^ {33}\) The painful limb, or most painful limb if PFPS was present bilaterally, was tested in the subjects with PFPS. Control participants were tested on the same side as their dominance-matched counterparts, resulting in 24 dominant limbs (12 PFPS, 12 control) being tested. Both control and PFPS participants were asked to self-report pain in the test knee using the numeric rating scale before the warm-up, post-warm-up, and after sEMG testing (Table 1). The numeric rating scale is reliable (ICC .96), valid, and responsive.\(^ {34}\) Participants pointed to the number on the scale that best described their pain, with zero indicating no pain and 10 indicating worst possible pain.\(^ {35}\) Participant demographics including age, height, and weight were collected.

**Procedures**

Before testing, participants completed a 5-minute warm-up at a self-directed pace on a treadmill and performed

| Table 1 Baseline Characteristics, Mean ± SD |
|----------------|----------------|----------|
| PFPS | Healthy | \(P\) |
| Age (y) | 23 ± 4 | 21 ± 1 | .15 |
| Height (cm) | 165.7 ± 5.9 | 164.6 ± 7.9 | .68 |
| Weight (kg) | 62.8 ± 7.6 | 62.6 ± 9.9 | .96 |
| Body-mass index (kg/m\(^2\)) | 22.8 ± 2.0 | 22.8 ± 3.1 | .96 |
| AKPS | 78 ± 9 | 100 ± 0 | |
| NRS before warm-up | 0.33 ± 0.78 | 0 ± 0 | |
| NRS after warm-up | 1.25 ± 1.6 | 0 ± 0 | |
| NRS after sEMG testing | 2 ± 2.45 | 0 ± 0 | |

Abbreviations: PFPS, patellofemoral pain syndrome; AKPS, Anterior Knee Pain Scale; NRS, numeric rating scale; sEMG, surface electromyography.
gentle lower limb stretches to minimize any delayed muscle soreness and muscle fatigue. A Motion Lab Systems MA-300 multichannel EMG system (Motion Lab Systems, Inc, Baton Rouge, LA) was used to collect sEMG data using dry, bipolar, preamplified electrodes that were circular in shape and 144 mm² in size and had a fixed interelectrode distance of 18 mm. sEMG was used to record Gmed muscle activity because access to fine-wire EMG was not possible, and sEMG has been used in previous similar research. Three channels were used to record EMG activation in the different subdivisions of the Gmed. The sample rate was set at 1000 Hz per channel. The bandwidth was 500 Hz, with an amplifier gain setting of 2000. Before electrode placement the skin was cleansed using an isopropyl alcohol solution and abraded with fine sandpaper, and any excess hair was shaved to reduce skin impedance. One bipolar electrode each was placed on the anterior, middle, and posterior Gmed subdivisions in line with recent studies. One electrode was positioned on each Gmed subdivision, aligned parallel to the muscle-fiber orientation as illustrated in Figure 1. A ground electrode was placed over the ipsilateral ulnar styloid. The electrodes were secured in position using adhesive medical tape. Accurate positioning of the electrodes was visually confirmed by inspecting sEMG activity during manual muscle testing.

Each participant performed a maximal voluntary isometric contraction (MVIC) of the Gmed to allow for normalization of sEMG data. Participants were positioned in side lying on a plinth. The test limb was uppermost, in knee extension and hip abduction, with a 4-in. wedge between the lower limbs above the knee joints. In this position, participants completed three 5-second MVICs of hip abduction, consisting of 2 practice trials and 1 recorded trial, against manual resistance provided above the ankle. Standardized instructions of “ready, set, go” and verbal encouragement were given to each individual to promote maximal contraction of the Gmed. Participants were allowed a 30-second rest period between trials to minimize muscle fatigue. The highest EMG value for each Gmed subdivision was recorded, and data obtained from each exercise trial were later expressed as a percentage of this MVIC.

Standardized verbal instructions and demonstrations of the weight-bearing exercises were given to each participant before testing. Participants were given 3 practice trials of each exercise. The 4 exercises were then performed 3 times in the following nonrandomized sequence: wall press, pelvic drop, step-up-and-over, and unilateral squat. The exercises were performed in a nonrandomized sequence, with the unilateral squat performed last due to positioning of the electrogoniometer. Participants were allowed a 30-second rest period between trials and a 2-minute rest period between exercises to reduce fatigue. The step-up-and-over and wall-press exercises were performed over 5 seconds, and the pelvic drop and unilateral squat were each performed over 4 seconds, allowing these exercises to be clearly divided into 2-second eccentric and concentric phases. A metronome (Cherub Technology Co Ltd, Shenzhen, China) set at 60 beats/min enabled participants to pace the speed at which they performed each exercise.

For the wall-press exercise participants stood next to a wall with the test leg positioned farthest away, at a distance of 10 in. from the wall. Participants assumed single-leg stance by flexing the non-test hip and knee to 60° and 90°, respectively, measured using a handheld goniometer. Participants were required to maintain this position while pushing the non-test knee, leg, and ankle against the wall (Figure 2). Standardized verbal instructions were given to each individual to ensure that the pelvis was kept level and the trunk was maintained in vertical alignment during each exercise trial. During the pelvic drop, participants stood on the test leg on a 15.24-cm step. Both knees were fully extended as they eccentrically lowered the pelvis on the non-test side toward the floor and concentrically returned it back to a level position (Figure 3). For the step-up-and-over exercise participants stood with their feet aligned behind a 15.24-cm box. They stepped onto the box with the test leg and brought the non-test leg up and over the box onto the ground on the opposite side. Participants then stepped off the box with the test leg to come into standing (Figure 4). Heel strike and toe-off were identified during the step-up-and-over using a foot switch under the calcaneus and first metatarsal. During the unilateral squat participants stood on their test leg with the non-test leg held out in front of them. They were required to flex the knee of the test leg to 30° and return to the starting position (Figure 5). The degree of knee flexion was

Figure 1 — Standardized electrode placement for the subdivisions of gluteus medius. The X’s mark the landmarks used for determining electrode placement: the anterosuperior iliac spine, iliac crest, greater trochanter, and posterior ilium.
Figure 2 — Participant position for the wall-press exercise.

Figure 3 — Participant position for the pelvic-drop exercise.

Figure 4 — Participant position for the step-up-and-over exercise.

Figure 5 — Participant position for the unilateral-squat exercise.
monitored using an electromyograph (Biometrics Ltd, UK) over the lateral aspect of the test leg, in line with the tibia and femur. Participants aimed for 30° of knee flexion but were allowed a knee-flexion range of 25° to 35° during the exercise. When they did not achieve this range of knee flexion, trials were repeated until an appropriate knee-flexion angle was achieved. After testing was completed, the electrodes were removed and the skin was cleansed with an isopropyl alcohol solution.

EMG signals were processed with customized WinDaq software. All sEMG data were full-wave rectified and processed using a root-mean-square algorithm over 150 milliseconds. Data were analyzed over the entire 5-second period for the wall press and step-up-and-over and the entire 4-second period for the unilateral squat and pelvic drop. Mean root-mean-square amplitudes for each subdivision were averaged over the 3 trials for each exercise, normalized as a percentage of MVIC, and used for statistical analysis.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS), Version 16.0. Data were normally distributed (Shapiro–Wilks test, \(P > .05\)). Mixed between–within-subjects analysis of variance with post hoc Bonferroni analysis was performed, with group as the between-subjects factor and subdivision and exercise type as the within-subject factors. Furthermore, it was used to determine if there were any statistically significant differences between the exercise types and muscle subdivisions, both independent of and dependent on group status. The level of significance for all statistical tests was set at \(P < .05\) in accordance with previous research.

Results

Independent \(t\) tests demonstrated that the 2 groups were not significantly different in terms of age, height, and weight (Table 1). The PFPS group reported a low level of pain before, during, and after testing (Table 1). The mean (+ SD) muscle activation for each muscle subdivision for each exercise is displayed in Table 2.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Subdivision</th>
<th>PFPS</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD</td>
<td>anterior</td>
<td>77.1 ± 13.6</td>
<td>79.9 ± 24.8</td>
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<tr>
<td></td>
<td>middle</td>
<td>87.9 ± 19.5</td>
<td>87.6 ± 32.6</td>
</tr>
<tr>
<td></td>
<td>posterior</td>
<td>83.6 ± 13.9</td>
<td>87.9 ± 23.9</td>
</tr>
<tr>
<td>SUO</td>
<td>anterior</td>
<td>81.9 ± 19.1</td>
<td>88.4 ± 19.6</td>
</tr>
<tr>
<td></td>
<td>middle</td>
<td>91.2 ± 23.0</td>
<td>85.4 ± 29.6</td>
</tr>
<tr>
<td></td>
<td>posterior</td>
<td>78.4 ± 23.5</td>
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</tr>
<tr>
<td>WP</td>
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<td>88.2 ± 15.3</td>
<td>83.9 ± 19.5</td>
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<tr>
<td></td>
<td>middle</td>
<td>92.3 ± 19.9</td>
<td>87.5 ± 30.8</td>
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<tr>
<td></td>
<td>posterior</td>
<td>90.4 ± 18.8</td>
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</tr>
<tr>
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<td>anterior</td>
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<td>92.7 ± 22.0</td>
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<tr>
<td></td>
<td>posterior</td>
<td>84.0 ± 27.4</td>
<td>86.7 ± 16.0</td>
</tr>
</tbody>
</table>

Table 2 Muscle Activation for Each Muscle Subdivision During Each Exercise, Mean + SD

Abbreviations: PFPS, patellofemoral pain syndrome; PD, pelvic drop; SUO, step-up-and-over; WP, wall press; US, unilateral squat.

\(F = 1.05, \eta_p^2 = .05\); Figures 6–8). When data from both groups were analyzed together, there was, however, a statistically significant difference between exercise type and muscle subdivision, independent of group tested \((df = 6, P = .003, F = 3.54, \eta_p^2 = .14)\), implying that the 3 subdivisions of Gmed responded differently to the exercises performed (Figure 9).

Discussion

Altered neuromuscular control of the hip has been suggested to contribute to the development of PFPS. The primary findings of this study, however, revealed no significant differences in activation of the Gmed subdivisions between the PFPS group and healthy individuals.

Research on Gmed activity in individuals with PFPS has demonstrated conflicting results. The discrepancies arising in the literature may relate to differences in task performance, muscle-onset identification, and signal processing. All of which limit direct comparison of results between studies. Furthermore, previous research primarily looked at Gmed activation in the muscle as a whole rather than in the different functional subdivisions of the muscle. Only 3 studies to date have investigated EMG activity in the 3 subdivisions of Gmed, and all exclusively examined healthy individuals.

A similar study also reported no significant differences in levels of Gmed activation between PFPS and healthy individuals during a number of weight-bearing tasks. However, the participants with PFPS demonstrated altered activation of the gluteus maximus muscle, exhibiting 91% greater activation during running and 64% more during a step-down task than the healthy controls.
Simultaneous recording of activity in the key muscles of the hip, including the gluteus maximus, may provide a more comprehensive analysis of muscle-activation patterns in individuals with PFPS.

Brindle et al.\(^1\) reported delayed onset of Gmed activity during stair ascent and shorter duration of activity during stair ascent and descent in individuals with PFPS than in healthy controls. They hypothesized that such altered patterns of Gmed activation were the result of a compensatory strategy due to the PFPS. Although kinematic data were recorded by the researchers, kinematic changes in position during stair ascent and descent were not measured. The data may have explained why Gmed activation levels differed between the PFPS and healthy participants. While Brindle and colleagues\(^1\) did not specify which subdivision of Gmed was evaluated, a similar study by Cowan et al.\(^9\) reported delayed activation in both the anterior and posterior subdivisions of Gmed in PFPS participants. However, as the current study did not investigate timing of Gmed activation, our results cannot be directly compared with those of the aforementioned studies.

The secondary aim of this study was to identify which exercises generated the highest level of EMG activity in each Gmed subdivision in both healthy and PFPS subjects. Although there was some variation in muscle activation between Gmed subdivisions during the exercises, this was not statistically significant. This study found that while the anterior and middle fibers were most active during the unilateral squat, the posterior fibers demonstrated greatest levels of activation during the wall-press exercise, comparable to the findings of O’Sullivan et al.\(^14\) in uninjured participants using similar exercises and a similar methodology. We believe that the clinical relevance of these differences is that the results display a large degree of coactivation of the Gmed subdivisions, and yet the subdivisions, as demonstrated in previous studies,\(^4,13\) are not entirely homogeneous. As a result, rehabilitation programs for the Gmed should consider exercises that load the hip joint in a variety of movement planes.
A number of methodological differences between previous investigations and the current study need to be considered. Unlike the current study, Brindle et al. did not control the speed at which participants performed the stair-stepping task and acknowledge that slower velocities may generate longer periods of muscle activation. Cowan et al. used surface and fine-wire electrodes to examine anterior and posterior Gmed subdivision activity, respectively. As the posterior Gmed is partially located deep to the gluteus maximus muscle, fine-wire EMG may be a more suitable method of measuring activity in this subdivision than sEMG as it enables localized investigation of muscle divisions. However, while other studies appear to have primarily measured activity in the middle portion of the Gmed, Cowan et al. neglected to record activity in this specific subdivision.

Limitations of the current study include the use of sEMG rather than fine-wire, or needle, EMG to measure muscle activation. We did not use fine-wire EMG due to its invasive nature. Previous studies have documented the potential risk of crosstalk from neighboring muscles, such as the adjacent gluteal muscles and tensor fascia lata, when using sEMG to measure Gmed activity. The potential for crosstalk in this study was minimized by using a standardized method of electrode application and securing the electrodes with adhesive tape to prevent them from moving. Previous research has demonstrated that the Gmed is the muscle directly underlying these electrode positions. The results of this study may not be directly comparable with previous studies due to differences in Gmed MVIC testing positions. Previous studies positioned subjects in side-lying with the test leg upright in varying degrees of hip abduction. However, it has been found that EMG-signal amplitude increases with increasing hip abduction due to length-tension changes in the muscle. Furthermore, it is possible that participants did not generate a true MVIC of Gmed due to lack of effort or to pain inhibition among the PFPS participants. A further limitation is that exercises were not performed in a randomized sequence as in previous studies, which may have resulted in order bias or subject fatigue. To minimize potential fatigue, adequate rest periods were provided between tests. The low level of knee pain reported by several of the PFPS participants could be considered a limitation. Despite only including participants with pain of at least 3/10 during common functional tasks, the level of pain during testing was lower than this, so it may not have significantly inhibited muscle activation. It is possible that in PFPS subjects with greater pain, differences in Gmed activation may be more pronounced. However, the low level of pain reported in this study may actually reflect the sort of mild PFPS commonly seen in clinical practice. Based on previous studies, all PFPS participants were required to have self-reported knee pain of at least 3/10 during at least 2 common aggravating activities. As the testing procedure specifically incorporated both squatting and stair ascent/descent, we expected that knee pain would be aggrivated in the PFPS participants during testing. However, many of the PFPS participants reported very low levels of pain pretesting and posttesting. We acknowledge that hip muscles other than the Gmed are involved in the exercises and tasks studied here, including the gluteus maximus and the deep hip muscles, and these are worthy of further study. It is possible the exercises chosen were not challenging enough, but the effort associated with them is consistent with the exercises and tasks used in previous studies. Variations in hip-flexion angle between the exercises could affect muscle activation, but the degree of variation in hip flexion between exercises was relatively small. No sample-size calculation was performed, but the data suggest that no difference between the PFPS group and healthy individuals is likely in a larger sample. Finally, this study investigated Gmed subdivision activity exclusively in active women 18 to 35 years of age. Generalizing the results of this study to other populations including men with PFPS or individuals with patellofemoral joint instability should be done with caution, as results may differ in other such populations.

A number of previous studies identified differences in onset and duration of Gmed activation in PFPS participants but failed to look at all 3 subdivisions of the muscle. Consequently, future studies should investigate onset and duration of activity in all Gmed subdivisions to comprehensively determine if altered Gmed activity coincides with PFPS. Furthermore, future EMG studies recording Gmed activity should perform concurrent recordings of muscle activity in other key hip muscles including the gluteus maximus, gluteus minimus, and tensor fascia lata to obtain a more global insight into muscle-activation patterns in individuals with PFPS.

**Conclusion**

Previous studies investigating Gmed activity in PFPS participants have reported conflicting results. In this study, similar levels of muscle activation were recorded in the subdivisions of Gmed in healthy and PFPS participants. However, this is the first study to examine activation in all 3 subdivisions of the muscle in individuals with PFPS. The findings may inform clinical rehabilitation programs. There is a need for future research to investigate whether onset and duration of activity in the subdivisions of the Gmed and adjacent muscles differ between PFPS and healthy individuals. Such investigations may help clinicians devise effective rehabilitation programs tailored to this population.

**Acknowledgments**

We thank Aidan McMoreland, BSc (physiotherapy); Cliona Twohig, BSc (physiotherapy); and Clodagh Toomey, BSc (physiotherapy), for assistance with participant recruitment.

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