Physical Therapy in Sport 38 (2019) 59–65

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

A proximal progressive resistance training program targeting strength and power is feasible in people with patellofemoral pain

Christian J. Barton [a, b, *], Danilo de Oliveira Silva [a, c], Brooke E. Patterson [a], Kay M. Crossley [a], Tania Pizzari [a], Guilherme S. Nunes [a, d]

[a] La Trobe Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Melbourne, Australia
[b] Department of Surgery, St Vincent's Hospital, University of Melbourne, Australia
[c] Department of Physiotherapy, School of Science and Technology, São Paulo State University (UNESP), Presidente Prudente, Brazil
[d] Department of Physiotherapy, São Carlos Federal University, São Carlos, Brazil

ARTICLE INFO

Article history:
Received 20 March 2019
Received in revised form
16 April 2019
Accepted 16 April 2019

Keywords:
Patellofemoral
Exercise
Strength
Power

ABSTRACT

Objectives: To evaluate the feasibility of a 12-week progressive resistance training program for people with patellofemoral pain (PFP) targeting proximal muscle strength and power; and resulting clinical and muscle capacity outcomes.
Design: Feasibility study.
Setting: Clinical environment.
Participants: Mixed-sex sample of people with PFP.
Main outcome measures: Feasibility outcomes included eligibility, recruitment rate, intervention adherence, and drop-outs. Secondary outcomes included perceived recovery, physical function (AKPS and KOOS-PF), worst pain (VAS-cm), kinesiophobia (Tampa), physical activity (IPAQ), and hip strength (isometric and 10 repetition maximum) and power.
Results: Eleven people, from 36 who responded to advertisements, commenced the program. One participant withdrew. Ten participants who completed the program reported improvement (3 completely recovered; 6 marked; and 1 moderate). Higher AKPS (effect size [ES] = 1.81), improved KOOS-PF (ES = 1.37), and reduced pain (ES = 3.36) occurred alongside increased hip abduction and extension dynamic strength (ES = 2.22 and 1.92, respectively) and power (ES = 0.78 and 0.77, respectively). Isometric strength improved for hip abduction (ES = 0.99), but not hip extension.
Conclusion: A 12-week progressive resistance training program targeting proximal muscle strength and power is feasible and associated with moderate-large improvements in pain, function, and hip muscle capacity in people with PFP. Further research evaluating the efficacy of progressive resistance training is warranted.

1. Introduction

Patellofemoral pain (PFP) affects approximately 23% of the general population (Smith et al., 2018), and is frequently aggravated by tasks that load the patellofemoral joint (PFJ), including stair negotiation, squatting, and sporting tasks such as running and landing (Neal, Barton, Gallie, O'Halloran, & Morrissey, 2016; Willson & Davis, 2008). Recommended treatments for PFP include exercise therapy targeting both the knee and hip, foot orthoses, and combined treatment approaches delivered by a physiotherapist (Collins et al., 2018; Crossley et al., 2016a,b). A tailored treatment approach is considered important (Barton, Lack, Hemmings, Tufail, & Morrissey, 2015). Of treatments available, exercise-therapy possesses the strongest supporting evidence for managing PFP (Holden, Rathleff, Jensen, & Barton, 2017; Lack, Barton, Sohan, Crossley, & Morrissey, 2015; van der Heijden, Lankhorst, van Linschoten, Bierma-Zeinstra, & van Middelkoop, 2015). Although both knee- and hip-targeted exercise-therapy are beneficial, hip-targeted programs appear to provide greater benefits to pain and function in the short-medium term (Lack et al., 2015).

Despite numerous effective treatments, more than 40% of people with PFP have persistent symptoms (Collins et al., 2013;

* Corresponding author. La Trobe Sport and Exercise Medicine Research Centre, Bundoora, VIC, 3086, Australia.
E-mail address: christian@completesportscare.com.au (C.J. Barton).

https://doi.org/10.1016/j.ptsp.2019.04.010
1466-853X/

Lankhorst et al., 2016; Nimon, Murray, Sandow, & Goodfellow, 1998). Highlighting the recalcitrant nature of PFP, recent reports indicate 57% of people with PFP have unfavorable outcomes 5–8 years following enrollment in a clinical trial (Lankhorst et al., 2016). A number of factors are linked to poor long term outcomes, including longer symptom duration, bilateral symptoms, female sex, higher pain frequency and intensity, poorer function, and lower health and education levels (Matthews et al., 2017). It is suggested that longer term outcomes may be improved through treatment that is more tailored to patient needs (Barton, Crossley, & Macri, 2018; Maclachlan, Collins, Matthews, Hodges, & Vicenzino, 2017; Selfe et al., 2016) and preferences (Barton & Crossley, 2016).

Enhanced long-term outcomes for people with PFP may be achieved following exercise-therapy programs incorporating appropriate progressive resistance training principles (Lack, Neal, Silva, & Barton, 2018). Cross-sectional research consistently reports deficits in hip muscle function and capacity, including impaired neuromotor function of the gluteals (Barton, Lack, Malliaras, & Morrissey, 2013) and strength (isometric and concentric) deficits compared to asymptomatic people (Rathleff, Rathleff, Crossley, & Barton, 2014). More recently, we identified large deficits in dynamic strength (10 repetition maximum), muscle power and rate of force development (RFD) at the hip in people with PFP (Nunes, Barton, & Serrão, 2018; Nunes et al., 2019). To date, no study has evaluated an exercise therapy program of adequate progression in load/intensity, or adequate duration to sufficiently target proximal muscle strength and power deficits reported in people with PFP. Most studies evaluating proximally targeted exercise therapy have not provided sufficient exercise progression to induce strength changes (Lack et al., 2015). Additionally, the only study evaluating an exercise program of adequate progression to improve proximal muscle power was limited to a 6-week intervention (Tyler, Nicholas, Mullaney, & McHugh, 2006), which may be too short to facilitate sustained muscle strength or power changes (Garber et al., 2011). Importantly, this short time-period is consistent with most exercise therapy programs evaluated in the PFP literature, typically limited to between 3 and 8 weeks duration (Lack et al., 2015; van der Heijden et al., 2015), a period during which heavier loads are often limited due to potential pain flares. Considering sustained improvements in muscle strength, power, and hypertrophy requires greater progressive overload and program length (≥6-weeks of adequate load) (Garber et al., 2011), more intensive and targeted exercise-therapy programs warrant consideration for people with PFP.

This feasibility study aims to evaluate (i) the feasibility of a 12-week progressive resistance training program targeting proximal muscle strength and power; and (ii) clinical outcomes and changes in hip strength and power in people with PFP. We hypothesised we would recruit at least 10 participants over a 12-week period, and that the exercise-therapy program would have high adherence (average > 70% of prescribed exercise tasks per week) and low adverse (<20% of participants) event rates.

2. Methods

2.1. Participants and recruitment

Assessment of participant eligibility was performed by a physiotherapist following recommendations of the 4th Patellofemoral Pain Consensus Statement (Crossley et al., 2016a,b). The inclusion criteria were the presence of retropatellar or peripatellar pain for at least two months with insidious onset of symptoms unrelated to a traumatic event, and presence of retropatellar or peripatellar pain (minimum 3/10 points on a visual analogue scale [VAS]) in at least three of the following activities: negotiating stairs, running, kneeling, squatting, prolonged sitting, jumping and isometric contraction of quadriceps. Exclusion criteria included events of patellar subluxation or dislocation, chronic inflammatory disease, lower limb surgery, patellar tendon or meniscus tears, bursitis, ligament tears, or the presence of neurological disease. Those who had received oral steroids, opiate treatment, acupuncture, physiotherapy, or any other treatment for pain during the preceding six months were also excluded. All the potential participants were first screened online using a subjective diagnostic survey. This study was approved by the La Trobe University's Human Research Ethics Committee (HEC 16–141) and written informed consent was obtained from all participants.

2.2. Procedures

Baseline and follow-up assessments were performed over approximately one hour. First, participants completed questionnaires to assess patient reported outcomes including pain, self-reported function, level of physical activity and kinesiophobia. Participants then underwent assessment of hip abduction and extension isometric strength, dynamic strength and power. The affected knee or the more painful knee was assessed. After baseline assessment, participants completed a progressive resistance training program targeting proximal (hip and trunk) muscle strength and power.

2.3. Intervention, including progressive resistance training approach

Each participant was provided with a standardized patient education leaflet, titled 'Managing My Patellofemoral Pain' (https://bmjopensem.bmj.com/content/bmjosem/2/1/e000086/F1.large.jpg) (Barton & Rathleff, 2016). The leaflet covers various topics including 'What might cause my knee pain?' and 'Treatment options', which are divided into exercise and additional treatments.

The exercise program provided to participants (see supplementary materials 1 and 2) was pragmatically designed based on accepted resistance training principles (Garber et al., 2011), and with input from experienced clinicians. The program was designed to be long enough (>6 weeks) with adequate progression (load/intensity) to target strength and power of the proximal musculature in people with PFP (Garber et al., 2011; Lack et al., 2015). Prescription for each exercise, including progressions, were based on the American College of Sports Medicine Position Statement (Garber et al., 2011), a commonly used document for guiding exercise prescription principles (see 'general exercise principles' section in supplementary material 2). Principles of the exercise program first focused on neuromotor control and endurance, before being progressed to strength and power once correct exercise technique and motor control were obtained. Once working on strength and power, participants were typically asked to focus on strength for one session, power for another session and choose between strength and power for the third session each week. Specific details of the exercise program, including principles and progressions used by treating physiotherapists can be found in supplementary material 2.

Exercises targeted hip extension (component 1 - bridging), hip abduction (component 2 – side lying and weight bearing), and the trunk stability (component 3 – front and side planks), with multiple options to allow tailoring based on individual capability and needs. Each participant was initially provided with one exercise option for hip extension, hip abduction and trunk stability. After four weeks, knee exercises (weight-bearing or non-weight-bearing) could be added to the program if deemed necessary by the physiotherapists or requested by the patient (see optional

components 1–2 in supplementary material 2). Options for knee exercises included knee extension, hamstring curl, long lever bridge, or squatting (double and single legged). Regardless, hip abduction, hip extension and trunk exercises with relevant progressions were continued for the duration of the program.

Participants were instructed to complete the program independently three times per week for 12 weeks, in a gymnasium (convenient to them) and/or at home. If participants were unable to complete at least two sessions in any given week, they were asked to repeat the week, and this was allowable as long as the program did not extend beyond 16 weeks. Guidance and progression of the program was facilitated via 5–8 face-to-face physiotherapy sessions (30 min) with one of two experienced (>5 years) physiotherapists (CB or BP) at La Trobe University, or a private practice (Complete Sports Care, Melbourne) gymnasium. Physiotherapy sessions involved both progression (increasing load, adding speed) of previously provided exercises, and progression to, or addition of new exercise options or components. Additional exercises could target the same component (e.g. completion of both side lying and standing hip abduction) or involve an optional component (knee extension or flexion). No more than five exercises were to be provided to participants at any time point.

Videos and written instructions, along with reminders were provided to each participant via smartphone application PhysiApp®. Participants were asked to use PhysiApp® to document compliance to the exercise program, and pain during exercise sessions.

2.4. Primary outcome

Feasibility outcomes included proportion of eligible participants from advertisement responses; willingness to participate (proportion of participants eligible to participate who chose to enroll); recruitment rate (number per week); adherence to the intervention (proportion of prescribed exercise tasks, including all sets, completed each week); and drop-out rate. Adverse events were recorded.

2.5. Secondary outcomes: patient-reported outcome measures (PROMs)

Global rating of change (GROC) – Participants rated their perceived recovery on a 6-point Likert scale (completely recovered, markedly better, moderately better, same, moderately worse, markedly worse). Measuring patient perceived outcomes via these types of scales is clinically relevant and a stable concept for interpreting meaningful improvements from an individual perspective (Kamper, Maher, & Mackay, 2009).

Pain was measured as 'worst pain during the preceding week' using a 10 cm visual analogue scale (VAS) (Crossley, Bennell, Cowan, & Green, 2004).

Self-reported function was assessed using the Anterior Knee Pain Scale (AKPS), a reliable 13-item questionnaire (0–100 points) evaluating subjective symptoms and functional limitations associated with PFP, with a score of 100 indicating no disability (Crossley et al., 2004).

Self-reported function specific to PFJ was assessed using the Knee injury and Osteoarthritis Outcome Score for patellofemoral pain and osteoarthritis (KOOS-PF), an 11-item questionnaire evaluating patellofemoral-specific symptoms (0–100 points), with a score of 100 indicating no disability (Crossley, Macri, Cowan, Collins, & Roos, 2018).

Self-reported physical activity was assessed using the International Physical Activity Questionnaire Scoring Protocol short form (IPAQ-S), and measured in METs (MET-min/week). The total physical activity MET-minutes/week was calculated using the following formula: Walking (3.3 METs*min*days) + Moderate Intensity (4.0 METs*min*days) + Vigorous Intensity (8.0 METs*min*days) (Craig et al., 2003).

Kinesiophobia (Fear of Movement) was assessed using the Tampa Scale for Kinesiophobia, a 17-item questionnaire to quantify fear of movement and re-injury due to movement and physical activity (17–68 points), where 68 indicates greatest fear of re-injury due to movement (French, France, Vigneau, French, & Evans, 2007).

2.6. Secondary outcomes: muscle capacity

Detailed description of muscle capacity testing for hip strength (isometric and 10 repetition maximum [10RM]) and power has been provided in a previous publication (Nunes et al., 2019), and video demonstrations can be found here: bit.ly/hipmuscleassess.

In brief, *isometric strength* for hip abduction and hip extension was measured using a hand held dynamometer (HHD; JTech Commander PowerTrack, JTech Medical Industries Inc., Midvale, USA). Hip abduction was assessed in side lying with the hip in a neutral position (Bazett-Jones et al., 2013; Ireland, Willson, Ballantyne, & Davis, 2003), and hip extension was assessed in prone with the knee of the assessed lower limb flexed to 90°, and the hip in a neutral position (Bazett-Jones et al., 2013). Data were converted into torque (multiplying by lever arm [distance between greater trochanter and lateral malleolus or lateral condyle of the femur]) and normalized by body weight ([N.m/kg]*100 = %BW), with the mean of three trials used for analysis (Bazett-Jones et al., 2013).

Dynamic muscle strength was measured using trial and error to establish 10RM in standing with a gym cable machine (Nautilus Freedom Trainer, Nautilus Inc., Vancouver, Canada) (Maddigan, Button, & Behm, 2014). Hip abduction range was from neutral to approximately 30 degrees of hip abduction, and hip extension range was from approximately 20 degrees of hip flexion to 20 degrees of hip extension (Bazett-Jones et al., 2013; Maddigan et al., 2014). Participants were instructed to perform one repetition every two seconds (one second concentric; one second eccentric), paced with a metronome (Maddigan et al., 2014). The load for the 10RM was normalized by body weight ([kg (10RM)/kg (body weight)]*100 = %BW).

Muscle power was assessed using a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) (Banyard, Nosaka, Sato, & Haff, 2017), which measures time and displacement during movement, and based on the informed load, calculates power. Hip abduction and extension were assessed at 80% of 10RM using the same testing position and range of movement for the 10RM test, and completed after five minutes of rest following the 10RM. Peak power was normalized by body weight (W/kg) during each trial, with the mean of the five trials (separated by 30 s) was used in the analysis.

2.7. Statistical analysis

All analyses were performed using Statistical Package for the Social Sciences software program (version 18.0, SPSS, INC., Chicago, IL) with an a priori level of significance of 0.05. All variables were assessed for normality and found to be normally distributed on the basis of obtainment of $p > 0.05$ in the Shapiro-Wilk test.

Descriptive characteristics were presented in mean and standard deviation. Paired t-tests were used to compare patient reported and muscle capacity outcomes between assessments (baseline and follow-up). Effect sizes (and 95% confidence intervals) for pre/post comparisons were calculated according to previous recommendations where a correction for dependence among

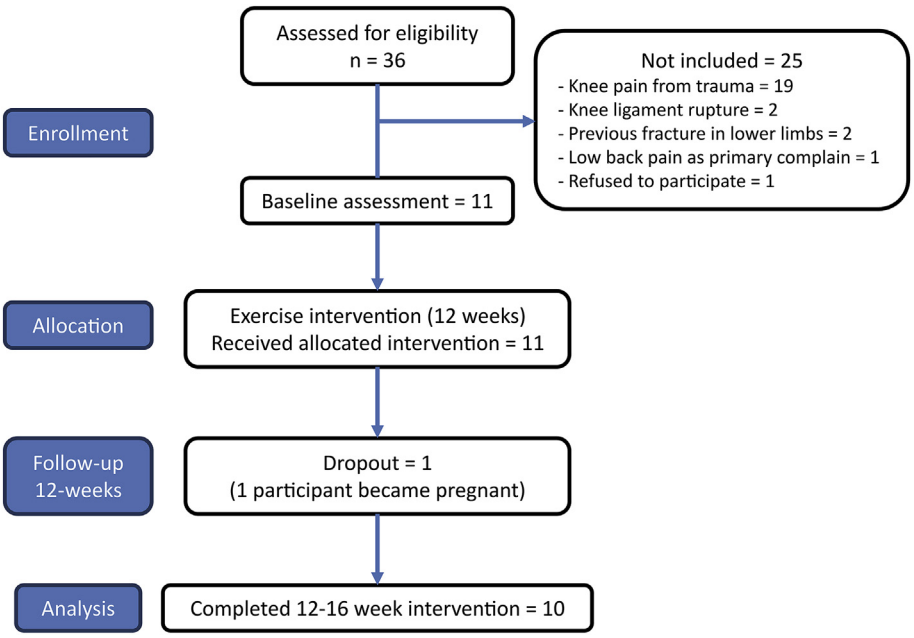

Fig. 1. Participant flow through the study.

means must be applied (Gibbons, Hedeker, & Davis, 1993; Morris & DeShon, 2002). Thus, we entered the correlation between the pre and post assessments into the equation. Interpretation of the effect sizes were: small (>0.2), medium (>0.5), large (>0.8) (Cohen, 1992).

3. Results

Thirty-six participants were assessed for eligibility over a 12-week period after responding to advertisements posted at the University and via social media channels (Twitter and Facebook). The most common reason for ineligibility was knee pain caused by trauma (n = 19, Fig. 1). After eligibility criteria screening, 12 participants were deemed eligible with a diagnosis of PFP (33%), and invited to enroll in the study. Eleven chose to enroll (92%), with characteristics outlined in Table 1. One participant withdrew after becoming pregnant at week 5. The remaining 10 participants completed the full progressive resistance training program (exercise completion at least 2 times per week for 12 weeks) within 15 weeks of commencing participation, and were followed up at 12–16 weeks after baseline (Fig. 1).

3.1. Exercise program data – adherence, exercises and pain

Exercise program data as recorded by PhysiApp® from the 10 participants who completed the program is presented in supplementary material 3. Two out of the ten participants who completed the 12-week program, did not use PhysiApp® at all. From the remaining eight participants who used PhysiApp®, data indicated average adherence to completing prescribed exercises was 70–82% in weeks 1–3; 50–68% in weeks 4–6; and 33–45% in weeks 7–12 (see supplementary material 3). However, of note, participants retrospectively reported much higher adherence to the exercise program during physiotherapist follow up sessions, stating they typically forgot to enter any data once they felt comfortable with the exercises they were completing.

One adverse event was reported, involving a pain flare following completion of an exercise session, which resolved within one week. This event occurred during week 5 of the program after the participant was prescribed a new knee-targeted (squatting) exercise. With removal of this exercise, the participant continued to progress and completed the full 12-week program. All exercise sessions documented on PhysiApp® were completed with pain levels 3/10 or less, with the majority or exercises and sessions completed as part of the program being pain free (0/10). Almost all sessions completed pain free (see supplementary material 3).

Table 1
Participant characteristics [mean (SD)].

	All sample (n = 11)	Men (n = 5)	Women (n = 6)
Age (y)	33 (10)	35 (9)	32 (11)
Height (m)	1.69 (0.13)	1.80 (0.05)	1.59 (0.09)
Body Mass (kg)	66 (16)	79 (9)	56 (12)
BMI (kg/m^2)	23.0 (3.0)	24.3 (1.5)	21.9 (3.6)

3.2. Patient reported outcome measures

All 10 participants who completed the 12-week program reported improvement (3 completely recovered; 6 marked; and 1 moderate). Other patient reported outcomes, including pre and post scores, mean differences, and calculated effect sizes are presented in Fig. 2. Large improvements in worst pain last week (ES, 95% CI = −3.36, −3.98 to −2.74), the AKPS (−1.81, −2.53 to −1.09) and KOOS-PF (−1.37, −1.99 to −0.75) occurred following the 12-week exercise program. Kinesiophobia and physical activity did not change significantly ($p > 0.05$).

3.3. Hip muscle capacity measures

All hip muscle capacity measures, including pre and post scores, mean differences, and calculated effect sizes are presented in Fig. 3. Moderate to large increases in hip abduction and extension 10RM (ES, 95% CI = −2.22, −2.55 to −1.97; and −1.92, −2.29 to −1.55 respectively), and power (−0.78, −1.48 to −0.13; and −0.77, −1.26 to −0.28, respectively) occurred following the exercise program. Increases in isometric strength occurred for hip abduction (−0.99, −1.49 to −0.49) but not hip extension ($p > 0.05$).

	Pre	Post	Mean difference	Effect size (95%CI)
	Mean (SD)	Mean (SD)	(95%CI)	Favours improvement / Favours worsening
Worst pain last week	5.7 (1.57)	1.0 (1.3)	4.7 (3.7; 5.7)*	
AKPS	76 (12)	90 (9)	-14 (-20; -8)*	
KOOS-PF	74 (18)	89 (10)	-15 (-24; -5)*	
Kinesiophobia	34 (8)	29 (6)	5 (-1; 10)	
Physical activity level	3,567 (5,092)	5,944 (5,955)	-2,376 (-6,606; 1,853)	

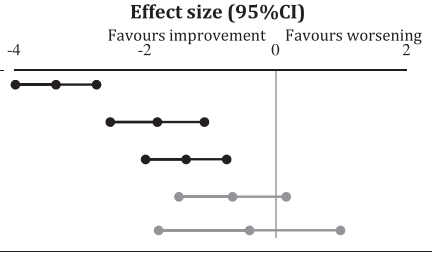

Fig. 2. Patient reported outcome measures.
*indicates statistically significant difference ($p < 0.05$).
Worst pain last week was obtained using a VAS (0–10 cm); AKPS: Anterior knee pain scale; KOOS-PF: KOOS patellofemoral subscale; Kinesiophobia: obtained using the Tampa scale for kinesiophobia. Physical activity level ($MET \cdot min \cdot wk^{-1}$): Calculated using the International Questionnaire of Physical Activity. The effect sizes of worst pain last week and kinesiophobia were transformed into negative value in order to make the graph presentation clearer.

	Pre	Post	Mean difference	Effect size (95%CI)
	Mean (SD)	Mean (SD)	(95%CI)	Favours improvement / Favours worsening
Isometric strength				
Hip abduction	123 (20)	136 (31)	-13 (-26; -1)*	
Hip extension	83 (34)	96 (34)	-13 (-28; 1)	
10 Repetition Maximum				
Hip abduction	54 (14)	72 (12)	-19 (-25; -12)*	
Hip extension	55 (15)	74 (7)	-19 (-28; -10)*	
Power				
Hip abduction	2.0 (0.9)	2.5 (1.2)	-0.6 (-1.1; -0.1)*	
Hip extension	3.0 (1.4)	3.6 (1.2)	-0.65 (-1.3; 0.00)*	

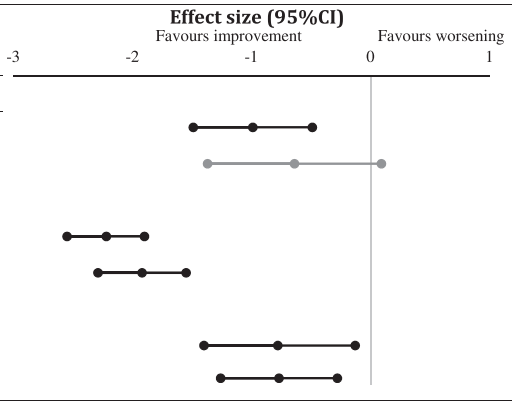

Fig. 3. Hip muscle capacity measures.
*indicates statistically significant difference ($p < 0.05$).

4. Discussion

Findings from this study indicate that a 12-week program targeting proximal muscle strength and power is feasible in people with PFP. Potential recruitment rate was one eligible participant per week, over a twelve week period, with 33% (12/36) of people who enquired being diagnosed with PFP. Knee pain from trauma was the main reason for ineligibility of participants. Of those eligible 92% (11/12) chose to enroll, and only one dropped out due to pregnancy related sickness. Importantly, the program was able to be completed and progressed safely, with almost all sessions completed pain free, and no serious adverse events.

All 10 participants who completed the 12-week program reported perceived improvement. Nine could be considered successful outcomes (3 completely recovered and 6 markedly better) based on previous definitions in the PFP literature (Barton, Menz, & Crossley, 2011; Vicenzino, Collins, Cleland, & McPoil, 2010). Mean within-participant reduction in worst pain following the program was also large (4.7/10 on VAS), far exceeding the minimally clinical important difference (MCID) of 2.0 for this measure (Crossley et al., 2004). The follow up worst pain level among our cohort was also very low (1.0 ± 1.3), particularly in comparison to other published clinical trials evaluating exercise therapy programs for PFP (~3.0) (Lack et al., 2015; van der Heijden et al., 2015). Both the AKPS and KOOS-PF improved with large within-participant effects above what is considered a MCID (Crossley et al., 2004, 2018). Together, large improvements in PROMs highlight the potential value of an exercise-therapy program targeting proximal muscle strength and power in improving pain, function and disability. Further adequately powered randomized trials with longer term follow up evaluating outcomes of this program compared with usual physiotherapy care (Collins et al., 2009) or other published exercise programs (van Linschoten et al., 2009) are needed.

Moderate to large increases in hip muscle strength were found following completion of the 12-week program. The largest improvements were for dynamic hip abduction (35%) and extension (34%) strength, which is not surprising considering the focus of the program. Specifically, participants were progressed to strength training targeting hip extension and abduction, involving sets of 8–12 repetitions, as soon as possible (typically weeks 2–5). Increases to isometric strength were much lower (11–16%). The inconsistency between improvements in dynamic and isometric hip strength in our study may reflect program specificity, with no inclusion of isometric hip strength exercise.

A novel finding from this study was the ability of a progressive resistance training program to increase hip abduction and extension muscle power (22–28%). While not as great as increases to dynamic strength, these increases showed a large effect, likely reflecting the emphasis on muscle power of the program evaluated. Importantly, findings from this study indicate a 12-week progressive resistance training program may adequately address deficits in hip muscle power previously identified in people with PFP (Nunes et al., 2019).

Despite large increases in muscle capacity, no significant improvements in kinesiophobia or physical activity levels were identified. Considering both variables improved following the exercise-therapy program, this may be partially explained by a lack of statistical power. A key consideration was that patient education, which might address fear associated with movement and physical activity, was not emphasized. Future research evaluating the efficacy of progressive resistance training may consider the addition of education to target kinesiophobia (de Oliveira Silva et al., 2019;

Maclachlan, Matthews, Hodges, Collins, & Vicenzino, 2018; Priore et al., 2019) and reduced physical activity (Glaviano, Baellow, & Saliba, 2017). An additional consideration related to the exercise-therapy program is that knee targeted exercise was not a focus, and this may help address kinesiophobia.

4.1. Limitations and future directions

Exercise program data as recorded by PhysiApp® from the 10 participants who completed the program poorly reflected retrospectively reported adherence, with two out of the ten participants never using the mobile application at all. Of note, self-reported adherence in participants who did use the app in our study dropped below 70% after week 3, and substantially following week 6 ($\leq$45%), indicating our methods of promoting or monitoring adherence is inadequate. Future research should consider reminder emails or phone calls to improve participant exercise logging, or additionally providing paper-based diaries as an alternative option. Our protocol was designed to prescribe a maximum of five exercises. However, some participants completed more than this, based on requests by them for more variety or additional exercises. These preferences and associated implications on dose require consideration in future trials when comparing a pragmatic program like the one evaluated in this study.

The small participant numbers and lack of a control group in this feasibility study limit our ability to draw clear conclusions to guide clinical practice. Low participant numbers also mean the study may have been underpowered to detect potential benefits of the exercise-therapy program on kinesiophobia and physical activity. Nonetheless, feasibility, perceived improvement, and large improvements in pain were identified following the 12-week progressive resistance training program evaluated. This highlights the need for well powered randomized controlled trials (RCTs) to test efficacy of this exercise-therapy program.

The exercise-therapy program evaluated had a strong focus on proximal muscle capacity, despite evidence that both hip and knee targeted exercise can be beneficial for people with PFP (Lack et al., 2015; van der Heijden et al., 2015). Future studies evaluating the efficacy of progressive resistance training programs targeting muscle strength and power should consider also including knee targeted exercise to address muscle capacity impairments, along with altered movement patterns and kinetics during activities like running (Neal et al., 2016) and landing (Nunes, Barton, & Serrão, 2019). Additionally, minimal education was provided, despite growing emphasis of its importance in PFP (Barton & Crossley, 2016; Barton et al., 2015; Barton et al., 2018; Barton & Rathleff, 2016; Lack et al., 2018) and recent research highlighting a number of potential education targets such as psychological factors including kinesiophobia (de Oliveira Silva et al., 2019; Maclachlan et al., 2018, 2017; Priore et al., 2019), load management (Esculier et al., 2018), and weight management (Hart, Barton, Khan, Riel, & Crossley, 2017). A more holistic intervention including an emphasis on education may optimize outcomes and should be considered for any future trials evaluating progressive resistance training.

Our findings are limited to young adults (18–47 years), and applicability of findings to adolescents or older adults is unknown. Additionally, our small mixed-sex cohort did not allow us to determine the influence of adherence on outcomes, or complete any sub-analysis to determine whether sex influences outcomes. This may be important considering greater strength deficits reported in females with PFP (Rathleff et al., 2014).

5. Conclusion

A 12-week progressive resistance training program targeting proximal muscle strength and power following accepted exercise prescription principles is feasible in people with PFP. All participants in this feasibility study reported improvements. Large improvements in pain and function occurred alongside moderate-large increases in dynamic strength and power at the hip. High quality RCTs evaluating the efficacy of progressive resistance training programs following accepted exercise prescription principles in people with PFP are warranted.

Conflicts of interest

None declared.

Ethical approval

This study was approved by the Human Research Ethics Committee of La Trobe University (registration number 16–141).

Funding

This work was supported by São Paulo Research Foundation/FAPESP (scholarship to Guilherme S Nunes).

Acknowledgment

The authors would like to acknowledge the São Paulo Research Foundation – FAPESP (process 2015/01704-7 and 2016/09438-7).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.04.010.

Ethical statement

This study was approved by the La Trobe University's Human Research Ethics Committee (HEC 16–141) and written informed consent was obtained from all participants.

References

Banyard, H. G., Nosaka, K., Sato, K., & Haff, G. G. (2017). Validity of various methods for determining velocity, force and power in the back squat. *International Journal of Sports Physiology and Performance*, 1–25. https://doi.org/10.1123/ijspp.2016-0627.

Barton, C. J., & Crossley, K. M. (2016). Sharing decision-making between patient and clinician: The next step in evidence-based practice for patellofemoral pain? *British Journal of Sports Medicine, 50*(14), 833–834. https://doi.org/10.1136/bjsports-2015-095607.

Barton, C. J., Crossley, K. M., & Macri, E. M. (2018). Should we consider changing traditional physiotherapy treatment of patellofemoral pain based on recent insights from the literature? *British Journal of Sports Medicine, 52*(24), 1546–1547. https://doi.org/10.1136/bjsports-2017-098695.

Barton, C. J., Lack, S., Hemmings, S., Tufail, S., & Morrissey, D. (2015). The "best practice guide to conservative management of patellofemoral pain": Incorporating level 1 evidence with expert clinical reasoning. *British Journal of Sports Medicine, 49*(14), 923–934. https://doi.org/10.1136/bjsports-2014-093637.

Barton, C. J., Lack, S., Malliaras, P., & Morrissey, D. (2013). Gluteal muscle activity and patellofemoral pain syndrome: A systematic review. *British Journal of Sports Medicine, 47*(4), 207–214. https://doi.org/10.1136/bjsports-2012-090953.

Barton, C. J., Menz, H. B., & Crossley, K. M. (2011). Clinical predictors of foot orthoses efficacy in individuals with patellofemoral pain. *Medicine & Science in Sports & Exercise, 43*(9), 1603–1610. https://doi.org/10.1249/MSS.0b013e318211c45d.

Barton, C. J., & Rathleff, M. S. (2016). 'Managing my patellofemoral pain': The creation of an education leaflet for patients. *BMJ Open Sport & Exercise Medicine, 2*(1), e000086. https://doi.org/10.1136/bmjsem-2015-000086.

Bazett-Jones, D. M., Cobb, S. C., Huddleston, W. E., O'Connor, K. M., Armstrong, B. S. R., & Earl-Boehm, J. E. (2013). Effect of patellofemoral pain on

strength and mechanics after an exhaustive run. *Medicine & Science in Sports & Exercise, 45*(7), 1331–1339. https://doi.org/10.1249/MSS.0b013e3182880019.
Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155–159.
Collins, N. J., Barton, C. J., Middelkoop, M. van, Callaghan, M. J., Rathleff, M. S., Vicenzino, B. T., et al. (2018). 2018 consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: Recommendations from the 5th international patellofemoral pain research retreat, gold coast, Australia, 2017. *British Journal of Sports Medicine, 52*(18), 1170–1178. https://doi.org/10.1136/bjsports-2018-099397.
Collins, N. J., Bierma-Zeinstra, S. M. A., Crossley, K. M., van Linschoten, R. L., Vicenzino, B., & van Middelkoop, M. (2013). Prognostic factors for patellofemoral pain: A multicentre observational analysis. *British Journal of Sports Medicine, 47*(4), 227–233. https://doi.org/10.1136/bjsports-2012-091696.
Collins, N., Crossley, K., Beller, E., Darnell, R., McPoil, T., & Vicenzino, B. (2009). Foot orthoses and physiotherapy in the treatment of patellofemoral pain syndrome: Randomised clinical trial. *British Journal of Sports Medicine, 43*(3), 163–168. https://doi.org/10.1136/bmj.a1735.
Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., et al. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise, 35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB.
Crossley, K. M., Bennell, K. L., Cowan, S. M., & Green, S. (2004). Analysis of outcome measures for persons with patellofemoral pain: Which are reliable and valid? *Archives of Physical Medicine and Rehabilitation, 85*(5), 815–822.
Crossley, K. M., Macri, E. M., Cowan, S. M., Collins, N. J., & Roos, E. M. (2018). The patellofemoral pain and osteoarthritis subscale of the KOOS (KOOS-PF): Development and validation using the COSMIN checklist. *British Journal of Sports Medicine, 52*(17), 1130–1136. https://doi.org/10.1136/bjsports-2016-096776.
Crossley, K. M., Stefanik, J. J., Selfe, J., Collins, N. J., Davis, I. S., Powers, C. M., et al. (2016). 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. *British Journal of Sports Medicine, 50*(14), 839–843. bjsports-2016-096384 https://doi.org/10.1136/bjsports-2016-096384.
Crossley, K. M., van Middelkoop, M., Callaghan, M. J., Collins, N. J., Rathleff, M. S., & Barton, C. J. (2016). 2016 patellofemoral pain consensus statement from the 4th international patellofemoral pain research retreat, manchester. Part 2: Recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). *British Journal of Sports Medicine, 50*(14), 844–852. https://doi.org/10.1136/bjsports-2016-096268.
Esculier, J.-F., Bouyer, L. J., Dubois, B., Fremont, P., Moore, L., McFadyen, B., et al. (2018). Is combining gait retraining or an exercise programme with education better than education alone in treating runners with patellofemoral pain?A randomised clinical trial. *British Journal of Sports Medicine, 52*(10), 659–666. https://doi.org/10.1136/bjsports-2016-096988.
French, D. J., France, C. R., Vigneau, F., French, J. A., & Evans, R. T. (2007). Fear of movement/(re)injury in chronic pain: A psychometric assessment of the original English version of the Tampa scale for kinesiophobia (TSK). *Pain, 127*(1–2), 42–51. https://doi.org/10.1016/j.pain.2006.07.016.
Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., et al.. position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. Medicine & Science in Sports & Exercise, 43(7), 1334–1359 https://doi.org/10.1249/MSS.0b013e318213fefb.
Gibbons, R. D., Hedeker, D. R., & Davis, J. M. (1993). Estimation of effect size from a series of experiments involving paired comparisons. *Journal of Educational Statistics, 18*(3), 271–279. https://doi.org/10.3102/10769986018003271.
Glaviano, N. R., Baellow, A., & Saliba, S. (2017). Physical activity levels in individuals with and without patellofemoral pain. *Physical Therapy in Sport, 27*, 12–16. https://doi.org/10.1016/j.ptsp.2017.07.002.
Hart, H. F., Barton, C. J., Khan, K. M., Riel, H., & Crossley, K. M. (2017). Is body mass index associated with patellofemoral pain and patellofemoral osteoarthritis? A systematic review and meta-regression and analysis. *British Journal of Sports Medicine, 51*(10), 781–790. https://doi.org/10.1136/bjsports-2016-096768.
van der Heijden, R. A., Lankhorst, N. E., van Linschoten, R., Bierma-Zeinstra, S. M. A., & van Middelkoop, M. (2015). Exercise for treating patellofemoral pain syndrome. *Cochrane Database of Systematic Reviews, 1*, CD010387. https://doi.org/10.1002/14651858.CD010387.pub2.
Holden, S., Rathleff, M. S., Jensen, M. B., & Barton, C. J. (2017). How can we implement exercise therapy for patellofemoral pain if we don't know what was prescribed? A systematic review. *British Journal of Sports Medicine, 52*(6), 385. https://doi.org/10.1136/bjsports-2017-097547.
Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2003). Hip strength in females with and without patellofemoral pain. *Journal of Orthopaedic & Sports Physical Therapy, 33*(11), 671–676. https://doi.org/10.2519/jospt.2003.33.11.671.
Kamper, S. J., Maher, C. G., & Mackay, G. (2009). Global rating of change scales: A review of strengths and weaknesses and considerations for design. *Journal of Manual & Manipulative Therapy, 17*(3), 163–170.
Lack, S., Barton, C., Sohan, O., Crossley, K., & Morrissey, D. (2015). Proximal muscle rehabilitation is effective for patellofemoral pain: A systematic review with meta-analysis. *British Journal of Sports Medicine, 49*(21), 1365–1376. https://doi.org/10.1136/bjsports-2015-094723.
Lack, S., Neal, B., Silva, D. D. O., & Barton, C. (2018). How to manage patellofemoral pain – understanding the multifactorial nature and treatment options. *Physical Therapy in Sport, 32*, 155–166. https://doi.org/10.1016/j.ptsp.2018.04.010.
Lankhorst, N. E., van Middelkoop, M., Crossley, K. M., Bierma-Zeinstra, S. M. A., Oei, E. H. G., Vicenzino, B., et al. (2016). Factors that predict a poor outcome 5-8 years after the diagnosis of patellofemoral pain: A multicentre observational analysis. *British Journal of Sports Medicine, 50*(14), 881–886. https://doi.org/10.1136/bjsports-2015-094664.
van Linschoten, R., Middelkoop, M. van, Berger, M. Y., Heintjes, E. M., Verhaar, J. a. N., Willemsen, S. P., et al. (2009). Supervised exercise therapy versus usual care for patellofemoral pain syndrome: An open label randomised controlled trial. *BMJ, 339*, b4074. https://doi.org/10.1136/bmj.b4074.
Maclachlan, L. R., Collins, N. J., Matthews, M. L. G., Hodges, P. W., & Vicenzino, B. (2017). The psychological features of patellofemoral pain: A systematic review. *British Journal of Sports Medicine, 51*(9), 732–742. https://doi.org/10.1136/bjsports-2016-096705.
Maclachlan, L. R., Matthews, M., Hodges, P. W., Collins, N. J., & Vicenzino, B. (2018). The psychological features of patellofemoral pain: A cross-sectional study. *Scandinavian Journal of Pain, 18*(2), 261–271. https://doi.org/10.1515/sjpain-2018-0025.
Maddigan, M. E., Button, D. C., & Behm, D. G. (2014). Lower-limb and trunk muscle activation with back squats and weighted sled apparatus. *The Journal of Strength & Conditioning Research, 28*(12), 3346–3353. https://doi.org/10.1519/JSC.0000000000000697.
Matthews, M., Rathleff, M. S., Claus, A., McPoil, T., Nee, R., Crossley, K., et al. (2017). Can we predict the outcome for people with patellofemoral pain? A systematic review on prognostic factors and treatment effect modifiers. *British Journal of Sports Medicine, 51*(23), 1650–1660. https://doi.org/10.1136/bjsports-2016-096545.
Morris, S. B., & DeShon, R. P. (2002). Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychological Methods, 7*(1), 105–125.
Neal, B. S., Barton, C. J., Gallie, R., O'Halloran, P., & Morrissey, D. (2016). Runners with patellofemoral pain have altered biomechanics which targeted interventions can modify: A systematic review and meta-analysis. *Gait & Posture, 45*, 69–82. https://doi.org/10.1016/j.gaitpost.2015.11.018.
Nimon, G., Murray, D., Sandow, M., & Goodfellow, J. (1998). Natural history of anterior knee pain: A 14- to 20-year follow-up of nonoperative management. *Journal of Pediatric Orthopedics, 18*(1), 118–122.
Nunes, G. S., Barton, C. J., & Serrão, F. V. (2018). Hip rate of force development and strength are impaired in females with patellofemoral pain without signs of altered gluteus medius and maximus morphology. *Journal of Science and Medicine in Sport, 21*(2), 123–128. https://doi.org/10.1016/j.jsams.2017.05.014.
Nunes, G. S., Barton, C. J., & Serrão, F. V. (2019). Females with patellofemoral pain have impaired impact absorption during a single-legged drop vertical jump. *Gait & Posture, 68*, 346–351. https://doi.org/10.1016/j.gaitpost.2018.12.013.
Nunes, G. S., Silva, D. de O., Pizzari, T., Serrão, F. V., Crossley, K. M., & Barton, C. J. (2019). Clinically measured hip muscle capacity deficits in people with patellofemoral pain. *Physical Therapy in Sport, 35*, 69–74. https://doi.org/10.1016/j.ptsp.2018.11.003.
de Oliveira Silva, D., Barton, C. J., Briani, R. V., Taborda, B., Ferreira, A. S., Pazzinatto, M. F., et al. (2019). Kinesiophobia, but not strength is associated with altered movement in women with patellofemoral pain. *Gait & Posture, 68*, 1–5. https://doi.org/10.1016/j.gaitpost.2018.10.033.
Priore, L. B., Azevedo, F. M., Pazzinatto, M. F., Ferreira, A. S., Hart, H. F., Barton, C., et al. (2019). Influence of kinesiophobia and pain catastrophism on objective function in women with patellofemoral pain. *Physical Therapy in Sport, 35*, 116–121. https://doi.org/10.1016/j.ptsp.2018.11.013.
Rathleff, M. S., Rathleff, C. R., Crossley, K. M., & Barton, C. J. (2014). Is hip strength a risk factor for patellofemoral pain? A systematic review and meta-analysis. *British Journal of Sports Medicine, 48*(14), 1088. https://doi.org/10.1136/bjsports-2013-093305.
Selfe, J., Janssen, J., Callaghan, M., Witvrouw, E., Sutton, C., Richards, J., et al. (2016). Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs). *British Journal of Sports Medicine, 50*, 873–880. https://doi.org/10.1136/bjsports-2015-094792.
Smith, B. E., Selfe, J., Thacker, D., Hendrick, P., Bateman, M., Moffatt, F., et al. (2018). Incidence and prevalence of patellofemoral pain: A systematic review and meta-analysis. *PLoS One, 13*(1), e0190892. https://doi.org/10.1371/journal.pone.0190892.
Tyler, T. F., Nicholas, S. J., Mullaney, M. J., & McHugh, M. P. (2006). The role of hip muscle function in the treatment of patellofemoral pain syndrome. *The American Journal of Sports Medicine, 34*(4), 630–636. https://doi.org/10.1177/0363546505281808.
Vicenzino, B., Collins, N., Cleland, J., & McPoil, T. (2010). A clinical prediction rule for identifying patients with patellofemoral pain who are likely to benefit from foot orthoses: A preliminary determination. *British Journal of Sports Medicine, 44*(12), 862–866. https://doi.org/10.1136/bjsm.2008.052613.
Willson, J. D., & Davis, I. S. (2008). Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands. *Clinical Biomechanics, 23*(2), 203–211. https://doi.org/10.1016/j.clinbiomech.2007.08.025.