

Effect of a toe-walking protocol in plantar heel pain: A pilot study

Dean Huffer

South Yarra Spine and Sports Medicine / Bond University

Wayne Hing

Bond University

John Charles (✉ johnc@sysm.com.au)

South Yarra Spine and Sports Medicine <https://orcid.org/0000-0002-0988-9876>

Richard Newton

Bond University

Mike Clair

Physioflex Sports

Elisa F. D. Canetti

Bond University

Research Article

Keywords: plantar, heel, fasciitis, loading

Posted Date: July 9th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-676307/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Introduction/Purpose: Plantar heel pain (PHP) is one of most common disorders of the foot treated in primary care. It affects athletic and sedentary populations, with patient reports of activity-limiting pain and reduced quality of life. Recently, atrophy of the forefoot plantar intrinsic musculature was identified in patients with PHP.

Therefore, the purpose of this study was to assess whether loading the plantar fascia strengthens the intrinsic foot musculature (IFM) and decreases PHP sufferers' symptoms.

Methods: A within-subjects experimental design assessed Foot Function Index (FFI) and IFM strength via hand-held dynamometry (HHD) in 12 patients with PHP prior to and at the end of a six-week toe-walking program.

Results: After six weeks of treatment, the mean (SD) FFI score significantly decreased from 73.2 (32.4) to 43.3 (22.8) points ($p = 0.010$, ES = 1.1). HHD measures: Both great toe flexion and lesser toes flexion strength measures demonstrated significant force increase of 7.8N 95%CI [1.3, 14.4] ($p = 0.024$, ES = 1.0) and 6.6N 95%CI [1.8, 11.4] ($p = 0.010$, ES = 0.9), respectively.

Conclusion: Results suggest toe-walking reduces PHP symptoms and increases IFM strength. There was no identified correlation between the IFM and FFI changes. Symptom reduction may potentially be due to a reduction in cortical inhibition rather than IFM strength changes. Findings provide foundation for future studies, employing imaging, to further validate the effectiveness of toe-walking in reducing symptoms of PHP patients.

Trial registration: PROSPERO 2016 CRD42016036302 Registered 10 March 2016, https://www.crd.york.ac.uk/prospERO/display_record.php?ID=CRD42016036302

Introduction

Plantar heel pain (PHP) is one of the most common musculoskeletal disorders of the foot treated in primary care [1, 2, 3]. The condition affects both elderly and athletic populations[4] and is estimated to affect 10% of the population at some point in their life [5]. The condition is typically characterised by pain radiating from the anteromedial aspect of the plantar heel [6]. It is most intense with the first steps of the day, or after rest and often reduces with activity [2]. As the condition progresses these symptoms can become more debilitating reducing the sufferers' ability to weight bear.

The condition has a long history of changing terms for the condition including Gonorrhoeal Heel, Policeman's heel, Heel spur syndrome, subcalcaneal pain, Jogger's Heel, plantar fasciitis, plantar fasciopathy and plantar fasciosis [6].

More contemporarily the terms "plantar fasciosis" and "plantar fasciopathy" were proposed as the

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js ther lower limb degenerative tendon disorders

such as Achilles and patella tendinopathy [4, 7] that have showed promising responses to high load isometric and strength exercises [8, 9]. A systematic review by Huffer et al. [10] indicated that high-load plantar fascia resistance training may aid in a reduction of PHP and improvements in function. As relates to IFM, Latey et al. [11] documented a link between intrinsic foot muscle weakness and painful foot pathologies such as plantar heel pain.

Rathleff et al. [12] was the first RCT to support this approach in the management of PHP, concluding that over a 12-week period that a modified high load heel raise may aid in a quicker reduction and improvement in function than traditional treatment (heel insert and plantar-specific stretching). However, a subsequent randomised crossover trial by Riel et al. [13] found that an isometric heel raise was no better than isotonic exercise or walking at reducing PHP sufferers' pain over a two-week period.

Another isometric loading approach that could potentially improve intrinsic foot muscle strength and reduce PHP is toe walking [11]. This study's aim is to address whether this clinically utilised, but not researched, approach of progressively loading the plantar fascia strengthens the intrinsic foot musculature and reduces PHP sufferers' symptoms over a six-week period.

Methods

Participants

PHP sufferers were recruited through a public advertising campaign including print, online and radio advertisements that were titled using the publicly identifiable title "Plantar Fasciitis Trial".

Plantar heel pain sufferer eligibility criteria were stipulated in these advertisements with the following wording:

- *Men and women aged between 18 and 60-years of age*
- *Proficient in English*
- *Not currently receiving treatment for a lower limb pathology*
- *No neurological condition that may affect lower limb muscle strength (i.e., stroke, motor vehicle accident or polio)*
- *No Autoimmune Disease (i.e., multiple sclerosis, rheumatoid arthritis or systemic lupus erythematosus)*
- *Able to ambulate 10-metres without an assistive device*
- *Suffering from unilateral heel pain that is characterised by the following three symptoms:*
 - *Radiating from the medial aspect of the heel into the arch of foot*
 - *Most intense with the first steps of the day or after rest or warming up with activity*
 - *Reduces the patient's ability to weight bear on the foot.*

The purpose of outlining the initial eligibility in these advertisements was to minimise the number of ineligible participants registering interest. The maximum age was set at 60 years, as toe walking intervention requires good levels of proprioception and balance to safely perform. Participants with co-existing lower limb pathologies, neurological conditions, autoimmune and with bilateral symptoms were also excluded.

The key differentials for PHP as established in the background for research were “(i) pain radiating from the medial aspect of the heel into the arch of foot, (ii) pain most intense with the first steps of the day or after rest or warming up with activity, (iii) pain that reduces the patient’s ability to weight bear on the foot” [2]. The first two of these differentials were assessed at their initial screening assessment. While the third, the participant’s reduced ability to weight bear was quantified by their Foot Function Index (FFI) scores.

English proficiency was particularly important as all patient instructions and the toe walking learning material (handout, video clip and technique cueing) were delivered in English.

Screening

Participants were initially screened by one researcher (DH) against the advertised plantar heel pain sufferer eligibility criteria. Then by differential diagnosis for conditions such as fat pad contusion, and less common conditions such as calcaneal stress and traumatic fractures, medial calcaneal nerve entrapment, lateral plantar nerve entrapment, tarsal tunnel syndrome, talar stress fracture, retrocalcaneal bursitis, along with not to be missed pathologies such as spondyloarthropathies, osteoid osteoma and post knee or ankle injury complex pain syndrome (CRPS) [7]. It should be acknowledged that this was a clinical assessment only with no radiological imaging. Medical imaging may have subsequently provided a more specific diagnosis; however it is not routinely indicated unless atypical symptoms present [14] and the key is careful clinical assessment [15].

Primary Outcome

Foot Function Index (FFI)

The FFI, a self-report questionnaire that quantifies the impact of foot pathology, was completed pre/post the six-week toe walking intervention. The questionnaire consisted of 23 items divided into three subscales (i) pain, (ii) disability, and (iii) activity limitation. Scoring ranges from 0 to 230, with 0 reflecting no pain, disability, or activity limitations [16]. The minimal important change is 7-points for the total scale [17].

Secondary Outcome

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js

Handheld Dynamometry (HHD)

Intrinsic Foot Musculature (IFM) strength was measured isometrically using the Commander Muscle Tester (JTECH Medical Midvale, UT) Handheld Dynamometer (HHD) for: (i) hallux (great toe) strength, and (ii) digits 2-4 (lesser toe) strength pre and post the six-week intervention.

Intervention

Technique

The intervention, a toe-walking protocol, was developed to provide isometric loading to the plantar aponeurosis in a functional movement. To perform the technique correctly participants were required to perform tip-toe walk maintaining the heels only slightly above the ground (approximately 0-2cm) throughout the entirety of the gait cycle adopted in the intervention. Participants were instructed to keep their steps very short (half the foot length maximum) (Figure 1).

The technique was performed more dynamically characterised with a brief flight. However, the steps were still to remain short, no longer than half of the length of the participant's foot.

Following their initial screening, completion of the FFI and HHD measurements, each participant had an individual 15-minute briefing on the technique, which included watching a 90-second instructional video clip that was emailed to them for reference.

All participants then trialled the toe-walking and toe running techniques with the examiner providing cues until they were performing the technique to the examiner's satisfaction. Participants were also provided with written instructions and the examiner's email contact if they had any queries or concerns regarding their technique throughout the intervention. They were also instructed to refrain from activities that had been previously aggravating them prior to assessment i.e., running, walking barefoot other than their prescribed toe-walking.

Prescription

The toe-walking was to be completed daily beginning at 1-minute per day for week one, 2-minutes per day in week two and progressing up to 6-minutes a day in week six.

If participants were planning on returning to running based activities they were instructed to increase the cadence of their toe walking at week 3. Participants were instructed to aim for a minimum of five days compliance a week, and were sent weekly reminder emails, along with being provided with a tracking sheet. They were also warned that the intervention may potentially exacerbate their plantar heel symptoms and to attempt to work through this; if they were able to tolerate the discomfort. No restrictions

Procedure

Prior to commencement participants self-reported their age, height, and weight. This was not verified to protect patient dignity and not to deter participation. The strength of the participant's IFM was then measured with hand-held dynamometer for both their PHP symptomatic and asymptomatic feet. Great and lesser toe HHD strength measures were obtained using the 'make' technique, whereby the dynamometer is held stationary by an examiner and the participants maximally exert a force against it [18].

All participants were positioned in long sitting with hips flexed and knee fully extended on an examination table. Participants were permitted to hold the edge of the table at the level of their hip for sitting balance. A towel was positioned under the distal aspect of the lower limb being tested. The assessor then passively positioned the foot into maximum plantar flexion to minimise the influence of the extrinsic muscles of the foot.

The HHD was positioned in neutral on the plantar aspect of the phalanges, just distal to the metatarsophalangeal (MTP) joints. Participant's hallux and lesser toes (digits 2-4) were assessed separately. Participants were asked to complete three maximum contractions with 3-second holds for both the hallux (great toe) and then lesser toes. Participants were allowed up to a 15-second break between contractions (Figure 2).

As discussed in the "Technique" and "Prescription" sections, participants then viewed a video demonstration of barefoot toe-walking, before attempting the toe-walking technique with technical feedback provided from the examiner. Finally, participants completed their day one (first minute) of toe-walking, before being provided with a home exercise completion record to track their compliance. At the completion of the six-weeks, the participant's exercise compliance was recorded, and intrinsic foot muscle strength re-tested using the same manner as the initial assessment. Participants were excluded from the study if they did not attend their completion assessment (post-test) at the six-week mark which included re-assessment of outcome measures and reviewing their toe-walking technique.

Statistical Analysis

IBM SPSS Statistics release 23.0.0 was used for all data analysis. Three hallux (great toe) and lesser toes (2-4) HHD strength measures for both the symptomatic and asymptomatic foot were taken pre and post the six-week toe walking intervention. Measures were not pooled to account for the nature of the paired data. To establish HHD intra-rater reliability intra-class correlation coefficients (ICC) and 95% confidence intervals (CIs) were calculated. It has been suggested that ICC values of 0.75 and greater indicate excellent reliability, 0.4–0.75 fair to good reliability, and 0.4 and less, poor reliability [19]. Continuous

variables were summarised using means and standard deviations. Normality was checked with a combination of graphs such as histograms, normal Q-Q plots and boxplots, and the Shapiro-Wilk test. Pre-and post-test differences in FFI and IFM strength were analysed with paired *t*-tests, and *p*-values less than 0.05 were considered significant. Follow up analysis (Cohen's *d*) were calculated and *d* values equal or less than 0.2 were considered to have small, 0.5 medium and 0.8 large effect size (ES) [20].

Results

Participants

Twelve participants met the eligibility criteria of completing the six-week toe-walking program and attended their pre-test and post-test assessments.

Compliance

Participant self-reported compliance was 32-days(4.9) out of a maximum 42-days (6-weeks) (76.2%) (Table 1).

Table 1
Study Group Characteristics

	Mean (Standard Deviation)					
Symptomatic Foot (L:R)	Gender (M:F)	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m ²)	
(<i>n</i> =12)	5:7	3: 9	45.7 (± 10.0)	171.4 (± 7.4)	74.1 (± 12.0)	25.1 (± 4.8)
L = left, R = right, M = male, F = female, yrs = years, cm = centimetres, kg = kilograms						

Primary Outcome

Foot Function Index (FFI)

There was a significant decrease in FFI scores at the six-week completion mark with mean scores reducing by 29.9 points 95% CI [8.7, 51.2] (*p* = 0.01) (Table 2). Eight participants (66.7%) had a significant decrease in symptoms (> 7 point FFI score reduction), three participants (25%) symptoms worsened (> 7 point FFI score increase) and one participant (8.3%) had no detectable change (≤ 7 point change).

Secondary Outcome

The asymptomatic foot pre-test HHD measures were used to establish intra-rater reliability of the Commander hand-held dynamometer to assess IFM muscle strength. Intra-rater reliability was found to

be excellent for both hallux (great toe) flexion (ICC: 0.89; 95% CI [0.72, 0.97]) and digits 2–4 (lesser toes) flexion (ICC: 0.92; 95% CI [0.79, 0.97]).

No significant difference was found between the participants’ “asymptomatic” and “symptomatic” IFM strength measures pre-test and post-test (Table 2).

Table 2
Asymptomatic-foot/symptomatic-foot IFM strength measures

Measure: Group(s) (<i>n</i> = 12)	Difference	<i>t</i> -value	<i>p</i> -value
Pre great toe: Asymptomatic Vs Symptomatic	-0.1 (± 7.3)	0.051	0.960
Pre lesser toes: Asymptomatic Vs Symptomatic	-0.2 (± 6.6)	0.083	0.935
Post great toe: Asymptomatic Vs Symptomatic	-1.6 (± 7.2)	0.772	0.457
Post lesser toes: Asymptomatic Vs Symptomatic	-0.3 (± 6.3)	0.185	0.857
* <i>p</i> -value < 0.05 is considered significant			

Both (great toe flexion and lesser toe flexion) strength measures improved significantly at the completion of the six-week toe-walking protocol (Table 3).

Table 3
Pre-test/post-test IFM strength changes

Group: Measure (<i>n</i> = 12)	Force (Newtons)			<i>t</i> -value	<i>p</i> -value
	Pre	Post	Difference		
Asymptomatic great toe	21.9 (± 6.7)	31.3 (± 8.9)	9.3 (± 9.5)	3.387	0.006*
Symptomatic great toe	21.8 (± 6.2)	29.6 (± 9.6)	7.8 (± 10.3)	2.627	0.024*
Asymptomatic lesser toes	21.6 (± 5.8)	28.4 (± 9.9)	6.8 (± 9.6)	2.432	0.033*
Symptomatic lesser toes	21.4 (± 5.6)	28.0 (± 8.6)	6.6 (± 7.5)	3.018	0.012*
* <i>p</i> -value < 0.05 is considered significant					

Discussion

The results of this study show a 29.9-point reduction in FFI scores at six-weeks, a significant reduction in treatment time compared to the 13 weeks reported in Rathleff et al[12] to achieve a 29-point reduction in FFI scores.

The strengthening approach described in Rathleff et al. [12], consisted of a progressive single leg heel raise protocol, with toes dorsiflexed under a towel. The protocol progressed at two weeks to a backpack

filled with books for 4 sets of 10 repetitions, then at 4 weeks to the maximum prescription of 5 sets of 8 repetitions and was completed on alternate days throughout.

In comparison, despite the absence of external weight, in terms of progressive loading principles the toe walking protocol can be seen as quite aggressive. It is repeated every day and is conducted whilst weight bearing. Even at day one of toe walking the plantar aponeurosis on each foot is exposed to this repeated load between 30–40 times. There still remains conjecture whether these loading protocols could be considered high-load, however in comparison to traditional strength training interventions for plantar fasciopathy such as short foot exercises[21, 22] they do signify a move towards increasing plantar aponeurosis loading.

Despite this study suggesting that a toe-walking protocol produces faster reductions in FFI scores than the Rathleff et al.[12] protocol, it must be acknowledged that there were the following shortcomings in the research design and the results should be interpreted with caution. These include the small sample size, mismatched gender split, participants withdrawing possibly to worsening symptoms and the lack of a true non-interventional study control group.

A limitation regarding the toe-walking intervention is that it requires good levels of proprioception and balance to safely perform. Therefore, it may be unsuitable for elderly populations or those with co-ordination issues. For safety reasons, these populations were screened out with the initial inclusion/exclusion criteria. Due to the toe-walking requiring some skill acquisition, this study was limited by not having a mid-point review to assess participant's technique. It was suspected upon re-examination of participant's toe-walking techniques at their completion assessments, that the participants whose condition worsened were performing the technique incorrectly. These participants were characterised by excessive plantar-flexion, and a greater than 2cm calcaneal elevation causing them to bounce up and down performing the intervention and resulting in increased concentric-eccentric trauma on the fascia.

There is limited research on the use of the HHD in assessing IFM strength. Soysa et al. [23], reported that toe dynamometry has consistently demonstrated excellent intra-rater reliability, with ICC values greater than 0.83. However, Spink et al. [24], is the only other study to look at the intra-rater reliability of a HHD for assessing IFM strength. There are two main differences between the Soysa et al.[23] and Spink et al.[24] studies, namely, the type of hand-held dynamometer used (Commander HHD vs CIT Technics, Haren, The Netherlands HHD, respectively) and the number of lesser toes involved in the assessment (2–4 and 2–5, respectively). This latter difference was attributed to toe deformities and the smaller force plate size of the Commander HHD. The findings of Spink et al. [24], are consistent with this study for HHD toe flexion strength measures having excellent intra-rater reliability with all ICC values above 0.78. However, evaluating the validity of a device such as the HDD to assess IFM strength is challenging. It is difficult to isolate the IFM from the extrinsic foot muscles in any position due to their tendon insertions being in close proximity. Until it is assured that IFM is being assessed in isolation, it can only be assumed as an estimate of IFM strength through toe flexion at the MTP. It should also be acknowledged that the

between-day reliability of the Commander HDD to measure intrinsic foot muscle strength was not assessed.

Latey et al.[11] proposed that there is a significant association between IFM weakness and painful foot pathologies such as plantar heel pain. This was supported by Cheung et al. [25], who found that runners with chronic plantar heel pain have smaller intrinsic foot muscle volume than their healthy counterparts. Similarly, Sullivan et al.[26] when comparing musculoskeletal and activity-related variables in participants with PHP ($n = 202$) and asymptomatic controls ($n = 70$), identified significant reductions in strength in both great and lesser toe flexion in the PHP cohort. The findings of this research showed the toe-walking intervention significantly improved IFM strength measures with pre-test/post-test comparative analysis of the participant's asymptomatic and symptomatic foot showing no significant difference in IFM strength measures.

General adaptation syndrome (GAS) provides potential explanation for the distribution of the results [27], particularly, when taking into account the third of participants whose symptoms worsened or were unchanged. GAS asserts that a bodily system will adapt with increased function when faced with a stress to which it is not accustomed. It describes a three-stage process in which a system responds to a new stimulus. Firstly, the "alarm phase" when it is introduced, then the "resistance phase" characterised by adaptations occurring in the system to meet the demands of the stimulus, and thirdly if the stimulus is too strong or presented too long, "the exhaustion phase" is reached where adaptations plateau [28]. Given the chronic nature of PHP and with the possibility of participants still being in the "alarm stage" at the study's conclusion GAS presents a strong case for the need for a study of longer duration.

While there is evolutionary evidence that the IFM develop in response to the increased demands of load carriage and running [29], it remains questionable whether a six-week toe-walking program allows sufficient time to elicit an IFM hypertrophic response. It has been found that increases in muscular strength during the initial periods of a resistance training program are not associated with changes in cross-sectional area of the muscle [30], but with neural adaptations [31]. Hence, a "desensitisation" or an altered "central pain processing" [32], consistent with contemporary research investigating corticospinal excitability and short interval cortical inhibition in tendinopathy[33] may offer a plausible explanation for the plantar heel pain sufferer's reduced pain levels following six-weeks of the toe-walking intervention.

Conclusion

The findings of this study make an encouraging suggestion that plantar heel pain sufferers' symptoms may be reduced by a progressive loading toe-walking program. Results however, should be interpreted with caution due to flaws in the study design including the lack of a non-interventional control group.

HDD was found to have excellent intra-rater reliability as outcome measure to clinically assess intrinsic foot muscle change. However, the between-day reliability was not assessed and the validity of the measure, particularly regarding the influence of the extrinsic foot muscles is questionable.

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js a future level II randomised controlled trial to

assess the effectiveness of toe-walking. Further, it is recommended that future research aim to investigate, with imaging, structural changes occurring within the plantar aponeurosis and the IFM in response to toe-walking.

Finally, it should be emphasised that plantar heel pain is a debilitating condition, and, despite an identified reduction in participants' symptoms, no one was completely pain-free at the six-week mark. Therefore, a longer duration study is required to monitor the long-term effectiveness of this intervention.

Declarations

Ethics Approval and Consent to Participate - Prior to commencement the study was approved by Bond University Ethics Committee (BUHREC Protocol No. 1908), and written informed consent was obtained from all participants.

Consent for Publication – Not Applicable.

Availability of Data and Materials - The datasets during and/or analysed during this study are available from Bond University on reasonable request.

Competing Interests – The authors declare that they have no competing interests.

Funding – All equipment was supplied by Bond University. No funding expenses were involved.

Authors Contributions - DH – Lead author/researcher, Study convener + data collection. WH – Academic supervisor, Co-author. JC – Co-author. RH – Toe-walking protocol developer/ Preliminary toe-walking/HHD research. MC – Preliminary toe-walking/HHD research. EFDC – Statistical analysis

Acknowledgements – Not Applicable

References

1. Young C. Plantar fasciitis. *Annals of internal medicine*. 2012;156(1 Pt 1).
2. Thing J, Maruthappu M, Rogers J. Diagnosis and management of plantar fasciitis in primary care. *The British Journal of General Practice*. 2012;62(601):443–4.
3. McPoil TG, Martin RL, Cornwall MW, Wukich DK, Irrgang JJ, Godges JJ. Heel Pain—Plantar Fasciitis *Journal of Orthopaedic Sports Physical Therapy*. 2008;38(4):A1–18.
4. Schwartz EN, Su J. Plantar Fasciitis: A Concise Review. *The Permanente Journal*. 2014;18(1):e105–e7.
5. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: a matched case-control study. *The Journal of bone and joint surgery American volume*. 2003;85-a(5):872–7.
6. Riel H, Cotchett M, Delahunt E, Rathleff MS, Vicenzino B, Weir A, Landorf KB. Is 'plantar heel pain' a
Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js o move on. *Br J Sports Med*. 2017;51(22):1576–

- 7.
7. Brukner P, Khan K Brukner & Khan's Clinical Sports Medicine 4th Edition. McGraw-Hill Australia Pty Ltd; 2012:844–851.
8. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. *Br J Sports Med.* 2004;38(1):8–11. discussion.
9. Jensen K, Di Fabio RP. Evaluation of eccentric exercise in treatment of patellar tendinitis. *Physical therapy.* 1989;69(3):211–6.
10. Huffer D, Hing W, Newton R, Clair M. Strength training for plantar fasciitis and the intrinsic foot musculature: A systematic review. *Phys Ther Sport.* 2017;24:44–52.
11. Latey PJ, Burns J, Hiller C, Nightingale EJ. Relationship between intrinsic foot muscle weakness and pain: a systematic review. *Journal of Foot Ankle Research.* 2014;7(Suppl 1):A51-A.
12. Rathleff MS, Molgaard CM, Fredberg U, Kaalund S, Andersen KB, Jensen TT, Aaskov S, Olesen JL. High-load strength training improves outcome in patients with plantar fasciitis: A randomized controlled trial with 12-month follow-up. *Scand J Med Sci Sport.* 2015;25(3):e292–300.
13. Riel H, Vicenzino B, Jensen MB, Olesen JL, Holden S, Rathleff MS. The effect of isometric exercise on pain in individuals with plantar fasciopathy: A randomized crossover trial. *Scandinavian Journal of Medicine Sports Science.* 2018;28:2643–50.
14. Chimutengwende-Gordon M, O'Donnell P, Singh D. Magnetic resonance imaging in plantar heel pain. *Foot Ankle Int.* 2010;31(10):865–70.
15. Fazal MA, Tsekas D, Baloch I. Is There a Role for MRI in Plantar Heel Pain. *Foot ankle specialist.* 2018;11(3):242–5.
16. Budiman-Mak E, Conrad KJ, Roach KE. The foot function index: a measure of foot pain and disability. *J Clin Epidemiol.* 1991;44(6):561–70.
17. Landorf KB, Radford JA. Minimal important difference: Values for the Foot Health Status Questionnaire, Foot Function Index and Visual Analogue Scale. *The Foot.* 2008;18(1):15–9.
18. Wang CY, Olson SL, Protas EJ. Test-retest strength reliability: hand-held dynamometry in community-dwelling elderly fallers. *Arch Phys Med Rehabil.* 2002;83(6):811–5.
19. Fleiss JL. *The design and analysis of clinical experiments.* New York: Wiley; 1986. 1–31 p.
20. Allen P, Bennett K, Heritage B. *SPSS statistics version 22: a practical guide.* 3rd edition. South Melbourne, VIC.: Cengage Learning Australia; 2014:68 – 9.
21. Lynn SK, Padilla RA, Tsang KK. Differences in static- and dynamic-balance task performance after 4 weeks of intrinsic-foot-muscle training: the short-foot exercise versus the towel-curl exercise. *Journal of sport rehabilitation.* 2012;21(4):327–33.
22. Mulligan EP, Cook PG. Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Manual Therapy.* 2013;18(5):425–30.

23. Soysa A, Hiller C, Refshaug K, Burns J. Importance and challenges of measuring intrinsic foot muscle strength. *Journal of Foot Ankle Research*. 2012;5(1):29.
24. Spink MJ, Fotoohabadi MR, Menz HB. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. *Gerontology*. 2010;56(6):525–32.
25. Cheung RT, Sze LK, Mok NW, Ng GY. Intrinsic foot muscle volume in experienced runners with and without chronic plantar fasciitis. *Journal of science medicine in sport*. 2016;19(9):713–5.
26. Sullivan J, Burns J, Adams R, Pappas E, Crosbie J. Musculoskeletal and activity-related factors associated with plantar heel pain. *Foot Ankle International*. 2014;36(1):37–45.
27. Selye H. The general adaptation syndrome and the diseases of adaptation. *The Journal of Clinical Endocrinology*. 1946;6(2):117–230.
28. Rhea MR, Alvar BA, Ball SD, Burkett LN. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *Journal of strength conditioning research*. 2002;16(4):525–9.
29. Bennett MR, Harris JWK, Richmond BG, Braun DR, Mbua E, Kiura P, Olago D, Kibunjia M, Omuombo C, Behrensmeyer AK, Huddart D, Gonzalez S. Early hominin foot morphology based on 1.5-million-year-old footprints from Ileret, Kenya. *Science*. 2009;323(5918):1197–201.
30. Sale DG. Neural adaptation to resistance training. *Med Sci sports Exerc*. 1988;20(5 Suppl):135-45.
31. Moritani T, deVries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. *American journal of physical medicine*. 1979;58(3):115–30.
32. Tompra N, van Dieen JH, Coppieters MW. Central pain processing is altered in people with Achilles tendinopathy. *Br J Sports Med*. 2016;50(16):1004–7.
33. Rio E, Kidgell D, Moseley GL, Gaida J, Docking S, Purdam C, Cook J. Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a narrative review. *Br J Sports Med*. 2016;50(4):209–15.

Figures

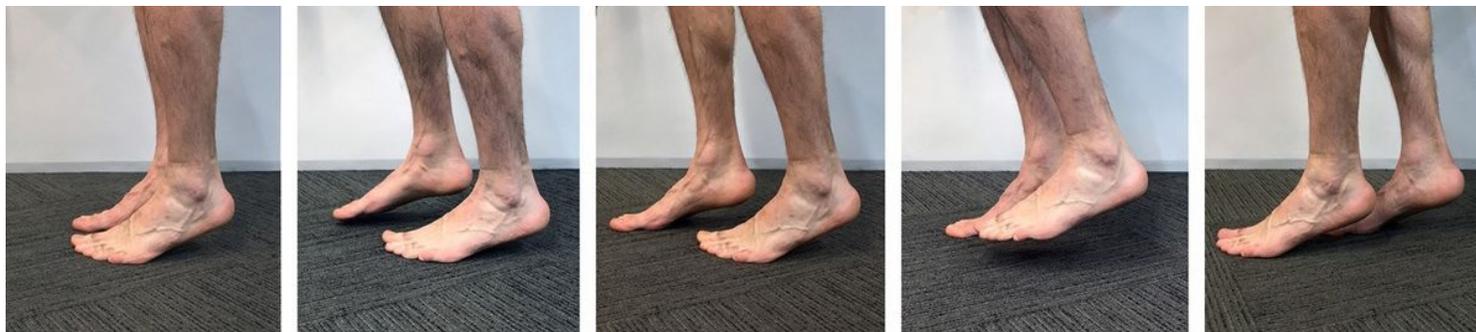


Figure 1

Toe walking gait



Figure 2

Commander hand-held dynamometer to measure intrinsic foot muscle strength (Left to Right) 2.1: Assessment set-up. 2.2: HHD plate placement to measure hallux (great toe) flexion strength 2.3: HHD plate placement to measure lesser toes (2-4) strength.

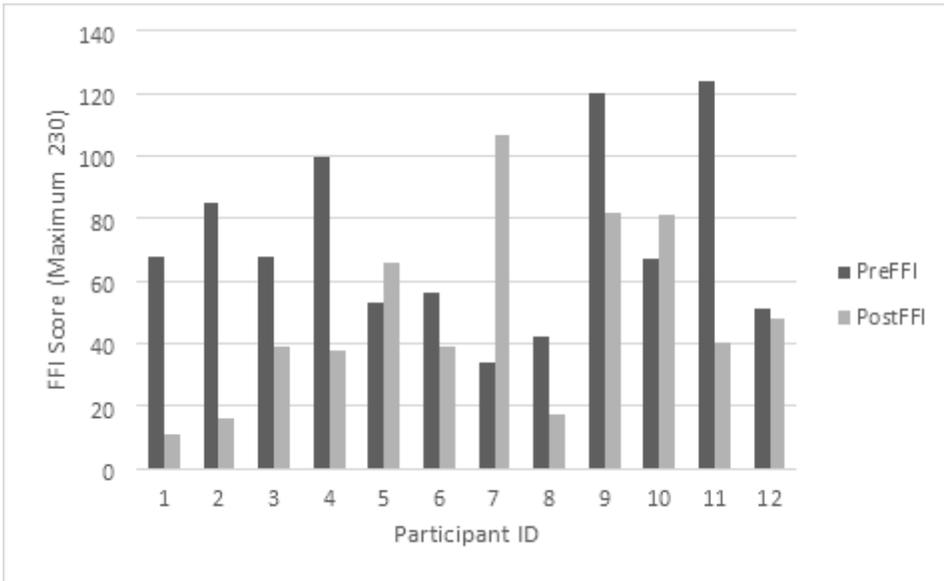


Figure 3

Pre-test/post-test FFI Scores