Physical Therapy in Sport 35 (2019) 69–74

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original Research

Clinically measured hip muscle capacity deficits in people with patellofemoral pain

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A R T I C L E I N F O

Article history:
Received 4 September 2018
Received in revised form
21 October 2018
Accepted 5 November 2018

Keywords:
Power
Muscle strength
Physical endurance
Concentric
Eccentric
Knee

A B S T R A C T

Objective: To evaluate differences in clinical measures of hip abductor and extensor capacity (strength, endurance and power) in people with patellofemoral pain (PFP) compared to asymptomatic controls.
Design: Cross-sectional.
Settings: Laboratory.
Participants: Thirty-two physically active people (16 with PFP and 16 controls).
Main outcome measures: Strength was evaluated isometrically using a hand-held dynamometer and dynamically using 10 repetitions maximum (10RM) tests. Power was assessed using a linear position transducer. Endurance was assessed using maximum number of repetitions.
Results: The PFP group had significant deficits compared to the control group in isometric strength (21−25%) for hip abduction (ES = 0.98) and extension (ES = 0.85); in 10RM (15–18%) for hip abduction (ES = 0.72) and extension (ES = 0.85); and in power (24–31%) for hip abduction (ES = 0.80), and extension (ES = 0.94). No difference was identified for hip abduction and extension in endurance tests.
Conclusion: Clinical assessments can identify deficits in isometric and dynamic hip strength, as well as power in people with PFP. Hip muscle capacity deficits in people with PFP including strength and power highlight a potential need for more progressive resistance training in this population.

1. Introduction

Hip muscle capacity impairments are evident in people with patellofemoral pain (PFP) (Barton, Lack, Malliaras, & Morrissey, 2013; Rathleff, Rathleff, Crossley, & Barton, 2014), with growing evidence to support exercise therapy to target these deficits (Lack, Barton, Sohan, Crossley, & Morrissey, 2015; van der Heijden, Lankhorst, van Linschoten, Bierma-Zeinstra, & van Middelkoop, 2015). Previous theories have suggested that impaired hip muscle capacity may be associated with biomechanical alterations thought to increase PFJ stress in people with PFP (Powers, 2010). However, recent research indicates that hip muscle weakness measured isometrically may not be associated with greater risk of PFP development (Neal et al., 2018; Rathleff et al., 2014), indicating alterations in hip muscles capacity may instead be a consequence of PFP development.

Isometric hip strength deficits are evident in people with PFP (Rathleff et al., 2014). Additional studies have evaluated strength during dynamic motion (Boling, Padua, & Alexander Creighton, 2009; Souza & Powers, 2009), with this research also indicating impaired concentric and eccentric hip strength (Rathleff et al., 2014). When measuring hip abductor muscle endurance, two studies report contradictory results in women with PFP (McMoreland, O'Sullivan, Sainsbury, Clifford, & McCreesh, 2011; Van Cant, Pitance, & Feipel, 2017). Van Cant et al. (2017) reported impaired isometric endurance of the hip abductors assessed as the time which participants in side-lying could hold the leg in neutral position. However, McMoreland et al. (2011) reported no differences in concentric endurance of the hip abductors using isokinetic dynamometry. Only one study has measured hip extensor muscle endurance (Souza & Powers, 2009); and reported women with PFP

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https://doi.org/10.1016/j.ptsp.2018.11.003
1466-853X/

have lower concentric endurance of the hip extensors compared to asymptomatic females when measured with isokinetic dynamometry.

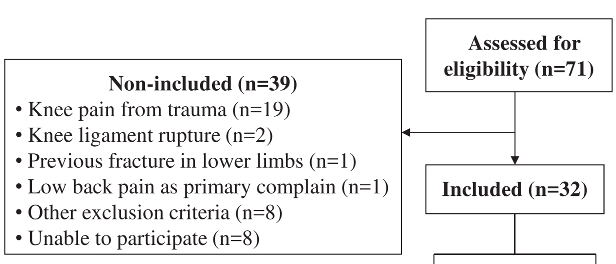
More recently, we evaluated both isometric strength and rate of force development (RFD) of the hip musculature in women with and without PFP (Nunes, Barton, & Serrão, 2018), identifying deficits of up to 55% in RFD for hip abduction and extension (Nunes et al., 2018). Of note, RFD deficits were far greater than the 15% deficits found for isometric hip strength in the same cohort, indicating hip muscle power may be more impaired than strength in people with PFP (Nunes et al., 2018). A limitation of this study was the use of an isokinetic dynamometer, which may not be easily accessible to clinicians (Nunes et al., 2018). If hip muscle strength and power deficits are to be assessed and targeted by clinicians treating PFP, more clinically applicable tools and methods are required.

To date, no study has evaluated hip muscle capacity including endurance, strength, and power in the same PFP cohort to ascertain the potential importance of each. This study evaluated different hip muscle capacity parameters (strength, endurance and power) in people with PFP compared to asymptomatic controls using clinically applicable methods to determine their relative importance. Ultimately, this information may be useful for clinicians and researchers to prioritise which parameters of hip muscle capacity are most likely impaired in patients with PFP they manage. We hypothesised that people with PFP would have less strength, endurance and power in the hip abductors and extensors compared to asymptomatic people assessed using clinically applicable methods.

2. Materials and methods

2.1. Participants

The study included 32 physically active people (16 with PFP and 16 asymptomatic controls) between the ages of 18 and 50 (Fig. 1). The sample size was determined based on data from a pilot study



	PFP group (n = 16)	Control group (n = 16)
Gender (women/men)	9/7	9/7
Age (years)	32.3 (9.1)	28.7 (6.9)
Height (m)	1.67 (0.12)	1.70 (0.10)
Body mass (Kg)	67.3 (14.6)	66.4 (14.2)
IPAQ (MET minutes/week)	3401.1 (4299.7)	3804.4 (2576.8)
Assessed side (right/left)	12/4	13/3
Duration of symptoms (yr)	2.3 (1.7)	–
Worst pain (points)*	6.5 (1.8)	–
AKPS (points)	76.3 (12.5)	99.5 (1.1)

Fig. 1. Flow diagram and participants characteristics [mean (SD)]. (IPAQ = International Physical Activity Questionnaire; AKPS = Anterior Knee Pain Scale; yr = years. *worst pain during the previous week of the data collection using visual analogue scale.)

with four participants in each group using peak power (W/kg) during hip abduction for the calculation (control group = 3.4 ± 0.8 W/kg; PFP group = 2.3 ± 1.1 W/kg). This indicated a minimum of 14 participants per group was required for an alpha of 0.05 and statistical power of 80%.

Participants were recruited through advertisements posted at the University and via social media channels (Twitter and Facebook). The inclusion criteria for the PFP group were insidious onset of symptoms unrelated to a traumatic event; presence of retropatellar or peripatellar pain (minimum 3/10 points on the visual analogue scale) in at least three of the following activities: using stairs, running, kneeling, squatting, prolonged sitting, jumping, isometric contraction of quadriceps, and palpation of the medial or lateral facet of the patella; and presence of pain for at least two months (Nunes et al., 2018). The control group included participants with no history of injury or pain in the knees, similar with the PFP group for age (range of five years), height (range of five cm) and body mass (range of five kg). The exclusion criteria for both groups were history of surgery in either knee, injury or pain in the hip, patellar instability, signs or symptoms of meniscal or knee ligament injuries, presence of Osgood-Schlatter and Sinding-Larsen-Johansson syndrome or pain on palpation of the patellar tendon area, Hoffa's fat pad, iliotibial band, pes anserinus tendon or knee joint line, or musculoskeletal changes that interfere or contraindicate the measurement procedures of the study (Nunes et al., 2018). This study was approved by the Human Research Ethics Committee of La Trobe University (registration number 16–141) and written informed consent was obtained from all participants.

2.2. Procedures

Assessments were performed over two sessions separated by 2–7 days. All assessments were performed by a physiotherapist with over seven years' experience blinded to group allocation. In the first session, isometric strength and endurance assessments were completed. In the second session, dynamic strength and power assessments were completed. In the PFP group, the lower limb of the affected knee or the more painful knee was assessed. In the control group, the assessed lower limb was determined by flipping a coin. A different assessor determined which lower limb should be tested to keep the main assessor blinded. Initially, participants answered the International Physical Activity Questionnaire - short form (IPAQ) (Craig et al., 2003) to characterize the level of physical activity and the Anterior Knee Pain Scale (AKPS) (Kujala et al., 1993) to characterize the functional capacity. At the beginning of each session, participants warmed-up for 5 min on a bicycle ergometer. Participants performed at least two practice trials to familiarize themselves with the tests. At least 3 min of rest was allowed between each hip muscle capacity test. Video descriptions of all hip muscle capacity tests can be found via the following link (http://bit.ly/hipmuscleassess).

A test-retest reliability evaluation with six asymptomatic participants was completed to verify the intra-rater reliability ($ICC_{3,1}$) and standard error of measurement (SEM) of the measures used. ICCs ranged from 0.81 to 0.98, indicating good to excellent reliability for all measures used (Portney & Watkins, 2009).

2.3. Assessments

2.3.1. Isometric strength

Maximum voluntary isometric contractions (MVICs) of hip abduction and hip extension were 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 lower limbs in neutral position and an inelastic strap positioned around the knee (Bazett-Jones et al., 2013; Ireland, Willson, Ballantyne, & Davis, 2003). Hip extension was assessed in prone with the knee of the assessed lower limb flexed to 90°, and the hip in neutral position, with the strap positioned proximal to the popliteal fossa (Bazett-Jones et al., 2013; Scattone Silva et al., 2016). For both test positions the HHD was placed between the strap and participant. Participants were instructed to start the contractions slowly until they reached the maximal effort. Participants performed three trials of 5s with 1min between each trial. For each trial, we recorded the maximal force value in Newtons. Maximal isometric force was converted into torque (multiplying by lever arm [distance between greater trochanter and lateral condyle of the femur]) and then, normalised by body mass ([Nm/kg] *100 = %BM) (Bazett-Jones et al., 2013; Scattone Silva et al., 2016). The mean of the three trials was used in the statistical analysis. The $ICC_{3,1}$ and SEM were 0.93 (6.6 %BM) for hip abduction and 0.91 (9.2 %BM) for hip extension.

2.3.2. Dynamic strength

Dynamic strength of hip abduction and extension were measured using a gym cable machine (Nautilus Freedom Trainer, Nautilus Inc., Vancouver, Canada) to perform 10 repetition maximum test (10RM) (Maddigan, Button, & Behm, 2014). Hip abduction was assessed in standing, moving from neutral to approximately 30 degrees of hip abduction. Hip extension was assessed in standing, moving from approximately 20 degrees of hip flexion to 20 degrees of hip extension. Lines on the floor were used as reference to guarantee the aimed range of motion. First, participants performed a familiarization and warm-up procedure involving 10 repetitions with the lowest load (9 kg), five repetitions at 16 kg and five repetitions at 23 kg. Following 3 min of rest, trial-and-error procedure was adopted to determine the maximal 10RM load that participants could perform (Maddigan et al., 2014). At the fifth repetition of each trialled weight, participants reported if the load was too light, too heavy or if they thought that was the right load. If some adjustment was necessary, participants rested for 3 min and performed the trial again. The procedure was repeated until the load of the 10RM was determined (Maddigan et al., 2014). Participants were instructed to perform one repetition every 2 s (1 s concentric; 1 s eccentric), paced with a metronome (Maddigan et al., 2014). The load for the 10RM was normalised by body mass ($[kg^{(10RM)}/kg^{(body\ mass)}]*100$ = %BM). The $ICC_{3,1}$ and SEM were 0.94 (2.6 %BM) for hip abduction and 0.96 (3.6 %BM) for hip extension.

2.3.3. Endurance

Hip abduction endurance was assessed in side-lying with both knees fully extended. From the initial position (approximately 10 degrees of hip adduction), participants performed hip abduction until approximately 30 degrees and returned to the starting position once every 2 s, (1 s concentric; 1 s eccentric), paced with a metronome (Van Cant, Dumont, Pitance, Demoulin, & Feipel, 2016). Hip extension endurance was assessed in prone with lower limbs off the edge of the testing table (hips in approximately 60 degrees of flexion) and knee of the assessed side extended. From the initial position, participants performed hip extension until neutral position and returned to the starting position once every 2 s (1 s concentric; 1 s eccentric), paced with a metronome (Souza & Powers, 2009; Van Cant et al., 2016). An adjustable height stand positioned next to participant was used to indicate the aimed range of motion. Participants were instructed to repeat the movements as many times as possible until they were unable to complete any further repetitions, and this number recorded. Participant scored their perceived exertion after the endurance tests using the Borg Rating of Perceived Exertion Scale which varies from 6 (no exertion) to 20 (maximum exertion) (Van Cant et al., 2016, 2017). The $ICC_{3,1}$ and SEM were 0.98 (10 repetitions) for hip abduction and 0.81 (29 repetitions) for hip extension.

2.3.4. Power

Hip abduction and extension power was assessed using a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia) (Banyard, Nosaka, Sato, & Haff, 2017). The device measures time and displacement during movement, and based on the informed load, calculates power produced during movement. Hip abduction and extension was assessed using the same testing position and range of movement for the 10RM test, and were completed after 5 min of rest following the 10RM. Participants performed power trials with 80% of the 10RM load previously assessed. Participants were instructed to perform tasks as fast and as strong as possible and the peak of power normalised by body mass (W/kg) during each trial was recorded. For each power test, participants first performed one trial as familiarization and then, five trials with 30 s of interval in each task. The mean of the five trials was used in the analysis. The $ICC_{3,1}$ and SEM were 0.96 (0.2 W/kg) for hip abduction and 0.98 (0.2 W/kg) for hip extension.

2.4. Statistical analysis

To compare the characterization data, strength and power measures between the groups, multiple independent t-tests were used. In order to avoid missing potentially clinically meaningful findings, no statistical correction was applied (Perneger, 1998). Due to non-normally distributed data, hip abduction and extension endurance data were analysed using Mann-Whitney test. The effect size (ES; Hedges' g) was calculated using Review Manager (RevMan) (Version 5.2, Copenhagen, Denmark) for each comparison and significant differences were classified according to ES values as follows: small (>0.2), medium (>0.5), large (>0.8), and very large (>1.3) (Sullivan & Feinn, 2012). Endurance data were transformed in logarithm (log-transformed) (Bland & Altman, 1996) for the effect size calculation. The confidence level was set at 5%. Data were analysed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA).

3. Results

Both groups were similar in age, body mass, height and level of physical activity ($p > 0.05$) (Fig. 1).

3.1. Strength

The PFP group had medium to large (ES = 0.72–0.98) strength deficits compared to the control group (Table 1). Isometric strength for hip abduction ($p < 0.01$; ES = 0.98) and extension ($p = 0.02$; ES = 0.85) was 21% and 25% lower respectively in the PFP group compared to controls. Additionally, 10RM for hip abduction ($p = 0.05$; ES = 0.72) and extension ($p = 0.02$; ES = 0.85) was 15% and 18% lower respectively in the PFP group compared to controls.

3.2. Endurance

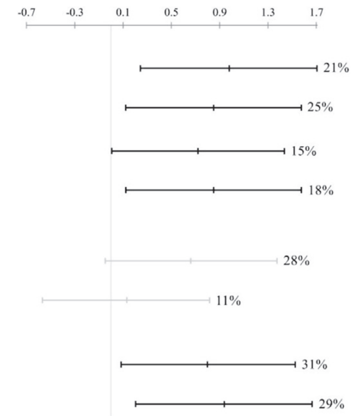
There was no difference between groups for hip abduction or extension endurance measures (Table 1). The Borg rating for the PFP group was similar to the control group for hip abduction (16 ± 3 vs. 15 ± 3 points) and extension (16 ± 2 vs14 ± 3 points).

3.3. Power

The PFP group had large deficits for both power assessments compared to control group (Table 1). Peak power during hip abduction ($p = 0.02$; ES = 0.80), and hip extension ($p = 0.01$;

Table 1
Strength, endurance and power related measures for comparisons between groups [mean (SD)].

	PFP group (n=16)	Control group (n=16)	Mean difference (95% CI)	p value	Effect size (95% CI) and % of difference‡
Strength (%BM)					
Isometric – hip abductors*	117.9 (23.4)	149.9 (38.7)	32.0 (8.9 to 55.1)	**<0.01**	21%
Isometric – hip extensors*	82.3 (33.1)	110.3 (31.0)	28.0 (4.9 to 51.1)	**0.02**	25%
10 RM – hip abductors†	53.1 (13.9)	62.1 (10.3)	9.0 (0.2 to 17.9)	**0.05**	15%
10 RM – hip extensors†	58.2 (14.7)	70.8 (14.1)	12.6 (2.2 to 23.0)	**0.02**	18%
Endurance (repetitions)					
Hip abductors¥	54.5 (32 – 98)	75.5 (28 – 261)	na	0.10	28%
Hip extensors¥	81 (31 – 291)	91 (35 – 245)	na	0.70	11%
Power (W/kg)					
Hip abduction	1.9 (0.8)	2.6 (0.9)	0.8 (0.2 to 1.4)	**0.02**	31%
Hip extensors	2.9 (1.2)	4.1 (1.3)	1.2 (0.3 to 2.1)	**0.01**	29%



PFP: patellofemoral pain; 10RM: 10 repetition maximum; na: not applicable. Numbers in bold indicate significant difference ($p < 0.05$). *%BM = (Nm/kg) x 100; †% BM = (kg$^{(10RM)}$/kg$^{(body\ mass)}$) x 100. ‡all percentages indicate deficits of the PFP group in relation to the control group; ¥ data presented in median (minimum – maximum values).

ES = 0.94) was 31% and 29% lower respectively in the PFP group (Table 1).

4. Discussion

This study identified deficits in hip muscle strength (isometric and dynamic – 10RM) and power in people with PFP. These deficits were identified using clinically applicable methods and highlight a potential need to target strength and power via progressive resistance training programs during exercise therapy for people with PFP. No differences between groups were identified for hip muscle endurance, indicating this may be less relevant compared to strength and power during assessment and management of people with PFP.

A large number of studies have previously reported impairments in isometric hip muscle strength of people with PFP (Rathleff et al., 2014), with this research primarily evaluating strength with HHD (Rathleff et al., 2014). Our findings reinforce that the HHD is sensitive to detect large isometric hip abduction and extension strength deficits in people with PFP (Rathleff et al., 2014). This indicates use of isometric strength assessment at the hip provides a reliable and sensitive measurement for the evaluation of people with PFP before and after therapeutic interventions.

A novel finding of this study was that dynamic hip abduction and extension strength (10RM) is impaired to a similar magnitude as isometric strength (15–25%). Importantly, the American College of Sports Medicine endorses the use of muscle capacity tests such as 10RM to guide resistance training prescription and progression (American College of Sports Medicine, 2009). Based on our findings, such testing may also prove useful to identify hip muscle capacity deficits in people with PFP, and to guide resistance training targeting dynamic hip strength. It is interesting to note that the majority of previous exercise therapy protocols targeting the hip have not been based on strength training principles thought to be required in order to adequately address these deficits in 10RM identified (Lack et al., 2015). Further research evaluating the value of using 10RM testing to guide progression of resistance training programs in people with PFP is recommended.

Hip muscle power deficits have been described in women with PFP using isometric testing (Nunes et al., 2018). The results from the present study indicate that power deficits of 29–31% during dynamic based assessment of our mixed-sex PFP group are also evident. Previously, only one published study has evaluated proximally targeted exercise therapy to address power deficits in people with PFP, reporting improved pain and function (Lack et al., 2015). Therefore, we encourage research to explore the potential benefits of exercise prescription to target the large hip muscle power deficits identified in our study.

No differences were found between groups for hip muscle endurance in this study. This finding is consistent with that of McMoreland et al. (2011) who reported no difference in hip abduction, internal rotation and external rotation muscle endurance between females with and without PFP using isokinetic dynamometry assessment. However, our findings differ to Souza and Powers (Souza & Powers, 2009) who reported that females with PFP have lower endurance for hip extensors compared to healthy controls when measured using isokinetic dynamometry testing. Van Cant et al. (2017) also reported that females with PFP have lower hip abduction isometric endurance. The reasons for currently inconsistent findings among studies are not clear, but may be the result of different testing protocols used. In the present study we applied a clinical test based on dynamic endurance to reflect functional muscle patterning. However, endurance deficits may be more likely using static tests similar to those used by Van Cant et al. (2017). Inconsistencies among the studies may also highlight the multifactorial nature of PFP and potential for subgroups of people with PFP who do and do not possess hip muscle endurance deficits. Regardless, further research may consider evaluating hip muscle endurance using both static and dynamic methods to provide further clarity on current inconsistencies in the literature.

4.1. Clinical and research considerations

Our findings indicate that deficits in isometric and dynamic hip strength and power can be identified using clinically applicable tests. All instruments and procedures used are feasible in clinical practice, considering that the devices used are inexpensive when compared to the gold standard approaches often used in research to assess strength and power (i.e. isokinetic dynamometer). Further guidance on how to complete measures used in this study is provided via instructional videos (http://bit.ly/hipmuscleassess).

Additional research is now needed to determine the usefulness of various hip muscle capacity assessments to guide exercise prescription and progression in people with PFP.

Short to moderate term improvements in pain and function have been reported following rehabilitation programs targeting the hip (Lack et al., 2015; van der Heijden et al., 2015). However, improvements tend not to be sustained in the in long term (Lack et al., 2015), and recent reports indicate that more than 50% of people with PFP are likely to report unfavourable outcomes 5–8 years following entering a clinical trial (Lankhorst et al., 2016). There are multiple potential physical and non-physical factors that may influence poor long term outcomes (Matthews et al., 2017), and this is an area requiring further research. One factor may be the inadequate exercise prescription to address all hip muscle capacity deficits including isometric strength, dynamic strength and power identified in this study. A recent systematic review reported only three out of 14 studies incorporated a resistance training protocol likely to elicit strength gains, when assessed according to American College of Sports Medicine recommendations (American College of Sports Medicine, 2009; Lack et al., 2015). Just one of these studies prescribed power based exercises (Lack et al., 2015), which is noteworthy considering our findings indicate the highest deficits exist for hip muscle power in our PFP cohort. We encourage further research to investigate if more progressive resistance training programs targeting hip strength and power might improve clinical outcomes, particularly in the longer term.

4.2. Limitations

Few clinicians are likely to have access to a linear position transducer to measure muscle power currently. However, measures from this device are highly correlated with measures of other standard power measurement devices (Crewther et al., 2011; Lambert, Beck, & Weeks, 2017), and its relatively low cost could facilitate incorporation into clinical practice to provide quantifiable assessment of hip muscle power. The use of gym cable machine may also be a limitation for those who do not already have access to a gym. Perhaps, similar methods using elastic bands could be applied.

Our findings are also limited to a mixed sex population aged between 18 and 50 years. It is possible that factors including sex and age may influence results related to hip muscle strength and power found in this study. Relative to sex matched controls, greater deficits in isometric muscle strength at the hip have been reported in women compared to men with PFP (Rathleff et al., 2014). These sex differences in hip muscle capacity between men and women with PFP may have influenced our results. However, previous research with mixed-gender population with PFP also have reported impairments in hip muscle capacity (Boling et al., 2009; Ferber, Kendall, & Farr, 2011; Nakagawa, Moriya, Maciel, & Serrão, 2012) which reinforce the importance of the present study in providing options to assess hip muscle capacity of people with PFP regardless of sex using clinical methods. Further research with adequate power to subgroup for sex is encouraged.

When considering the influence of age, it must be noted that an absence of hip and knee muscle strength deficits has been reported in younger adolescents with PFP (Rathleff et al., 2013). Additionally, muscle strength and power is known to diminish with age (Metter, Conwit, Tobin, & Fozard, 1997). Our study was not powered to allow sub-grouping to explore these potential differences, and we encourage further research to this end. The population's age between 18 and 50 years could be pointed as a limitation due to potential presence of patellofemoral osteoarthritis (OA) in the older participants. However, PFP is thought to be a continuum and high prevalence of OA signals was found on imaging exams in a younger population with PFP (Collins, Oei, de Kanter, Vicenzino, & Crossley, 2018). Furthermore, people with PFP and patellofemoral OA seem to have similar deficits related to hip muscle function and capacity (Wyndow, Collins, Vicenzino, Tucker, & Crossley, 2016).

5. Conclusion

People with PFP have deficits ranging between 15 and 31% in isometric strength, dynamic strength, and power at the hip compared to those without pain. Importantly, these deficits can be assessed using clinically feasible measures. Considering the paucity of previous research that has evaluated the benefits of targeting or improving dynamic muscle strength and power at the hip in people with PFP, further research is encouraged in this area.

Declarations of interest

None.

Conflicts of interest

The authors report no conflict of interest.

Funding

We received financial support from São Paulo Research Foundation – FAPESP by scholarship to Guilherme S Nunes.

Ethical approval

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

Acknowledgments

The authors would like to acknowledge the São Paulo Research Foundation – FAPESP (process2015/01704-7 and 2016/09438-7).

References

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise, 41*(3), 687–708. https://doi.org/10.1249/MSS.0b013e3181915670.

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., 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.

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.

Bland, J. M., & Altman, D. G. (1996). Transformations, means, and confidence intervals. *BMJ, 312*(7038), 1079.

Boling, M. C., Padua, D. A., & Alexander Creighton, R. (2009). Concentric and eccentric torque of the hip musculature in individuals with and without patellofemoral pain. *Journal of Athletic Training, 44*(1), 7–13. https://doi.org/10.4085/1062-6050-44.1.7.

Collins, N. J., Oei, E. H. G., de Kanter, J. L., Vicenzino, B., & Crossley, K. M. (2018). *Prevalence of radiographic and MRI features of patellofemoral osteoarthritis in young and middle-aged adults with persistent patellofemoral pain*. Arthritis Care & Research (in press) https://doi.org/10.1002/acr.23726.

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.

Crewther, B. T., Kilduff, L. P., Cunningham, D. J., Cook, C., Owen, N., & Yang, G.-Z. (2011). Validating two systems for estimating force and power. *International Journal of Sports Medicine, 32*(4), 254–258. https://doi.org/10.1055/s-0030-

1270487.
Ferber, R., Kendall, K. D., & Farr, L. (2011). Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. *Journal of Athletic Training, 46*(2), 142–149. https://doi.org/10.4085/1062-6050-46.2.142.
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.
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.
Kujala, U. M., Jaakkola, L. H., Koskinen, S. K., Taimela, S., Hurme, M., & Nelimarkka, O. (1993). Scoring of patellofemoral disorders. *Arthroscopy, 9*(2), 159–163.
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.
Lambert, C., Beck, B. R., & Weeks, B. K. (2017). Concurrent validity and reliability of a linear positional transducer and an accelerometer to measure punch characteristics. *The Journal of Strength & Conditioning Research, 32*(3), 675–680. https://doi.org/10.1519/JSC.0000000000002284.
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.
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.
McMoreland, A., O'Sullivan, K., Sainsbury, D., Clifford, A., & McCreesh, K. (2011). No deficit in hip isometric strength or concentric endurance in young females with mild patellofemoral pain. *Isokinetics and Exercise Science, 19*(2), 117–125. https://doi.org/10.3233/IES-2011-0405.
Metter, E. J., Conwit, R., Tobin, J., & Fozard, J. L. (1997). Age-associated loss of power and strength in the upper extremities in women and men. *Journal of Gerontology, 52*(5), B267–B276.
Nakagawa, T. H., Moriya, E. T. U., Maciel, C. D., & Serrão, F. V. (2012). Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *Journal of Orthopaedic & Sports Physical Therapy, 42*(6), 491–501. https://doi.org/10.2519/jospt.2012.3987.
Neal, B. S., Lack, S. D., Lankhorst, N. E., Raye, A., Morrissey, D., & Middelkoop, M. van (2018). Risk factors for patellofemoral pain: A systematic review and meta-analysis. *British Journal of Sports Medicine* (in press) https://doi.org/10.1136/bjsports-2017-098890.
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.
Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *BMJ, 316*(7139), 1236–1238.
Portney, L. G., & Watkins, M. P. (2009). *Foundations of clinical research: Applications to practice* (3rd ed.). Connecticut: Appleton & Lange.
Powers, C. M. (2010). The influence of abnormal hip mechanics on knee injury: A biomechanical perspective. *Journal of Orthopaedic & Sports Physical Therapy, 40*(2), 42–51. https://doi.org/10.2519/jospt.2010.3337.
Rathleff, C. R., Baird, W. N., Olesen, J. L., Roos, E. M., Rasmussen, S., & Rathleff, M. S. (2013). Hip and knee strength is not affected in 12-16 year old adolescents with patellofemoral pain - a cross-sectional population-based study. *PloS One, 8*(11), e79153. https://doi.org/10.1371/journal.pone.0079153.
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.
Scattone Silva, R., Nakagawa, T. H., Ferreira, A. L. G., Garcia, L. C., Santos, J. E. M., & Serrão, F. V. (2016). Lower limb strength and flexibility in athletes with and without patellar tendinopathy. *Physical Therapy in Sport, 20*, 19–25. https://doi.org/10.1016/j.ptsp.2015.12.001.
Souza, R. B., & Powers, C. M. (2009). Predictors of hip internal rotation during running: An evaluation of hip strength and femoral structure in women with and without patellofemoral pain. *The American Journal of Sports Medicine, 37*(3), 579–587. https://doi.org/10.1177/0363546508326711.
Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the p value is not enough. *Journal of Graduate Medical Education, 4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1.
Van Cant, J., Dumont, G., Pitance, L., Demoulin, C., & Feipel, V. (2016). Test-retest reliability of two clinical tests for the assessment of hip abductor endurance in healthy females. *International Journal of Sports Physical Therapy, 11*(1), 24–33.
Van Cant, J., Pitance, L., & Feipel, V. (2017). Hip abductor, trunk extensor and ankle plantar flexor endurance in females with and without patellofemoral pain. *Journal of Back and Musculoskeletal Rehabilitation, 30*(2), 299–307. https://doi.org/10.3233/BMR-150505.
Wyndow, N., Collins, N., Vicenzino, B., Tucker, K., & Crossley, K. (2016). Is there a biomechanical link between patellofemoral pain and osteoarthritis? A narrative review. *Sports Medicine, 46*(12), 1797–1808. https://doi.org/10.1007/s40279-016-0545-6.