Effect of a Toe-Walking Protocol in Plantar Heel Pain: A Proof of Concept

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Abstract

Background: 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 symptoms in subjects with PHP

Methods: A within-subjects experimental design assessed foot function, foot pain, disability, and activity limitation in 12 subjects with PHP prior to and at the end of a six-week toe-walking program. The primary outcome measure was the Foot Function Index (FFI). IFM strength (both hallux flexion and lesser toe flexion) was measured as a secondary outcome.

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 increases from 21.8N to 29.6N (+7.8N) 95%CI [1.3, 14.4] ($p=0.024$, $ES=1.0$) and from 21.4N to 28.4N (+6.6N) 95%CI [1.8, 11.4] ($p=0.010$, $ES=0.9$), respectively.

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

Trial registration: Bond University Ethics Committee (BUHREC Protocol No. 1908)

Key Messages Regarding Feasibility

1. What uncertainties existed regarding the feasibility? Potential difficulties recruiting participants that fulfilled the eligibility criteria, participant adherence to protocol, and ability to perform correct technique.
2. What are the key feasibility findings? The need to recruit a far higher number of participants (only 12 of the original 34 recruits completed the study).
3. What are the implications of the feasibility findings for the design of the main study? The feasibility findings highlight the need for a 'control group', significantly greater participant recruitment and a mid-way review point to ensure participants are performing intervention correctly.

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 persons' ability to weight bear.

PHP is thought to resemble other 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] and Cheung et al. [12] documented a link between intrinsic foot muscle weakness and painful foot pathologies such as plantar heel pain. Furthermore, Kelly et al [13] demonstrated the importance of the IFM in contributing to foot arch posture, in activities such as walking.

Rathleff et al. [14] was the first RCT to support high load strength training in the management of PHP, concluding that over a 12-week period, 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. [15] 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]. The rationale being that toe walking is a barefoot intervention that loads the IFM isometrically with the great toe extended.

This study's aim is to address whether this clinically utilised, but not researched, approach of progressively loading the plantar fascia strengthens the IFM and reduces PHP sufferers' symptoms over a six-week period.

Methods

Participants

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

Eligibility criteria were stipulated in these advertisements as:

- Men and women aged between 18 and 60-years of age
- Proficient in English
- Not currently receiving treatment for a lower limb pathology including plantar heel pain
- *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
- Experiencing unilateral heel pain

The maximum age was set at 60 years, as toe walking intervention requires good levels of proprioception and balance to safely perform.

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, 7]. 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 a physiotherapist (DH) against the advertised plantar heel pain sufferer eligibility criteria. 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[16] and the key is careful clinical assessment [17].

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 (9 items), (ii) disability (9 items), and (iii) activity limitation (5 items). Total scoring ranges from 0 to 230, with 0 reflecting no pain, disability, or activity limitations [18]. The minimal important change is 7-points for the total scale [19]. The FFI was chosen for its good reliability and validity, and widespread usage by clinicians and research scientists [20].

Secondary Outcome

Handheld Dynamometry (HHD)

Intrinsic Foot Musculature (IFM) strength was measured isometrically by a physiotherapist (DH) 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. IFM was

measured with hand-held dynamometer for both 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 [21] .

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 1).

At the completion of the six-weeks, intrinsic foot muscle strength re-tested using the same manner as the initial assessment.

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 2).

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. Participants completed their day one (first minute) of toe-walking, with the examiner providing cues until they were performing the technique to the examiner's satisfaction. They were then provided with a home exercise completion record to track their adherence. This included 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 were placed on participants activities of daily living.

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 [22]. 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) [23].

Results

Participants

Twelve participants completed the six-week toe-walking program and attended their pre-test and post-test assessments (Figure 3). Study group characteristics are summarised in Table 1.

Table 1: Study Group Characteristics

		Mean (Standard Deviation)				
Symptomatic Foot		Gender	Age	Height	Weight	BMI
(L:R)		(M:F)	(yrs)	(cm)	(kg)	(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

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

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) (Figure 4).

Table 2 - Pre-test/post-test FFI Scores

Pre	Post	Mean Difference [95% CI]	<i>t</i> -value	<i>df</i>	<i>p</i> -value	<i>ES</i>
73.2 (32.4)	43.3 (22.8)	29.9 [8.7, 51.2]	3.10	11	0.010*	1.1

Data displayed as mean (SD). CI = confidence interval, *df*= degrees of freedom, *ES* = effect size

* Significant $p < 0.05$

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 3).

Table 3
Asymptomatic-foot/symptomatic-foot IFM strength measures

Group(s)	Mean Difference [95% CI]	<i>t</i> -value	<i>df</i>	<i>p</i> -value	<i>ES</i>
Pre great toe: Asymptomatic Vs Symptomatic	-0.1 [-4.8, 4.6]	0.05	11	0.960	0.02
Pre lesser toes: Asymptomatic Vs Symptomatic	-0.2 [-4.4, 4.0]	0.08	11	0.935	0.03
Post great toe: Asymptomatic Vs Symptomatic	-1.6 [-6.2, 3.0]	0.77	11	0.457	0.17
Post lesser toes: Asymptomatic Vs Symptomatic	-0.3 [-4.3, 3.6]	0.19	11	0.857	0.04
Negative values indicate that values for asymptomatic toe(s) were greater than those of symptomatic toe(s). CI = confidence interval, <i>df</i> = degrees of freedom, <i>ES</i> = effect size * Significant $p < 0.05$					

Table 4
– Pre-test/post-test IFM strength changes

Force (N)							
Group(s)	Pre	Post	Mean Difference [95% CI]	<i>t</i> -value	<i>df</i>	<i>p</i> -value	<i>ES</i>
Asymptomatic great toe	21.9 (6.7)	31.3 (8.9)	9.3 [3.4, 15.4]	3.39	11	0.006*	1.2
Symptomatic great toe			7.8 [1.3, 14.4]	2.63	11	0.024*	1.0
Asymptomatic lesser toes	21.8 (6.2)	29.6 (9.6)	6.8 [0.6, 12.9]	2.43	11	0.033*	0.9
Symptomatic lesser toes	21.6 (5.8)	28.4 (9.9)	6.6 [1.8, 11.4]	3.02	11	0.012*	0.9
	21.4 (5.6)	28.0 (8.6)					
Data displayed as mean (SD). N = Newtons, CI = confidence interval, <i>df</i> = degrees of freedom <i>ES</i> = effect size * Significant $p < 0.05$							

Both (great toe flexion and lesser toe flexion) strength measures improved significantly at the completion of the six-week toe-walking protocol (Table 4).

Discussion

The results of this study show a 29.9-point reduction in FFI scores at six-weeks and significantly improved IFM strength measures for both the participant's asymptomatic and symptomatic foot.

The rapid reduction in FFI may be explained by the aggressive nature of the toe walking protocol when compared to studies such that by Rathleff et al [14]. 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[24, 25] they do signify a move towards more intense loading of the foot.

As regards to IFM strength, 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 [26], but with neural adaptations [27].

Hence, a “desensitisation” or an altered “central pain processing” [28], consistent with contemporary research investigating corticospinal excitability and short interval cortical inhibition in tendinopathy [29] may offer a plausible explanation for increased IFM strength and reduced pain levels following six-weeks of the toe-walking intervention.

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, lack of recording adverse effects or reasons for withdrawing from the study, and the lack of a true non-interventional study control group.

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.

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. This proof of concept study has laid foundations for 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.

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

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Figures

Figure 1

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 2

Figure 3

Flow of Participants

Figure 4

Pre-test/post-test FFI Scores

Supplementary Files

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