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The effects of a 4-week barefoot exercise intervention on plantar pressure, impact, balance and pain in injured recreational runners: A pilot study

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ABSTRACT

Background: With recreational running's continued popularity and incidence of lower extremity injuries increasing, it is important from an osteopathic practitioner perspective, to be aware of treatment/interventions that may enhance recovery or prevent injury. With an osteopathic lens we postulate that improving function leads to symptomatic benefit in not only structure but throughout the kinetic chain.

Objectives: The present study aimed to assess the effects of a 4-week barefoot (BF) training intervention on; visual analog scale (VAS) pain scores, postural sway, plantar pressure, stride and foot impact.

Methods: In this parallel design study, eight recreational runners were recruited and blindly randomised to a control (CO) (1 M & 2F; aged 28.0 ± 12.1 years; weight 63.3 ± 11.6 kgs) or intervention (I) (4 M & 1F; aged 33.4 ± 9.3 years; weight 69.8 ± 7.6 kgs).

Results: No significant differences in plantar pressure or stride pre- or post-intervention for CO or I group. However, there were significant reductions in the intervention group for VAS walk (pre:mdn = 3 (IQR = 3.0–5.5; post:mdn = 1.5 (IQR = 1.0–4.0) and run (pre:mdn = 6 (IQR = 4.5–7.5; post:mdn = 2.0 (IQR = 1.5–5.0). Also, for medial-lateral eyes open sway condition for both left (pre:mdn = 2.94 (IQR = 2.54–5.42; post:mdn = 2.26 (IQR = 2.05–3.18) and right leg (pre:mdn = 3.55 (IQR = 2.79–4.32; post:mdn = 2.71 (IQR = 2.26–3.34). Finally, a significant decrease in rear-foot strike impulse (pre:mdn = 4.66 (IQR = 3.01–5.14; post:mdn = 2.66 (IQR = 1.81–3.54).

Conclusion: The present study assesses short-term balance and impact changes through a BF intervention. It is entirely probable plantar cutaneous mechanoreceptor activity has increased leading to peripheral and centrally mediated improvement in balance through reduction in sway. The reductions in impact outline the neuro-biomechanical relationship and importance of plantar sensitivity. For injuries where either factor is at play, BF activity may have clinical benefits.

Introduction

Recreational running is one of the most popular sports worldwide and recent data suggests around 8–12% regularly participate in running as a form of physical activity [1,2]. However, alongside increased participation we see a high incidence of lower extremity running injuries ranging from 19 to 79% [3,4] with the knee as the most common (32.5%) followed by the foot/ankle (25.3%) [5]. Therefore, it is crucial to understand the mechanisms underlying these injuries and to explore interventions and training that may enhance recovery and prevent future injury.

Hreljac [6] acknowledges that in sports-related injuries, the principal mechanism is mechanical loading, and a single load that exceeds maximum strength or cumulative overload (with insufficient recovery time) sets the stage for an acute rupture. According to Hreljac [6] during the stance phase of the running gait cycle, the runner experiences two peaks of force; the impact peak and the active peak. The impact peak occurs within the first 10% of the stance phase and has most often been blamed in overuse injuries due to the high frequency component. The second active peak takes place over the latter 60–75% of the stance phase at a lower frequency of around 200 m/s [6] and represents the movement of the runner during the stance phase. This low frequency component of ground reaction forces (GRF) typically creates injuries that are aetiologically connected to over pronation syndromes including; patellofemoral pain and shin splints [7,8].

So, it seems running is most injurious at the impact peak, the moment the foot collides with the ground and this collision can occur in three different ways; i). Firstly, the rear-foot strike (RFS) where the heel

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lands first; ii). A mid-foot strike (MFS), in which the heel and ball of the foot land simultaneously; and finally, iii). A fore-foot strike (FFS) in which the ball of the foot lands before the heel comes down.

A number of studies have investigated these foot strike patterns and in shod runners we see 75% RFS, 24% MFS and 1% FFS [9,10]. Other work has investigated types of runners and foot strike showing 80% of endurance runners use a RFS and sprinters predominantly using a FFS [11] and barefoot running is associated with FFS and MFS [9,11].

To try to understand this further, Lieberman and colleagues [9] examined the running gait of healthy habitually barefoot versus shod runners. They demonstrated that RFS generate higher impact peaks compared to FFS, where with similar speeds, magnitudes of peak vertical force at stance phase are three times higher in shod runners who habitually RFS compared to BF who habitually FFS.

More recent work by Perl and colleagues [12] supports Lieberman and colleagues [9] indicating that endurance runners with FFS are less susceptible to repetitive stress injuries (RSIs) than those who use a RFS. It seems RFS runners cope with a collision force of approximately 1.5–3 times body weight within the first 50 ms of stance. Impact transients associated with RFS running are sudden forces with high rates and magnitudes of loading that travel rapidly up the body and thus may contribute to the high incidence of running related injuries, especially tibial stress fractures and plantar fasciitis [3].

Therefore, a FFS seems to support less impact and susceptibility to RSIs and is common in barefoot running, these differences are the result of a more plantar-flexed foot at landing and more ankle compliance during impact, which inadvertently decreases the mass of body impacting the ground. This could indicate beneficial effects of barefoot running or training, so a number of studies have investigated differences in barefoot vs shod runners. Work by Squadrone and Gallozi [13] clearly supports the benefits of BF running, demonstrating increased plantar flexion at contact, shorter stride length and contact times with BF vs shod runners.

The cutaneous neurology of the foot may pre-empt the above biomechanical changes in relation to impact and balance. The aforementioned diminutive GRFs with BF running may be neurologically mediated due to an increase in foot surface sensory feedback allowing conscious and subconscious force attenuation [14]. They have proposed injuries to the lower limb to be of a “pseudo-neuropathic” origin where the runner damages their lower extremities due to a lack of somatosensory feedback as a result of excessive shoe cushioning.

Alongside this, research by Robbins and Waked [15] has outlined the strong association between balance and vertical impact suggesting that increased foot – ground interfaces may attenuate the proprioceptive function of the foot. It also seems tactile sensitivity within the foot has a strong influence on the maintenance of postural stability as evidenced by a loss of this input in diabetic neuropathy [16]. Kavounoudias and colleagues [17] suggest the sole of the foot acts as a “dynamometric map“, whereby cutaneous afferents from the main supporting zones of the feet have sufficient spatial relevance to inform the CNS about the body's position.

The studies discussed here report favourable findings regarding health and biomechanical benefits associated with barefoot running. From an osteopathic perspective we consider form and function to be reciprocally interrelated. If we review the basic anatomy of the foot, it suggests its role as a spring-like shock absorber in the bipedal human and this may be somewhat misunderstood in modern life with an over reliance on heavily cushioned footwear. The muscles which have been shown to give the foot arch its characteristic spring-like properties can be remodelled if appropriately activated. Therefore, this has great relevance for clinicians and osteopaths, particularly those working in sport or running. Muscular activation and heightened sensory feedback from BF activity may attenuate joint forces and reduce the aetiology of a number of running related lower limb injuries.

To date, there are no reported studies of barefoot interventions on individuals carrying chronic/overuse injuries. Therefore, the aims of the present study are to investigate the effect of a 4-week barefoot exercise intervention observing pre- and post-intervention changes in plantar pressure, impact, balance, pain and stiffness levels.

To achieve the aims of the study the experimental set up observed changes in symptoms pre- and post-intervention. Subjective measures of pain and stiffness were recorded pre- and post-intervention. Alongside these objective measures of balance, impact and plantar pressure were recorded pre- and post-intervention.

Methods

Subjects

The study was a parallel design study with an intervention (I) and control (CO) group conducted over a 4-week period with an initial convenience sample of 14 athletes identified, from University and a local triathlon club. The pre-screening tool identified suitable participants for inclusion in the study, with on-going chronic injuries ranging from iliotibial band friction syndrome to calcaneal tendinopathy. Data collection took place at the University laboratories, baseline measures were made on same day the subject was allocated to either the control or intervention group. They were all instructed to start their 4-week program the following day. At the conclusion of the 4-weeks they came back to the lab for post-testing the day after they completed the full 4-weeks.

A total of 14 subjects were screened for eligibility and 10 of these met eligibility criteria (Fig. 2). These 10 underwent baseline pre-intervention measures and then were randomly allocated to either the intervention or control group. Randomisation was carried out by the principal supervisor, the numbers 1 or 2 were written on slips of paper and folded up. Participants drew a number and were allocated to either the control (1) or intervention (2) group. After randomisation, two individuals dropped out of the study (both of these were allocated to the control group), both withdrew as they were unable to comply with the study protocol, leaving eight subjects in total.

Key Inclusion Criteria: A 15-day old minimum lower limb injury, distal to the sacroiliac joint and developed through overuse or sports activity. Participants are required to be currently running at least twice per week for duration of 20 min or more per session.

Key Exclusion Criteria: Suffering from any peripheral neuropathies, including diabetes; currently undergoing/planning to undergo medical or manual therapy treatment.

Prior to participation in the study, subjects were informed of the benefits and risk of the investigation and the testing procedures were explained in detail. After this information was given participants completed a general health questionnaire and signed an informed consent form. Oxford Brookes University Research Ethics Committee granted ethical approval. All procedures were carried out in accordance with the declaration of Helsinki.

The study commenced with eight individuals; five (4 M & 1 F) in intervention (I) group, aged 33.4 ± 19.3 years; weight 69.8 ± 7.6 kgs; and three (1 M & 2 F) in control (CO)) group aged 28.0 ± 12.1 years; weight 63.3 ± 11.6 kgs; running range per week 2–13 h. See full demographic data for the participants in Table 1.

Pre- and post-intervention measures

To achieve the aims of the study the experimental set up observed changes in symptoms pre- and post-intervention. Subjective measures of pain and stiffness were recorded pre- and post-intervention. Alongside these objective measures of balance, impact and plantar pressure were recorded pre- and post-intervention. The measures are outlined below:

Pain and stiffness

The visual analog scale (VAS) was used, as it is a valid and reliable

Table 1
Demographic data of intervention and control group, including age, weight, training, injury location, date of onset and perceived cause.

Subject	Gender	Age (years)	Weight (kg)	Injury Location	Date of onset	Perceived Cause	Hours training per week
1 I*	F	38	58.0	L.ankle/L.hip	2 years	Yoga & running	7
2 I	M	21	72.5	L.knee	4 mths	Increase in volume of running	13
3 I	M	47	75	R.knee (ITB syndrome)	7 mths	Running	6
4 I	M	21	69	L.ankle/L.tibia	2.5 years	Increase in running	10
5 I	M	21	79	L.knee (GI MCLtear)	4.5 mths	Acute onset football	5
6 C0*	F	21	59	R.calacaneal	2 years	Football, possibly acute onset	4
7 CO	M	21	76	L.med knee	1 year	Football -traumatic incident – ball kicked tibia ext rotated on Femur	7
8 C0	F	40	78	L&R. knees	1.5 years	Unknown	2

*I = intervention group; CO = control group.

measure of chronic pain intensity [18]. Pre- and Post-intervention pain levels were recorded for rest, walking and running on the VAS (0–10). Stiffness was also recorded using the VAS scale.

Plantar pressure

Plantar pressure measurements of balance were obtained using the Tekscan Matscan system (Tekscan Inc, Boston, USA) with a 3150E floor sensor attached to the wireless Verastek cuff, which communicated with the data logger and computer. This method allowed barefoot plantar pressure changes to be captured at 440 Hz, a frequency sensitive enough to observe subtle variations in balance and sway whilst conducting specific tasks.

Balance

Two experimental conditions were established for the balance task:

A) One legged stance with eyes open on each foot for 30 s. B) One legged stance blindfolded, 30 s. Centre of pressure or sway range measurements (cm) were made in centimetres with anterior to posterior and medial to lateral sway planes of motion similar to previous studies [17,19].

Impact and plantar pressure during running

Impact and plantar pressure measurements during a shod running task required an F-Scan wireless (Tekscan Inc, Boston, USA) in-shoe plantar pressure system consisting of 2 × in-shoe flat 300E F-scan sensors (Tekscan Inc, Boston, USA) connected with 2 × standard Ethernet cables to 2 × Versatek cuffs (Tekscan Inc, Boston, USA). For plantar pressure the foot was divided into 5 key areas, hallux, lesser toes, metarsal heads, midfoot and calcaneum (Fig. 1) as per Squadrone and Gallozi [13]. All stances over the 30-s running period were averaged using a function of the F-scan pressure software (Tekscan, Boston, USA) to reveal the peak plantar pressure in N/cm^2 in each foot area.

Impulse in kg per second was recorded according to Lieberman and colleagues protocol [9]. The foot was divided into forefoot, mid-foot and rear-foot using F-scan pressure measurement software (Tekscan, Boston, USA) and the average impulse in kg/sec were calculated from 3 consecutive steps.

Stride length and contact time

Stride length and contact time was established using a low-cost video camera (Sony MHS-FS1, 6-megapixel, Sony Europe, Surrey, UK), in which subjects were filmed in the sagittal plane from pelvis to foot level over a 30-s period, the capture rate was 60 frames per second (FPS). For the purposes of this study video recording using this method was preferred, as it was easy to set-up and analyze data and a good tool for use in the field, but capture is inferior if we compare to the 'gold standard' Vicon, whereby we have capture rates of 250 FPS. The video footage was then used to determine stride length (cm) and contact time (s) using Silicon Coach video analysis software (Silicon Coach Ltd. Auckland, NZ).

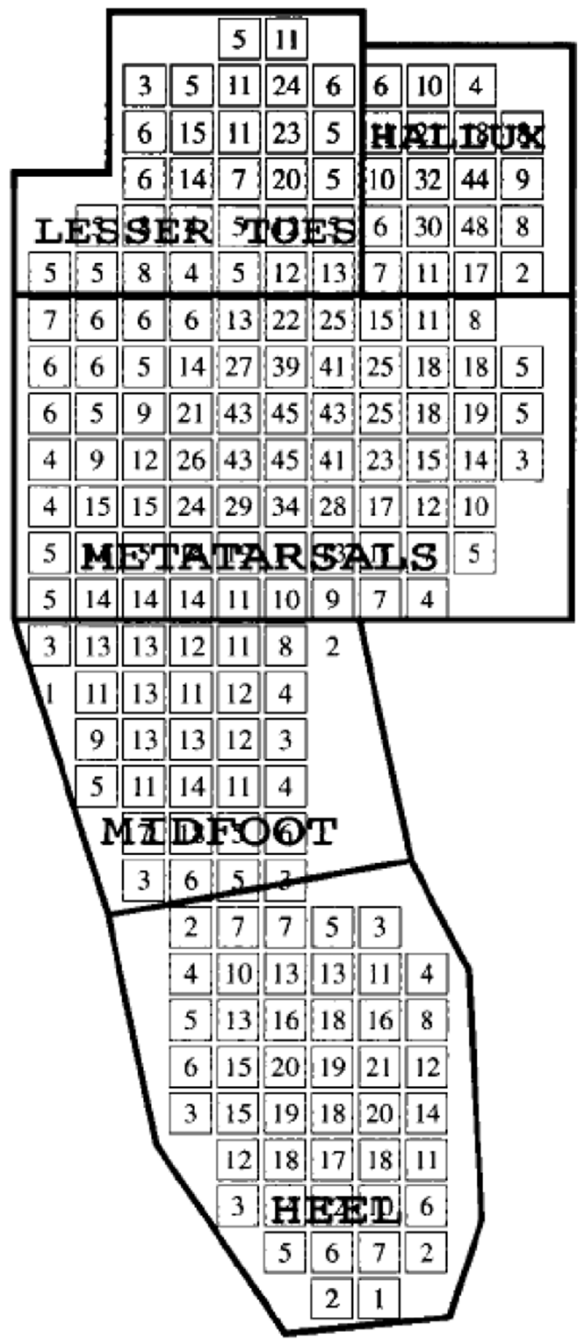

Fig. 1. Representation of the 5 plantar surface areas identified for regional analysis at the foot ground interface as per Squadrone and Galloiz [12].

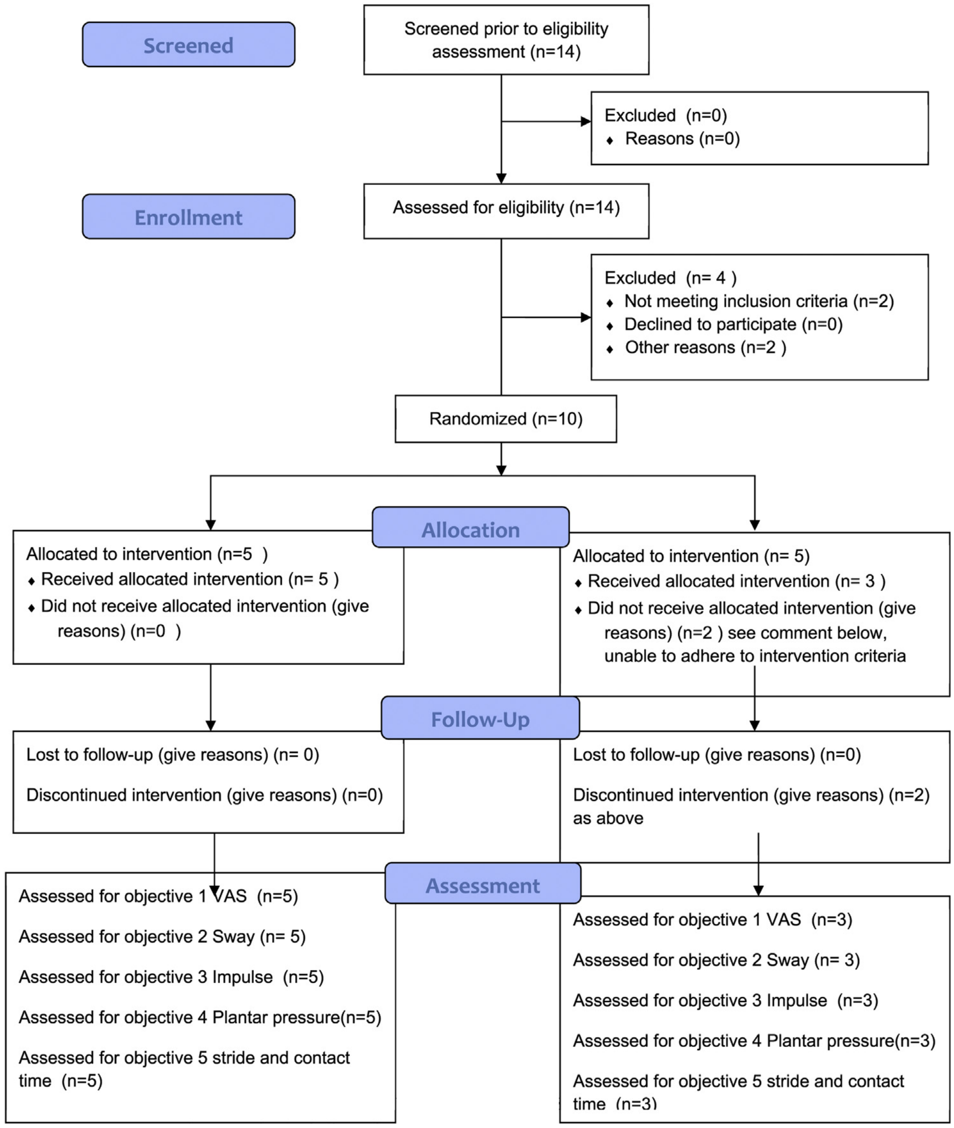

Fig. 2. CONSORT flow diagram of participant recruitment to RCT.

Intervention group. After randomisation the intervention group were given a training diary, which detailed the prescription of standardised barefoot interventions and exercises to complete a week at a time over a 4-week period. The rationale for intervention was simply that prior research as discussed in the introduction suggests that the intrinsic foot muscles could be activated and longitudinal arch height increased and that BF activity might strengthen the arch of the foot leading to control of pronation and proposed reduction in joint impact. At the end of each week participants filled out a weekly compliance chart and also recorded their pain score out of 10 to measure their relative progress.

Summary of interventions

- 30 min barefoot walking per day
- 1–2 × 30 min barefoot run per week
- Calcaneal tendon stretches 3 × 30 s per day
- 3 × 3 min of walking on balls of the feet per day
- Foot inversion/eversion/plantar flexion/dorsiflexion/toe flexion and extension. Completed daily in sets of 12
- 3 × 10 barefoot half squats 3 × week
- 1 legged barefoot balance task 2 × day

Control group

The control group were asked to continue their normal routine during the period of investigation but asked to refrain from running and not seek any forms of manual therapy during the period of investigation. Alternative activities such as cycling and swimming were recommended to the control group and all participants were expected to comply with these conditions. At the conclusion of the study the control group were offered the barefoot exercise programme.

Statistics

All raw data obtained was subject to statistical analysis using SPSS Version 19 for Mac (SPSS Inc, Chicago, IL, USA). A statistical significance level of $\alpha = 0.05$ was used. Data were assessed for normality using skewness and kurtosis values and observation of Q-Q plots. Homogeneity of variance of the data was assessed using Levene's test. The above tests indicated that non-parametric tests were required and the Wilcoxon signed rank test was applied to all data values. Data is reported as mean ± standard deviation due to small numbers and inability to report median and interquartile range (1st and 3rd) in the CO group.

Table 2
Baseline data for the Intervention and Control Groups.

Parameter	Intervention (N = 5) Mean ± SD	Control (N = 3) Mean ± SD
Age (years)	33.4 ± 19.3	28.0 ± 12.1
Weight (kg)	69.8 ± 7.6	63.3 ± 11.6
Running pain PRE (VAS 0–10)	6.0 ± 1.6	5.3 ± 4.0

Results

The final study had just 8 recreational runners (5 Male; 3 Female) carrying a recently diagnosed lower limb injury (> 15 days duration), running range per week 2–7 h. See Table 2 for baseline data.

Once randomised and baseline measures collected, the control and intervention group were tested for parity with the Wilcoxon signed rank test, which revealed no significant differences in terms of age, VAS, plantar, and impulse at baseline.

The Wilcoxon signed rank test revealed changes in VAS (pain) scores in the intervention group, with both the walk VAS ($z = -2.041$, N-ties = 5, $p = 0.041$, one tailed) and run VAS ($z = -1.769$, N-ties = 5, $p = 0.039$, one tailed), showing a significant reduction in pain post intervention (Table 3).

Sway

Observation of pre- and post-intervention balance measures (Table 4) using the Wilcoxon test, revealed significant decreases in the medial-lateral sway condition for both left ($z = 1.753$, N-ties = 5, $p = 0.040$, one tailed) and right leg ($z = 1.753$, N-ties = 5, $p = 0.040$, one tailed), in the eyes open condition in the intervention group only.

Impulse

The results for foot strike impulse in the forefoot, mid-foot and rear-foot (Table 5) revealed a statistically significant decrease in rear-foot strike impulse in the intervention group post-intervention ($z = -2.02$, N-ties = 5, $p = 0.043$, one tailed).

Plantar pressure

There were no significant differences between groups pre- and post-intervention for plantar pressure measures, stride length or contact time (Table 6).

Table 3
VAS pain and stiffness scores pre- and post-intervention.

Experimental	VAS	VAS
	Pre Mean ± SD	Post Mean ± SD
Rest	3.4 ± 2.4	2.0 ± 1.7
Walk	4.0 ± 1.7	2.3 ± 2.1*
Run	6.0 ± 1.5	3.0 ± 2.3*
Stiffness	4.4 ± 2.9	2.2 ± 1.4
Control	**VAS Pre Mean ± SD**	**VAS Post Mean ± SD**
Rest	1.3 ± 1.5	2.0 ± 2.6
Walk	4.6 ± 1.5	3.0 ± 2.0
Run	5.3 ± 4.0	3.0 ± 1.7
Stiffness	3.0 ± 1.0	2.3 ± 0.6

* Significant difference at $p < 0.05$.

Stride length and contact time

There were no significant differences between groups pre- and post-intervention for stride length and contact time (Table 7).

The participants in the intervention group did not report any side-effects from participation in the intervention program.

Discussion

This study provides preliminary evidence that a 4-week BF training program significantly reduces rear-foot impact, medial/lateral sway and pain in the intervention group post-intervention.

The significant reduction in rear-foot impact observed in this study corroborates previous studies [9,20], which have demonstrated reduced ground reaction forces at the calcaneum in BF runners. It is thought that BF activity may stimulate plantar cutaneous mechanoreceptors to evoke biomechanical adaptations [17] including a potential control of pronation, leading to a reduction in ground reaction force.

Previous studies [9,20] also observed ground reaction forces lacking in an impact transient, the reported cause of many lower limb injuries [6]. If individuals can run without an impact transient this may avoid injuries from becoming irritated, and this point may explain why the pain scores for experimental participants in the walking and running condition reduced significantly ($p = < 0.05$) over the 4-week intervention programme $p = 0.025$.

Previous explanations of these kinematic adjustments [14,21] have argued that peripheral cutaneous sensation of the BF evokes a biomechanical change to attenuate this ground reaction force. Whilst Lohmann and colleagues [20] suggest the adaptation is centrally mediated by a muscle tuning response and Zadpoor and Nikooyan [22] suggest that any changes are irrespective of the footwear worn, instead the system is moderated by speed, with a centrally stimulated dampening effect through increased stiffness of the lower limb “soft tissue package“ with increased speed.

Crucially it seems BF activity has an impact on foot-strike and it is possible the 4-week BF intervention gave increased conscious awareness of GRF on the plantar foot leading to a conscious central adaptation of lower limb kinematics.

Kinematic measures of stride length and contact time in this study showed no significant differences, which was not what we expected but this may be down to the small sample size. So while overall there was decrease in the stride length in the intervention group, we are unable to make any inferences until our sample size is increased and we see significant differences pre- and post-intervention.

The results for plantar pressure measures pre- and post-intervention results were not statistically significant, however, there are some interesting findings that we feel need to be highlighted. A decrease in plantar pressure of 11.0 N/cm^2 at the calcaneum in the intervention group from pre-to post-intervention. This finding concurs with previous studies [9,13] and suggests that a more plantar flexed fore-foot strike has been adopted potentially transferring ground reaction forces to the musculo-ligamentous structures supporting the medial longitudinal arch and the Achilles tendon/triceps surae complex. This means that the damaging forces of ground impact as reported by Hreljack [6] can be reduced by the method at which the runner strikes the ground, thus sparring injured tissues.

Interestingly COP sway changes were observed post-intervention, with significant decreases observed in left and right leg in the medial/lateral sway condition. The concept that BF activity could alter balance requires the assumption that BF activity in this study affects plantar sensitivity, this is supported by Wang and Lin [25] who found increased postural sway was related to experimentally induced loss of plantar cutaneous sensitivity, and gradually increasing the sensory loss lead to greater COP velocity and trajectory. In relevance to this investigation it would appear sensory gains with barefoot activity have led to improved

Table 4
Sway COP (cm) in eyes open and eyes closed condition in anterior-posterior (AP) and medial-lateral (ML) plane during a 30 s single-leg balance task.

Experimental	A/P (cm)	A/P (cm)	M/L (cm)	M/L (cm)
	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ± SD
Open Left	4.81 ± 3.02	4.11 ± 1.65	3.77 ± 1.77*	2.54 ± 0.59*
Closed Left	14.56 ± 7.82	10.07 ± 4.02	11.66 ± 15.67	4.77 ± 2.05
Open Right	4.06 ± 1.07	3.88 ± 1.62	3.56 ± 0.90*	2.79 ± 0.61*
Closed Right	9.74 ± 4.44	10.01 ± 5.37	4.45 ± 1.77	5.81 ± 2.53
Control	**A/P (cm) Pre Mean ± SD**	**A/P (cm) Post Mean ± SD**	**M/L (cm) Pre Mean ± SD**	**M/L (cm) Post Mean ± SD**
Open Left	3.55 ± 0.25	5.31 ± 1.31	2.50 ± 0.67	2.95 ± 0.42
Closed Left	6.24 ± 2.06	6.87 ± 1.26	5.13 ± 1.99	3.77 ± 0.60
Open Right	3.27 ± 0.14	3.84 ± 0.69	1.90 ± 0.63	2.06 ± 0.75
Closed Right	6.61 ± 1.82	6.35 ± 1.12	3.54 ± 0.25	3.55 ± 0.52

* Significant difference at $p < 0.05$.

balance on both feet ($p = 0.04$).

Studies similar in nature to this study using textured orthotics [26–28] are equivocal in their findings, some failing to establish changes in postural stability over a four-week period [26,27] and another demonstrating changes [28]. However, these studies highlight the importance of variability in sensory input as this allows individuals to explore their environment and pick up information for action and respond accordingly [29]. In relation to this study the variability of the BF intervention activity may explain the disparity shown to the other studies [26,27].

The VAS results indicate that scores for experimental participants in the walking condition reduced significantly over the 4-week intervention program. Reductions in pain as experienced by the experimental participants might be explained by the mobilization effects of the BF intervention and a more natural foot function, as it is reported that footwear can inhibit foot function [30]. From an osteopathic perspective it is thought that you not only gain symptomatic relief to the structure but the benefit will affect the entire kinetic chain, which in this study is evidenced by the reduction in pain and the significant decrease in rear-foot impact [31].

Limitations of the study

A higher participant number would have strengthened the study statistically, yet as a pilot study to signpost further research this is fully justified. Whilst significant changes in impact and balance were obtained, it remains unclear where these changes came from. It may have been more useful to assess muscular changes pre- and post-intervention, preferably with the use of EMG, which is a possible future research focus.

BF activity may improve balance through increased feedback and associated kinematic and muscular adaptations. However, the duration required allowing rehabilitation to take place, is partly unanswered, for instance; can the sensory changes gained offer longer lasting benefits? For this reason it may be useful to have a longer 12-week intervention period and re-assess participants at four week intervals and follow up assessment at 4,8 and 12 weeks, which may offer a clearer indication on the longevity of the intervention.

Table 6
Plantar pressure measures at the hallux, lesser toes, metatarsal heads, mid-foot and calcaneum in newton's per cm^2 (N/cm^2) pre and post-intervention for both groups.

Experimental	Plantar pressure (N/cm^2)	Plantar pressure (N/cm^2)
	Pre Mean ± SD	Post Mean ± SD
Hallux	37.0 ± 20.53	38.60 ± 8.6
Lesser Toes	17.00 ± 4.30	15.6 ± 6.5
Metatarsal heads	43.20 ± 10.33	48.8 ± 12.38
Midfoot	19.80 ± 7.66	17.4 ± 13.8
Calcaneum	23.4 ± 25.75	12.4 ± 6.27
Control	**Plantar pressure (N/cm^2) Pre Mean ± SD**	**Plantar pressure (N/cm^2) Post Mean ± SD**
Hallux	26.00 ± 8.72	29.33 ± 18.15
Lesser Toes	21.00 ± 13.00	15.00 ± 6.56
Metatarsal heads	40.00 ± 8.89	44.67 ± 8.6
Midfoot	13.67 ± 6.02	25.67 ± 14.57
Calcaneum	15.00 ± 7.94	13.33 ± 3.70

* Significant difference at $p < 0.05$.

The present study is the first to assess the short-term balance and impact changes associated with a short-term BF training program. It is entirely likely that an increase in plantar cutaneous mechanoreceptor activity has led to a peripheral and centrally mediated improvement in balance through a reduction in sway. The study also suggests the importance of tactile sensitivity in reducing ground reaction force and highlights the neuro-biomechanical relationship. However, as we did not measure tactile sensitivity, this is something that can be measured and corroborated in future studies. In both cases clinical benefits could be sought for those injuries where either reduced balance or excessive impact is at play.

Table 5
Impulse measures at fore, mid and rear foot in kilograms per second (kg/s) pre and post-intervention for the two groups.

	Fore-foot strike impulse (kg/s)	Fore-foot strike impulse (kg/s)	Mid-foot strike impulse (kg/s)	Mid-foot strike impulse (kg/s)	Rear-foot strike impulse (kg/s)	Rear-foot strike impulse (kg/s)
	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ± SD
Experimental	16.05 ± 5.67	17.35 ± 3.59	6.35 ± 1.23	5.90 ± 1.94	4.19 ± 1.58	2.67 ± 0.98*
Control	12.22 ± 7.0	11.76 ± 5.62	4.53 ± 1.90	4.46 ± 2.38	5.06 ± 0.50	3.01 ± 0.47

* Significant difference at $p < 0.05$.

Table 7
Stride length in centimetres (cm) and contact time in seconds (s) pre and post-intervention for both groups.

	Stride Length (cm)	Stride Length (cm)	Contact Time (s)	Contact Time (s)
	Pre Mean ± SD	Post Mean ± SD	Pre Mean ± SD	Post Mean ± SD
Experimental	105.95 ± 9.86	101.20 ± 16.84	0.26 ± 0.02	0.26 ± 0.02
Control	84.59 ± 4.39	94.40 ± 1.01	0.27 ± 0.03	0.24 ± 0.03

* Significant difference at $p < 0.05$.

Declaration of competing interest

1. There are no conflicts of interest.
2. The authors received no funding in undertaking this research project. It formed part of a Masters degree.
3. Ethical approval was granted by Oxford Brookes University Research Ethics Committee. All procedures were carried out in accordance with the declaration of Helsinki.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijosm.2019.10.005.

References

[1] Rothschild CE. Primitive running, a survey analysis of runners interest, participation, and implementation. J Strength Cond Res 2002;26:2012–26.
[2] National Statistics. Sport and leisure general household survey 2002. 2002 [online] Available from:. www.statistics.gov.uk/lib2002, Accessed date: 21 January 2018.
[3] Van Gent R. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. Br J Sports Med 2007;41:469–80.
[4] Lun V, Meeuwisse W, Stergiou P, Stefanyshyn D. Relation between running injury and static lower limb alignment in recreational runners. Br J Sports Med 2004;38:576–80.
[5] Chang W, Shih Y, Chen W. Running injuries and associated factors in participants of the ING Taipei marathon. Phys Ther Sport 2012;13(3):170–4.
[6] Hreljac A. Impact and overuse injuries in runners. Med Sci Sport Exerc 2004;36:845–9.
[7] Messier S, Pittala K. Etiologic factors associated with patellofemoral pain in runners. Med Sci Sport Exerc 1991;23:1008–15.
[8] Viitasalo J, Kvist M. Some biomechanical aspects of the foot and ankle in athletes with and without shin splints. Am J Sports Med 1983;11:125–30.
[9] Lieberman DE, Venkadesan M, Werbel WA, Daod AI, D'Andrea S, Davis IS, Mang'Eni RO, Pitsiladis Y. Foot strike patterns and collision forces in habitually barefoot versus shod runners. Nature 2010;463(28):531–5.
[10] Hasegawa H, Yamauchi Kraemer WJ. Foot strike patterns of runners at the 15-km point during an elite-level half marathon. J Strength Cond Res 2007;21(3):888–93.
[11] Cavanagh PR, Lafortune MA. Ground reaction forces in distance running. J Biomech 1980;13:397–406.
[12] Perl D, Daoud AI, Lieberman DE. Effects of footwear and strike type on running economy. Med Sci Sport Exerc 2012;44:1335–43.
[13] Squadrone R, Gallozi C. Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. J Sport Med Phys Fit 2009;49:6–13.
[14] Robbins S, Hanna M. Running related injury prevention through barefoot adaptations. Med Sci Sport Exerc 1987;19:148–56.
[15] Robbins S, Waked E. Balance and vertical impact in sports: role of shoe sole materials. Arch Phys Med Rehabil 1997;78:463–7.
[16] Gutierrez EM, Helber MD, Dealva D, Ashton-Miller JA, Richardson JK. Mild diabetic neuropathy affects ankle motor function. Clin Biomech 2001;16:522–8.
[17] Kavounoudias A, Roll R, Roll J. The plantar sole is a 'dynamometric map' for human balance control. Cogn Neurosci 1998;9:3247–52.
[18] McCormack HM, Horne DJL, Sheather S. Clinical applications of visual analogue scales: a critical review. Psychol Med 1988;18:1007–19.
[19] Geurts A, Mulder T, Neinhuis B, Rijken R. Influence of orthopaedic footwear on postural control in patients with hereditary and sensory neuropathy. J Rehabil Sci 1992;5:3–9.
[20] Lohman E, Sackiriyas K, Swen W. A comparison of the spatiotemporal parameters, kinematics and biomechanics between shod, unshod and minimally supported running as compared to walking. J Phys Ther Sci 2011;12:151–63.
[21] Robbins S, Gouw G. Athletic footwear and chronic overloading: a brief review. Sport Med 1990:76–85.
[22] Zadpoor A, Nikooyan A. Modelling muscle activity to study the effects of footwear on the impact forces and vibrations of the human body during running. J Biomech 2010;43:186–93.
[25] Wang T, Ling S. Sensitivity of plantar cutaneous sensation and postural stability. Clin Biomech 2008;23:493–9.
[26] Wilson M, Rome K, Hodgson D, Ball P. Effect of textured foot orthotics on static and dynamic postural stability in middle-aged females. J Gait Posture 2008;27:36–42.
[27] Hatton A, Dixon J, Martin D, Rome K. The effect of textured surfaces on postural stability and lower limb muscle activity. J Electromyogr Kinesiol 2009;19:957–64.
[28] Maurer C, Mergner T, Bohla B, Hlavacka F. Human balance control during cutaneous stimulation of the plantar soles. Neurosci Lett 2001;302:45–8.
[29] Davids K, Shuttleworth C, Button C, Renshaw I, Glazier P. Essential noise – enhancing variability of informational constraints benefits movement control: a comment on Waddington and Adams 2003. Br J Sports Med 2004;38:601–5.
[30] Morio C, Lake M, Gueguen N, Guillaume R, Baly L. The influence of footwear on foot motion during walking and running. J Biomech 2009;42:2081–8.
[31] Chilia A. Foundations of osteopathic medicine. Baltimore: Lipincott, Williams and Wilkins; 2010.