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Original Research

Education and exercise supplemented by a pain-guided hopping intervention for male recreational runners with midportion Achilles tendinopathy: A single cohort feasibility study

Igor Sancho [a], Dylan Morrissey [a, b], Richard W. Willy [c], Christian Barton [a, d, e], Peter Malliaras [a, f, *]

[a] Sports and Exercise Medicine. Queen Mary University of London, London, UK
[b] Physiotherapy Department, Barts Health NHS Trust, London, UK
[c] School of Physical Therapy and Rehabilitation Sciences, University of Montana, Missoula, MT, USA
[d] La Trobe Sport and Exercise Medicine Research Centre. College of Science, Health and Engineering, Australia
[e] Department of Surgery, St Vincent's Hospital, University of Melbourne, Australia
[f] Department of Physiotherapy, Monash University, Australia

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ABSTRACT

Objectives: To examine the feasibility of recommended education and exercise supplemented by a hopping intervention implemented based on self-reported pain over 12 weeks for recreational runners with Achilles tendinopathy.
Design: Single cohort feasibility study.
Setting: One private physiotherapy clinic in Melbourne, Australia.
Participants: Fifteen male recreational runners with midportion Achilles tendinopathy.
Main outcome measures: Recruitment and adherence measures, adverse events, intervention acceptability and treatment effect trends were measured at baseline, 4 and 12 weeks.
Results: Recruitment (100%), retention (87%) and follow-up (93%) rates were high. Exercise adherence was 70% (SD = 12.7) but fidelity was 50% (SD = 13.9). Three participants suffered adverse events (undertaking activities contrary to advice). Participants reported the education package, perceived benefit, and feedback frequency as intervention enablers; while the onerous time commitment was regarded a barrier.
At 12 weeks, five participants were satisfied and eight very satisfied, while VISA-A had improved 24 ± 20.65 points ($\mu 2 = 0.740$).
Conclusions: A randomised control trial including recommended education and exercise with a pain-guided hopping intervention as treatment for recreational runners with midportion Achilles tendinopathy may be warranted, once strategies to improve adherence and reduce adverse events are addressed.

1. Introduction

Achilles tendinopathy (AT) is characterised by localised pain, morning stiffness (Cook, Khan, & Purdam, 2002), and impaired function during activities such as running and hopping. AT is particularly prevalent among runners, accounting for 9–15% of total running injuries, but less active people can also be affected (Lysholm & Wiklander, 1987; Van Ginckel et al., 2009). The aetiology is multifactorial, with both intrinsic and extrinsic factors contributing. Common extrinsic factors may include training errors such as a change in training load (ClementDB & Smart, 1984; Di Caprio F, 2010; Galloway MT, 1992; Knobloch & Vogt, 2008) or training surface (Di Caprio F, 2010; Knobloch & Vogt, 2008). Proposed intrinsic risk factors include increasing age (Taunton JE, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2002), increased BMI or body mass (Gaida, Cook, & Bass, 2008; Scott et al., 2015), decreased plantar flexor strength (Mahieu, Witvrouw, Stevens, Van

* Corresponding author. Department of Physiotherapy, School of Primary and Allied Health Care, Building B, Monash University, Peninsula Campus, Victoria, 3199, Australia.
E-mail addresses: i.sanchoamundarain@qmul.ac.uk (I. Sancho), d.morrissey@qmul.ac.uk (D. Morrissey), richard.willy@mso.umt.edu (R.W. Willy), c.barton@latrobe.edu.au (C. Barton), peter.malliaras@monash.edu (P. Malliaras).

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Tiggelen, & Roget, 2006; O'Neill, Watson, & Barry, 2015), systemic diseases such as type 2 diabetes (Holmes GB, 2006), previous injuries (Saragiotto et al., 2014), exposure to drugs (corticosteroids, quinolones) (Barge-Caballero et al., 2008; Greene, 2002) and altered biomechanics (Sancho et al., 2019; S. E. Munteanu, & Barton, C. J., 2011; Ogbonmwan, Kumar, & Paton, 2018).

Among the many treatments for AT, education about safe levels of pain during exercise and progressively applied exercise are consistently recommended first line treatments in systematic reviews (Malliaras, Barton, Reeves, & Langberg, 2013; Murphy, Travers, et al., 2018 and in clinical practice guidelines (Martin et al., 2018; Rowe et al., 2012). The Alfredson eccentric program has been a popular exercise intervention for AT for over two decades and involves isolated and progressively loaded calf raises in standing performed twice a day (Alfredson, Pietilä, Jonsson, & Lorentzon, 1998). Beyer et al. recently compared the Alfredson program to the heavy slow resistance program (HSR) (Beyer et al., 2015). The HSR program included calf loading in standing and seated positions as well as in a leg press machine, progressed from endurance (15 repetitions to fatigue) to maximal strength (6 repetitions to fatigue) intensities (Bird, Tarpenning, & Marino, 2005) and was performed three times per week. Despite substantial differences in the Alfredson and HSR programs, there were no significant differences in pain and function outcomes up to 12 months. Hence, although a single specific loading program cannot be recommended, the current evidence supports progressive rehabilitation for 12 weeks or longer, and the use of a pain monitoring model to guide progression exercise (Malliaras, Palomino, & Barton, 2018).

Stretch-shortening cycle (SSC) activities such as walking, running and jumping are characterised by energy storage and release by the tendon, supported by strong (primarily isometric) contractions from the muscle (Hof, Van Zandwijk, & Bobbert, 2002). There is evidence that people with AT have deficits in SSC function. For example, a reduction in maximal hop distance (a measure of SSC power) (Wang, Lin, Su, Shih, & Huang, 2012) and leg stiffness during submaximal hopping (a measure of SSC efficiency) (Maquirriain, 2012) have been reported in the affected side of people with unilateral AT. Further, Silbernagel et al. found that despite receiving 6 months of recommended exercise treatment that included very little plyometric training, people with AT displayed persistent SSC impairments (e.g. hopping quotient) at one year follow up (K. G. Silbernagel, Thomee, Eriksson, & Karlsson, 2007a). Taken together, SSC dysfunction is a feature of AT and may persist after current exercise treatments.

Plyometric training is a common intervention among athletes and has been shown to improve maximal rate of torque development, maximal voluntary contraction, jump performance, running economy and leg stiffness in healthy people (Foure, Nordez, & Cornu, 2010; Kubo et al., 2007; Spurrs, Murphy, & Watsford, 2003). Kubo et al. compared the effects of heavy-slow resistance training and plyometric exercise in healthy individuals and concluded that heavy-slow training increased tendon stiffness and plyometric training increased joint stiffness and jumping performance (Kubo et al., 2007). This evidence suggests that plyometric training may have complimentary effects to currently recommended exercise for AT, and may also be able to address persistent SSC deficits that have been observed. Plyometric exercises are known to overload the Achilles tendon and aggravate symptoms in subjects with Achilles tendon pain if not applied progressively (Chmielewski, Myer, Kauffman, & Tillman, 2006; Kountouris & Cook, 2007), which may be a barrier. However, Silbernagel et al. reported similar pain and function outcomes among people with AT who continued SSC activity (running, sprinting, jumping or hopping) compared to those who ceased for six weeks, demonstrating that SSC loads are possible in AT as long as guided by symptom response (Karin Grävare Silbernagel, Thomee, et al., 2007b). Our study aimed to build on Silbernagel et al.'s findings and investigate the feasibility of adding a structured hopping intervention to a progressive loading program in managing male recreational runners with midportion AT.

Our overarching research question is whether a pain-guided progressive hopping intervention would be safe and improve outcomes among people with AT when added to currently recommended education and exercise. The current study aimed to assess the safety, feasibility and patient acceptability of adding a hopping intervention (often perceived as potentially damaging by patients and clinicians) to current recommended care, in preparation for an adequately powered randomised trial. The primary objective was to evaluate: i) recruitment, ii) retention, iii) response to follow-ups, iv) incidence of adverse events, v) exercise adherence and exercise fidelity, and vi) acceptability of interventions. The secondary objective was to gain indications of short-term treatment effects.

2. Methods

2.1. Study design

This single cohort feasibility study was designed to evaluate the feasibility and acceptability of recommended education and exercise supplemented by a pain-guided and structured hopping intervention for AT. The study was designed and reported following the CONsolidated Standard of Reporting Trials for pilot and feasibility studies (CONSORT-PF) statement (Eldridge et al., 2016) and approved by La Trobe University Human Research Ethics Committee (22216).

2.2. Participants

Participants were included if they were male, aged between 20 and 60 years old, had moderate to high activity levels as determined by the International Physical Activity Questionnaire (Lee, Macfarlane, Lam, & Stewart, 2011) and ran at least once per week. Clinical diagnosis for the AT group was determined by localised pain at the midportion of the Achilles tendon, pain with or after Achilles tendon loading (running, sprinting, hopping, jumping activities) and morning stiffness. The clinical diagnosis was confirmed by ultrasound imaging. An abnormal tendon structure was defined as hypoechoic region(s) in the midportion and an anteroposterior diameter > 6 mm in the sagittal plane (Archambault et al., 1998; Richards, Dheer, & McCall, 2001). Other inclusions were a minimum of 6-week clinical history and pain with sub-maximal single leg hopping test (>1/10 in a numeric rating scale (NRS), where 0 means “no pain” and 10 is “the worst possible pain”).

Participants were excluded if they had a medical condition precluding ability to participate in physical activity, insertional tendinopathy, previous Achilles tendon rupture or surgery on the currently affected side, an injection for their currently affected Achilles tendon problem in the last 3 months or current symptomatic lower limb or lumbar spine musculoskeletal condition.

Data collection took place at a private physical therapy clinic in Melbourne, Australia, from July to December of 2016. Potential participants were also recruited from other physical therapy clinics, running clubs, football clubs and by social and broadcast media. Participants were offered a free 12-week rehabilitation program and a pair of Mizuno running shoes at the end of the study. The first contact was by telephone or e-mail, and eligibility confirmed at first attendance. All participants provided oral and written informed consent before experimental testing.

3. Interventions

3.1. Education

Consistent with current recommendations (Martin et al., 2018), our intervention included thorough patient education and counselling. Participants were educated about AT pathology, potential pain mechanisms, risk factors, and prognosis. Strategies to address common mal-adaptive beliefs such as fear-avoidance and poor outcomes expectation from conservative treatment were included in the education that was delivered orally at baseline. The concept of load tolerance was defined and introduced as a basis for understanding acceptable pain with exercise and how to progress and regress exercise. Pain up to 3/10 during exercise was acceptable, and some increase in pain after exercise and the next day (based on daily self-reported morning stiffness discomfort or submaximal hopping test [5 consecutive hops]) was acceptable, as long as it recovered to the pre-exercise baseline level within approximately 24 h. However, participants were also advised not to progress loads too fast (i.e 10% maximum increase in running volume per week) and avoid explosive activities. Participants used a diary as a tool to monitor changes in pain, and facilitate appropriate progression and regression. The lead researcher (IS) contacted participants regularly (at least fortnightly) to offer assistance with any aspect of implementing the education and exercise intervention. Information provided to participants is provided in the Intervention Information File).

3.2. Pain-guided progressive exercise

Participants undertook a progressive 12-week exercise program with four levels of exercise. Levels 1 to 4 were progressively more challenging and more likely to provoke symptoms. Participants started on the level that they could undertake with acceptable symptoms. Participants who were only able to perform level 1 exercise with acceptable pain, started with level 1 only. Other participants started with level 2, 3 or even 4. Progression and regression levels were based on load tolerance and are presented as an Additional File in Educational Material. The exercise program is shown in Table 1.

Level 1 included daily isometric exercises in a seated position. Participants performed single leg plantar flexion holds in a seated position with approximately their bodyweight on the thigh. Up to five sets of 45 s, three times per day were permitted (once per day was the minimum), based on loads that reduce tendon pain in prior studies (Pearson et al., 2018; Rio et al., 2015); Level 2 added four triceps surae and kinetic chain isotonic exercises, designed to develop muscular strength and capacity. These exercises are presented as an Additional File in Table AF1; Level 3 introduced a double leg (DL) jump progression; Level 4 substituted DL jumps for single leg (SL) hops and running. The progressive hop program was based on previous programs described in the literature (Kountouris & Cook, 2007; Malliaras, Cook, Purdam, & Rio, 2015; Mascaró et al., 2018; Silbernagel et al., 2007a,b) and the authors' experience. Each hopping program (DL and SL) consisted of four different hop types with progressively increasing difficulty. The program commenced at the baseline and was progressed when participants successfully performed the hopping program at that level on two occasions. When the full hopping program had been introduced, participants were instructed to gradually increase the speed with the forward/backward and step hop components. Participants were advised to run for a duration that would not provoke a flare-up in their Achilles pain and to progress the volume every third running session with a maximum 10% increase in volume per week. Further, there were no restrictions to other physical activity, but they were encouraged to avoid sudden changes of running volume or intensity (e.g. starting sprinting or sport suddenly).

4. Outcomes

4.1. Primary outcomes

The primary outcome of the study was feasibility for a future full-scale adequately powered trial. The specific study processes that were monitored are listed below.

4.1.1. Rates of recruitment and retention

The number of eligible participants that were recruited (rate of recruitment) and the number of recruited participants that remained in the study at final follow-up (retention rate) were assessed. The retention rate target was 80%.

4.1.2. Response rates to questionnaires and other outcome data

The target was ≥80% completion of the 12 week (primary endpoint) questionnaires and physical outcomes (see below) among those who enrolled in the study.

Table 1
Pain-guided progressive exercise program.

LEVEL 1	**ISOMETRICS** (daily)			
Pain >3/10 NRS	Isometric seated heel raises up to 3/day, 5 × 45″ x BW			
LEVEL 2	**ISOMETRICS** (daily)	**ISOTONICS** (3 × week)		
Pain <3/10 NRS	Isometric seated heel raises	Standing heel raises (2 × 25 reps)		
Exercises ok	up to 3/day, 5 × 45″ x BW	Seated heel raises (3 × 8 × 80%6RM)		
		Hip abduction (individually tailored)		
		Hip extension (individually tailored)		
LEVEL 3	**ISOMETRICS** (daily)	**ISOTONICS** (3 × week)	**DL JUMPS** (3 × week)	
Pain <3/10 NRS	Isometric seated heel raises	Standing heel raises (2 × 25 reps)	3 × 60 DL	
20 DL jumps ok	up to 3/day, 5 × 45″ x BW	Seated heel raises (3 × 8 × 80%6RM)	3 × 30 DL stiff knee	
		Hip abduction (individually tailored)	3 × 5 DL forward/back	
		Hip extension (individually tailored)	3 × 5 DL onto a step	
LEVEL 4	**ISOMETRICS** (daily)	**ISOTONICS** (3 × week)	**SL HOPS** (1 × week)	**RUN** (2 × week)
Pain <3/10 NRS	Isometric seated heel raises	Standing heel raises (2 × 25 reps)	3 × 60 DL (warm up)	Warm up: 3 × 20 DL jumps + 1 × 10 SL hops
10 SL hops ok	up to 3/day, 5 × 45″ x BW	Seated heel raises (3 × 8 × 80%6RM)	3 × 30 SL	Run in relation to personal history, time
		Hip abduction (individually tailored)	3 × 15 SL stiff knee	injured and actual condition
		Hip extension (individually tailored)	3 × 5 SL forward/back	Cues: high cadence (±170spm), easy
			3 × 10 SL onto a step	pace,10% max volume increase/week

Abbreviations: NRS numeric rating scale, BW bodyweight, reps repetitions, RM repetition maximum, DL double leg, SL single leg, max maximum p to , STP steps per minute.

4.1.3. Exercise adherence and fidelity

Assessed via diary data over the 12 week intervention, where the participants recorded the exercises performed with sets and repetitions, as well as morning stiffness and submaximal hop test pain data. Exercise adherence was defined as the proportion of prescribed exercise sessions that were completed and adequate adherence was defined as ≥70%. Exercise fidelity was whether the participants followed the prescribed exercise, sets, repetitions, and progression/regression criteria. It was self-monitored and participants had to appropriately progress and regress their exercises according to their pain and based on our instructions. Fidelity was rated (based on weekly report in exercise diary) by the main researcher (IS) as achieved (1/1) if the correct exercise, sets, repetitions, progression and regression criteria were applied and not achieved (0/1) if one or more parameters were incorrect.

4.1.4. Incidence of adverse events

An adverse event was defined as any unfavourable or unintended diagnosis, sign, symptom, or disease associated with the study which may or may not be related to the intervention (e.g. tendon rupture, fall, injury). Participants recorded the frequency (number of cases during the study), severity (mild, moderate or severe) and length (days of program skipping) of the adverse events in their daily diary. Severity of adverse events was assessed according to the following definitions:

- Mild: Some discomfort noted but without disruption of daily life
- Moderate: Discomfort enough to affect/reduce normal activity
- Severe: Complete inability to perform daily activities and lead a normal life

4.1.5. Acceptability of interventions

At the end of the intervention, participants were asked open questions (via written questionnaire) about their perceptions of the positive and negative aspects of the intervention. The questions were: a) What aspect did you like most about the treatment?; b) What aspect did you like least about the treatment?

4.2. Secondary outcomes

The study duration and primary endpoint were 12 weeks and participants attended for outcome measure assessment on three occasions at baseline, four and 12 weeks. At each visit, a battery of patient-reported outcomes and physical tests were assessed by a single experienced physical therapist (IS).

4.2.1. Patient-reported outcomes

Six patient reported outcomes were included: (i) Pain and disability (primary patient reported outcome) assessed with Victorian Institute of Sport Assessment-Achilles (VISA-A), a disease specific outcome that has demonstrated construct validity and acceptable test-retest reliability (Robinson et al., 2001); (ii) Fear of movement measured with the validated Tampa Scale for Kinesiophobia (TSK) (Houben et al., 2005) (iii) Achilles Tendon Beliefs Questionnaire (ATBQ) adapted from the validated fear-avoidance beliefs questionnaire (Waddell et al., 1993); (iv) Pain related anxiety and avoidance measured with the short form of the Pain Anxiety Symptoms Scale (PASS-20) (McCracken & Dhingra, 2002; Roelofs et al., 2004), (v) Maximal pain during 10 submaximal hops and hopping to fatigue were assessed on a 0–10 point numeric rating scale (0 is no pain, and 10 is worst pain imaginable), and (vi) Patient satisfaction with the treatment at 4 weeks and after the 12-week intervention was measured on a 5-point Likert scale (very satisfied, satisfied, neutral, unsatisfied, very unsatisfied). Among people with midportion AT, the minimal clinically important difference (MCID) in VISA-A has not been determined, although most of previous trials have estimated MCID to be 10 points (Murphy, Rio, et al., 2018).

4.2.2. Physical tests

Seven physical tests were assessed in a randomised order, including standing heel raise to fatigue; seated heel raise, leg extension, and leg curl six repetition maximum (6RM) function; hip abduction and extension maximal voluntary isometric contraction; and ankle dorsiflexion flexibility at knee straight and knee bent positions. Both legs were tested in a randomised order with 2 min rest between trials. All isotonic tests (standing and seated heel raise, leg extension and curl) were performed in time with a metronome (1-second eccentric and 1-second concentric phases). For 6RM tests, 3–4 sets were performed on each side until the maximum weight that could be moved six times was identified.

Standing heel raise endurance: After a warm-up of 10 double leg heel raise repetitions, participants performed full range single leg plantarflexion repetitions in standing with the knee straight. The number of repetitions performed was recorded. Participants were cued during the test to maintain adequate plantarflexion and tempo, and the test was terminated if they failed to adhere to these instructions for three consecutive raises, or they stopped voluntarily due to fatigue (Silbernagel, Nilsson-Helander, Thomeé, Eriksson, & Karlsson, 2010).

Seated heel raise: Participants performed single leg seated (100 degrees of knee flexion) heel raises in a Smith machine with the bar on their thigh (padding between the thigh and bar ensured this was comfortable). The starting weight was 80% of the participant's bodyweight and warm up consisted of 10 double leg repetitions at this weight. The highest weight that could be moved for six repetitions with the appropriate tempo and plantarflexion height (based on tester's criteria) was recorded. Values for seated heel raise 6RM test include the weight of the Smith machine's bar (9.3 kg).

Leg extension: Assessed in a leg extension machine starting with 30% of the participant's bodyweight. Warm up consisted of 10 double leg repetitions at 30% of bodyweight load. The highest weight that the participant could move for six repetitions and with the appropriate tempo between zero and 80 degrees of knee flexion with a single leg was recorded.

Leg curl: Assessed in a prone leg curl machine starting with 10% of bodyweight load. Warm up consisted of 10 double leg repetitions at 10% of bodyweight load. The highest weight that the participants could move for six repetitions with the appropriate tempo between zero and 80 degrees of knee flexion with a single leg was recorded.

Dynamometry: Hip extension (EXT) and abduction (ABD) were assessed using a protocol with excellent re-test reliability (Thorborg, Petersen, Magnusson, & Holmich, 2010). This protocol utilises 'make' tests were the participant produces maximal force and the tester matches this resistance. Hip ABD was performed in a supine position and hip EXT was performed in a prone position. Warm up consisted of 3–4 submaximal and maximal trials. The mean value of three maximal test trials per side was used in analyses.

Ankle flexibility: Prior to commencing the ankle dorsiflexion assessment, participants undertook 5 min of triceps surae stretches in knee straight and knee bent positions. Ankle dorsiflexion range of motion was calculated with an inclinometer in knee extended and knee flexed positions using a reliable protocol (Bennell et al., 1998; Munteanu, Strawhorn, Landorf, Bird, & Murley, 2009). Participants placed their second toe and the centre of the heel directly over a line on the ground and moved their knee in the same plane as this line (towards a continuation of this line on a wall in front of

them) in order to standardise foot position and the influence of navicular drop on dorsiflexion range. The mean value of two measurements per leg was used in analyses.

4.2.3. Hopping outcomes

Two hopping tasks were performed including submaximal hopping followed by submaximal hopping to fatigue. The starting leg in each task was randomised. During submaximal hopping the participants performed 10 single leg hops with a self-selected frequency. They were instructed to place their hands on their hips and hop continuously whilst minimising contact time. During hopping to fatigue the participants performed submaximal single leg hopping with self-selected frequency until they felt they could not hop any longer. The instructions were to place hands on hips and 'hop as if you could hop forever'. One familiarisation trial and one recorded trial were performed per side for submaximal hopping followed by one hopping to fatigue trial per side. Submaximal hopping familiarisation trial was used to rate pain (VAS score) during hopping (described above under patient-reported outcomes). Participants were given a minimum of 2 min of rest between trials. Hopping trials were recorded on 2D video (Apple, iPad, California, USA) at 120 FPS. Leg stiffness (LS) was calculated using flight and contact times extracted from the 2D video (Dalleau, Belli, Viale, Lacour, & Bourdin, 2004). This method of assessing leg stiffness has been validated against the gold standard assessment (vGRF and 3D analysis) (Willy, 2017). For submaximal hopping, contact and flight times were extracted and averaged from the fourth to sixth hops. For hopping to fatigue, contact time and flight times were extracted from three hops at the beginning (fourth to sixth hops), middle (50% of total time) and end of the trial (the last three hops [after the last two had been excluded]). The duration of hopping to fatigue was also recorded.

5. Statistical analysis

Statistical analyses were performed using SPSS (Version 22, IBM Corp., NY, USA). Tests of normality were used to assess whether data were normally distributed (Shapiro-Wilk) and parametric and non-parametric analyses were performed based on the outcome. An intention-to-treat analysis approach was used to report secondary outcomes. Mean and SD of participant-reported outcomes, physical tests, and hopping outcomes were calculated. ANOVA for repeated measures was calculated to assess differences between baseline and follow-ups. Partial Eta Squared ($\eta 2$) between baseline and four weeks, four and 12 weeks, and baseline and 12 weeks were calculated to provide an estimate of the effect size (ES). ES were classified as small (0.01–0.06), medium (0.06–0.14), or large (>0.14). All strength outcomes were normalised to body weight.

6. Results

6.1. Primary outcomes

6.1.1. Recruitment, retention, and response to follow-ups

Twenty-two participants were screened and seven did not meet the eligibility criteria. Fifteen recreational runners with AT were eligible and enrolled in the study (100% rate of recruitment) but two withdrew (one after baseline and one after four weeks follow up) citing lack of time to undertake the rehabilitation program (87% retention rate). The CONSORT flow diagram is shown in Fig. 1. The outcome completion rate at 12 weeks was 93%. Demographic data are based in 15 participants with AT that were recruited (age: 37.86 ± 8.83 years, weight: 87.19 ± 10.57 kg, height: 178.50 ± 5.99 cm) and follow up data was only available for the 13 participants who completed the study.

6.1.2. Exercise adherence and fidelity

Adherence to exercises was acceptable with 70% of the exercises completed when considering all exercises together. However, for specific components of the interventions, adherence was less than 70% (Fig. 2). Adherence was highest for SL hops (100%) and lowest for seated heel raise (46%). Fidelity to the prescribed sets, repetitions and load was 50% overall but was particularly poor for certain exercises like DL jumps and SL hops (23% and 22% respectively). Seated heel raise had the highest fidelity (64%).

Four (30%) participants started the treatment in level 2, two (16%) in level 3 and seven (54%) in level 4. No participant was in level 1 during the 12 weeks of the program. At 12 weeks, 10 (77%) participants were at level 4 and three participants did not provide activity information but were likely to be in level 4 as per their activity in the prior week. On a group level, exercise progression of the program was in general correctly performed. This is evidenced by mean pain values on the hop test (5 single leg hops) which were 5.3 ± 1.18 points for participants starting level 2 (hopping not required), 3.04 ± 1.96 for participants starting level 3 (DL jumping but no single leg hopping required) and 2.51 ± 2.08 for participants starting level 4 (SL hopping required) (Table 3). At the individual level, three participants in level 2, one participant in level 3 and three participants in level 4 started with pain scores higher than recommended (pain >3/10 per each level criteria). Most participants followed the advice about gradually increasing volume of running to avoid unnecessary flare-up prior to progressing to sport. Five participants returned to sport during the program, including football (2 participants), basketball (1 participant), rugby (1 participant) and Australian football (1 participant). Participants progression through the program is shown as an Additional File in Table AF2.

6.1.3. Adverse events

Three participants suffered a moderate adverse event related to physical activities missing two weeks of the program. One participant tore the medial gastrocnemius of his affected leg playing basketball, another participant tore the medial gastrocnemius of his unaffected leg sprinting uphill and the third participant suffered a grade 1 lateral knee ligament tear playing football. Participants should not have been undertaking these activities based on their symptom level and specific activity modification advice they were given. Further, not directly related with the intervention, three participants did not provide information about their activity over a total period of four weeks. Two participants were ill for one week and one participant was ill for two weeks. One participant went on holiday for two weeks during the study period.

6.1.4. Acceptability of interventions

At the end of the program, participants reported the education package and regular feedback as the most positive aspects of the intervention. The time commitment and the requirement to perform the exercise in a gymnasium daily were cited as the most negative aspects.

6.2. Secondary outcomes

6.2.1. Patient-reported outcomes

Patient-reported outcome data is shown in Table 2. There was a clinically meaningful improvement in VISA-A between baseline and four weeks (11.77 ± 22.84), and four and 12 weeks (12.23 ± 18.59). ATBQ statistically decreased at 4 weeks (5.15 ± 12.63) but not between four and 12 weeks. Pain after 10 single leg hops significantly decreased at four weeks (2.99 ± 2.38) and between four and 12 weeks (0.98 ± 1.22), and pain after hopping to fatigue decreased significantly after four weeks (3.25 ± 2.51)

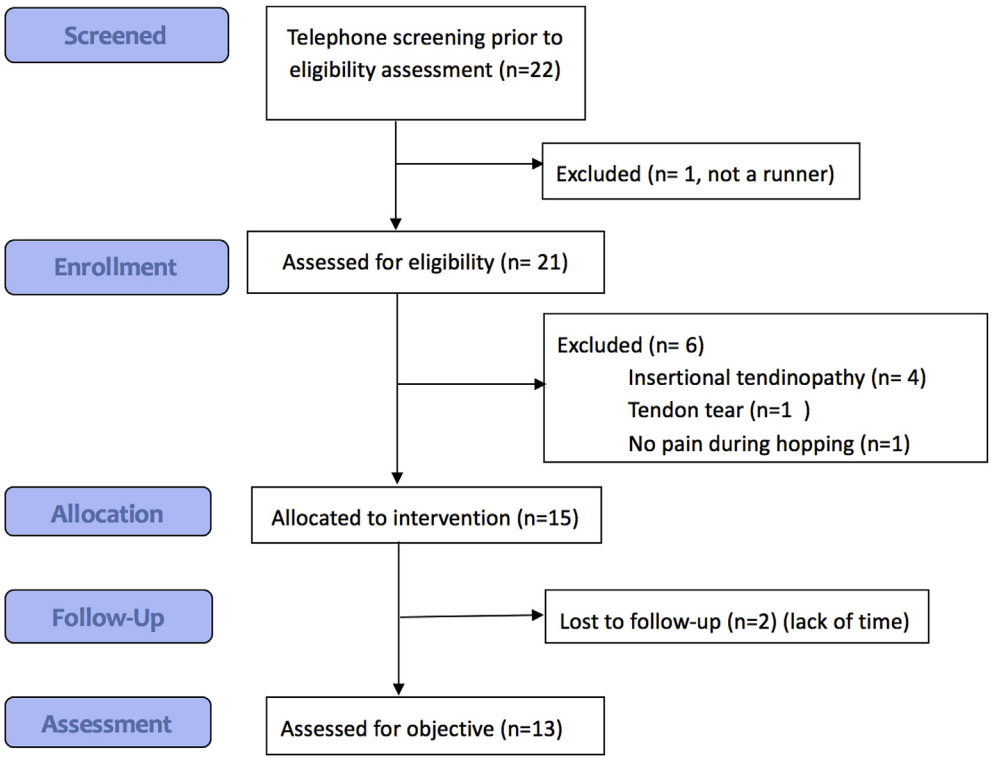

Fig. 1. Consort diagram.

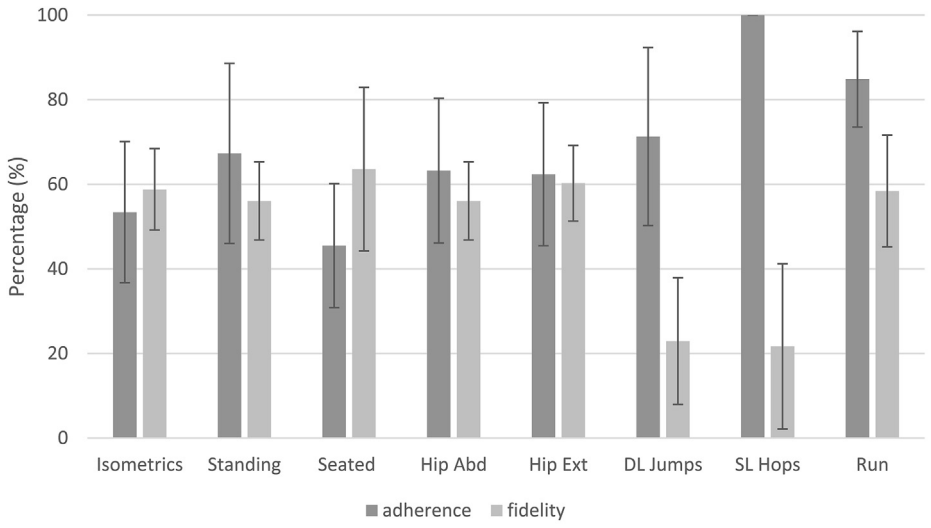

Fig. 2. Exercise adherence and fidelity.

and between four and 12 weeks (0.98 ± 1.13). Three participants were satisfied, eight very satisfied and three where neutral at four weeks, whereas five were satisfied and eight very satisfied at 12 weeks.

6.2.2. Physical tests

Physical test data is shown in Table 2. Standing heel raise test increased significantly at four weeks, and between four and 12 weeks. Seated heel raises had a significant change after 4 weeks but not between four and 12 weeks. Leg extension increased significantly at four weeks, and between four to 12 weeks. Hip abduction increased significantly at four weeks. Ankle dorsiflexion ROM for knee bent position significantly increased between four and 12 weeks, but the change was not clinically meaningful between any time point pairs.

6.2.3. Hopping function

Hopping function data is reported in Table 2 and Fig. 3. Leg stiffness during submaximal hopping significantly increased between zero and four weeks, and between four and 12 weeks (Fig. 3). For hopping to fatigue, leg stiffness increased at the beginning and end between zero and 12 weeks, and only at the end between zero and four weeks (Fig. 3). The duration of hopping to fatigue significantly increased at four weeks but did not continue to increase

Table 2
Secondary outcomes with effect size estimates (mean ± SD).

Outcome	Baseline	4 weeks	B-4η^2	12 weeks	4-12η^2	Total η^2
VISA-A	62.23 ± 17.36	74.00 ± 14.85*	0.452	86.23 ± 11.19*Δ	0.515	0.740
ATBQ	36.61 ± 9.28	31.46 ± 8.57*	0.518	28.54 ± 6.89Δ	0.231	0.508
PASS20	19.85 ± 12.44	15.69 ± 10.54	0.263	15.31 ± 12.94	0.001	0.206
TAMPA	35.38 ± 5.89	33.54 ± 5.07	0.145	32.15 ± 4.96Δ	0.068	0.411
Hop vas	4.21 ± 2.08	1.22 ± 1.16*	0.761	0.24 ± 0.39*Δ	0.461	0.788
Hop to Fatigue vas	4.46 ± 2.28	1.21 ± 1.07*	0.660	0.23 ± 0.38*Δ	0.533	0.772
Heel raise (reps/BW)	0.28 ± 0.12	0.34 ± 0.12*	0.457	0.37 ± 0.13*Δ	0.372	0.554
Seated heel raise (kg/BW)	1.20 ± 0.18	1.42 ± 0.22*	0.664	1.45 ± 0.23Δ	0.104	0.689
Leg extension (kg/BW)	0.59 ± 0.10	0.63 ± 0.09*	0.441	0.67 ± 0.11*Δ	0.597	0.638
Leg curl (kg/BW)	0.38 ± 0.09	0.40 ± 0.08	0.243	0.40 ± 0.07	0.000	0.177
Hip extension (kg/BW)	0.30 ± 0.08	0.30 ± 0.07	0.023	0.31 ± 0.04	0.003	0.031
Hip abduction (kg/BW)	0.17 ± 0.04	0.19 ± 0.03*	0.322	0.19 ± 0.03Δ	0.000	0.401
Ankle DF ROM kbent (°)	41.50 ± 5.26	42.00 ± 5.05	0.051	40.65 ± 5.19*	0.292	0.200
Ankle DF ROM kstraight (°)	44.61 ± 5.87	44.54 ± 4.37	0.000	43.80 ± 4.75	0.040	0.032
LS submaximal hop (kN/m)	44.99 ± 12.32	53.28 ± 14.30*	0.298	60.46 ± 15.36*Δ	0.482	0.540
LS begin fatigue (kN/m)	34.01 ± 10.62	39.36 ± 9.22	0.261	41.25 ± 7.31Δ	0.130	0.464
LS middle fatigue (kN/m)	35.59 ± 9.91	38.82 ± 9.44	0.156	41.13 ± 6.99	0.151	0.303
LS end fatigue (kN/m)	30.88 ± 8.63	36.14 ± 9.64*	0.298	39.00 ± 7.89Δ	0.209	0.529
Fatigue duration (seconds)	39.23 ± 14.85	47.15 ± 16.67*	0.367	55.38 ± 27.53Δ	0.181	0.441

Abbreviations: SD standard deviation, η^2 Partial Eta Squared, VISA-A Victorian Institute of Sports Assessment-Achilles, ATBQ Achilles Tendon Beliefs Questionnaire, PASS20 Pain Anxiety Symptoms Scale, TAMPA Tampa Scale of Kinesiophobia, vas visual analogue score, reps/BW repetitions per bodyweight, kg/BW kilograms per bodyweight, DF ROM dorsiflexion range of motion, kbent knee bent, kstraight knee straight, ° degrees, LS leg stiffness. B-4 η^2 effect size between baseline and 4 weeks, 4-12η^2 effect size between 4 and 12 weeks, Total η^2 effect size between baseline and 12 weeks, * significant difference with previous testing time, Δ overall significant difference.

Table 3
Relationship between pain and triceps surae strength tests at the beginning of each program level (mean ± SD).

	Pain during 5 SL hops (n)	Heel raise to endurance (reps/BW)	Seated heel raise 6RM (kg/BW)
Level 1	NA (0)	NA	NA
Level 2	5.3 ± 1.18 (4)	0.21 ± 0.12	0.97 ±0.04
Level 3	3.04 ± 1.96 (4)	0.26 ±0.09	1.31 ±0.05
Level 4	2.51 ± 2.08 (13)	0.33± 0.12	1.35 ± 0.24

Abbreviations: SD standard deviation, SL single leg, n number of participants, reps/BW repetitions per bodyweight, kg/BW kilograms per bodyweight, NA not applicable, 6RM six repetitium maximum. Level 1 included daily isometric exercises in a seated position; Level 2 included 4 triceps surae and kinetic chain isotonic exercises; Level 3 introduced a double leg (DL) jumps progression; Level 4 substituted DL jumps per SL hopping and running.

between four and 12 weeks (Fig. 3).

A post hoc observation was that there seemed to be a relationship between pain during hopping and calf strength at the commencement of each exercise level. This data is reported in Table 3 and suggests calf strength may be a mechanism for improved symptoms and progression through the exercise levels.

7. Discussion

7.1. Primary outcomes

We have demonstrated that recommended education and exercise supplemented by progressive hopping is a feasible intervention for recreational runners with AT. Safety is less clear, and needs to be closely monitored in future trials, as although no injuries occurred during treatment, three subjects who disregarded advice about other physical activity, suffered minor injuries during the study period. Further, other feasibility caveats need to be considered. While rate of recruitment, rate of retention and response rate to outcomes were acceptable, exercise adherence and fidelity were variable and not acceptable for all the exercises. Within this discussion, we will propose how these issues may be potentially addressed in subsequent trials adopting this intervention.

Exercise adherence was acceptable when considering all the exercises together but varied substantially depending on the type of exercise. The seated calf raise exercise that was intended to be performed daily (isometrically), and three times per week (isotonically) in a gymnasium had the lowest adherence rate with 53% and 46% respectively, whereas adherence was high for hopping (100%), jumping (71%) and running (85%) that could easily be performed in a range of environments. The apparently lower adherence compared to the Beyer study (92% for the HSR group and 78% for the eccentric group) may be explained by the daily isometric exercise, and a SSC program (jumping/hopping/running) on the alternative days that was not part of the exercise program in Beyer et al. We provided education designed to reduce potential barriers to adherence such as fear avoidance or poor exercise outcome expectation. Fostering self-management and regular access to the researchers to discuss issues with the exercises, were also offered in an attempt to maximise adherence (de Silva, 2011; Jones, 2006). It appears therefore that the main barrier for better adherence was time, and this is consistent with participants reporting that the time commitment and requirement to undertake exercise in a gymnasium was a challenge.

Fidelity errors can be categorised as relating to either inappropriate progression (e.g. progressing to the full hopping program too quickly or progressing to an incorrect exercise level) or errors related to exercise execution (e.g. performing hopping and running on the same day). In this pilot study, exercise prescription was personally tailored and feedback about the provided information and education was positive. However, it seems that some participants were unable to implement the self-management instructions appropriately. In future work this may be avoided by implementing a fidelity check in person or via tele-conference within a week of intervention commencement. Given the time-burden on participants, it is also worthwhile considering whether some exercises (e.g. daily isometric seated heel raises) could be omitted or replaced

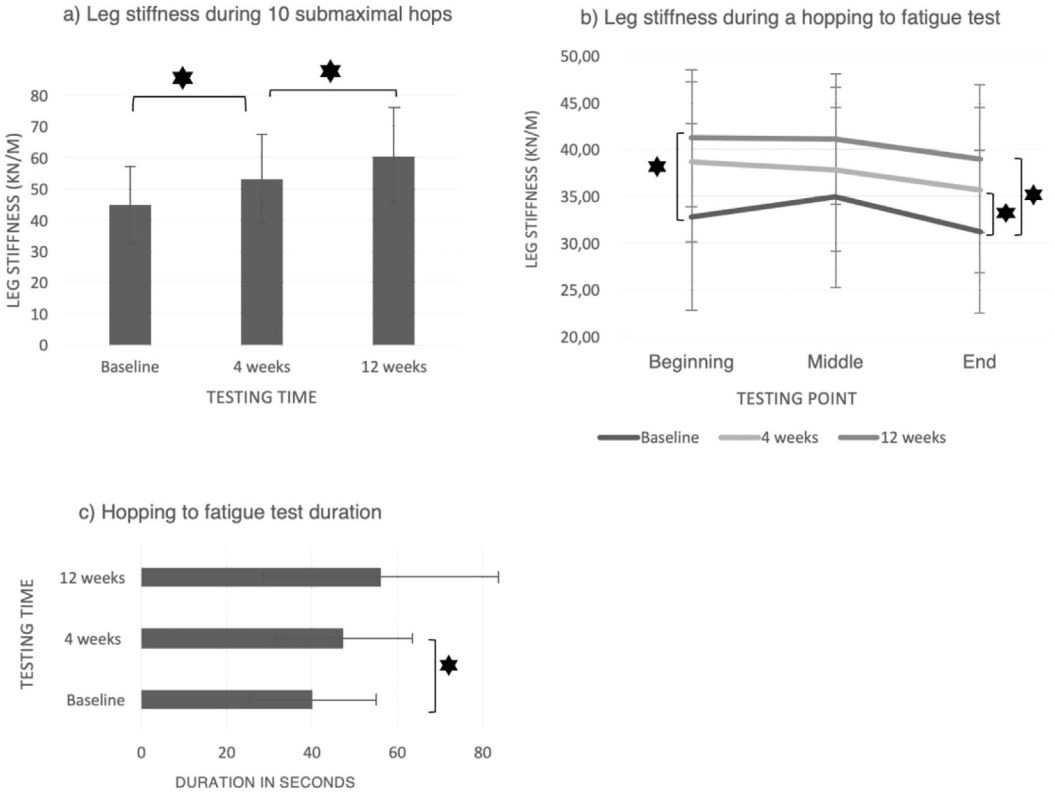

Fig. 3. Hopping data: a) leg stiffness during 10 submaximal hops, b) leg stiffness during a hopping to fatigue test and c) hopping to fatigue test duration (mean values with error bars).

with a more convenient option that can be performed at home.

Three participants had adverse events directly linked with explosive physical activities (not part of the intervention). Two adverse events were calf strains that occurred during explosive SSC activities undertaken despite advice to moderate these activities due to symptoms and greater likelihood to sustain a flare up. Interestingly, one of the partipants that tore his calf had the lowest seated heel raise 6RM among all the participants in level four (0.95BW). In fact, he was the only participant in level four with a seated heel raise 6RM score under his bodyweight. The second participant who suffered a calf tear (unaffected side) was a professional rugby sevens referee in preseason. He was one of the strongest in the cohort and was undertaking high volume and intense running (e.g. hill sprints) beyond what was recommended, in preparation for his season. It is possible that the overall volume of level four exercise increases the risk of calf fatigue and injury, but most participants in our cohort did not experience adverse events. It is likely that these calf strains could have been avoided if advice to perform activities only with acceptable pain and gradually progress SSC loads had been followed.

7.2. Secondary outcomes

Change in VISA-A scores among participants in our underpowered study (24 ± 20.65, $\mu^2 = 0.740$) is similar to the mean improvement reported in a recent systematic review of exercise studies among people with midportion AT (21.1 ± 6.61 points) (Murphy, Travers, et al., 2018). This study did not include a control group, therefore, the influence of non-specific effects including natural history or placebo is not known. An adequately powered trial is now needed to evaluate whether there is added benefit to patient important outcomes such as pain and function in adding a hopping intervention to recommended education and exercise for AT.

To date, whether high degrees of kinesiophobia is a feature of groups or sub-groups of participants with AT remains unclear. Participants in our study were mostly able to continue running throughout the intervention and this may explain why kinesiophobia scores were low, being below 37 which is considered the cut-off between high and low levels of kinesiophobia (Corrigan, Cortes, Pontiggia, & Silbernagel, 2018). Interestingly, participants' kinesiophobia scores improved to a large extent from baseline to week 12, so inclusion of the Tampa scale is recommended in a definitive trial.

As expected, some improvements in strength scores were found following the treatment. For example, triceps surae, leg extensors and hip abductors strength, as well as ankle flexibility, improved at 12 weeks. There was an increase in leg stiffness during hopping and hopping to fatigue, as well as improvement in the duration of hopping to fatigue among runners with AT following treatment. These preliminary findings suggest that, consistent with reports among healthy participants, hopping interventions may be useful in addressing SSC deficits observed among recreational runners with AT. We caution against translating these outcomes directly to clinical recommendations given our study was underpowered, the lack of a control group and the unclear safety profile.

A relationship between hopping pain and calf raise strength over time was observed. Although we did not plan to investigate this relationship, we have reported it as a post-hoc finding as it may be hypothesis generating. Participants commencing level 2 had mean hop pain of 5.3/10 and mean seated heel raise 6RM of 0.97BW (below BW), and participants commencing level 4 had mean hop pain of 2.51/10 and their seated heel raise 6RM had increased to 1.35BW on average. This preliminary data suggests a relationship

between reduced pain and increased strength which warrants further study to determine if pain reduction causes increased strength, possibly via reduced inhibition (Hodges & Smeets, 2015).

8. Conclusion

The results of this study suggest that the addition of a pain-guided progressive hopping intervention to recommended education and exercise is feasible for recreational runners with AT. There were meaningful improvements in patient-reported outcomes (e.g. pain and function) as well as leg stiffness during hopping and duration of hopping to fatigue. The time burden and requirement to undertake some exercises in the gym may be a barrier to adherence and should be considered in future work. Safety is not yet clear. This feasibility study provides useful information that can inform a future substantive trial investigating the efficacy and safety of adding a hopping intervention to currently recommended education and exercise treatment for AT.

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Ethical approval

The study was approved by La Trobe University Human Research Ethics Committee (22216).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.08.007.

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