Title

The effect of a home-based stretching exercise on the ground reaction force generation and absorption during walking in individuals with plantar fasciitis

Abstract

Objectives: This study aimed to investigate the effect of a home-based stretching exercise program in individuals with plantar fasciitis (PF), and to compare its effect on ground reaction force (GRF)-time variables between the mild, moderate, and severe pain subgroups as well as between before and after in each subgroup.

Design: A single cohort with pre-and post-test design.

Interventions: Twenty individuals with PF received 3 weeks of home-based stretching exercise program for calf muscles and plantar fascia. The data were compared between before and after exercise in a whole number of participants and were compared among the mild (n = 7), moderate (n = 7), and severe (n = 6) pain subgroups.

Main Outcome Measures: Force data were collected during walking using two force plates. GRF-time variables included the force and time at; first peak (F1 and TF1), valley (F2 and TF2), second peak (F3 and TF3) for the vertical forces, peak breaking (F4 and TF4) and propulsive (F5 and TF5) forces, first peak (F6 and TF6) and second peak lateral (F7 and TF7) forces. Additionally, worst pain was assessed using the visual analog scale.

Results: Significant reductions were seen in F2, TF2, TF3, TF5 and worst pain after exercise in individuals with PF ($P < 0.05$). No differences were seen between the three subgroups. For the within subgroup analysis, only the mild subgroup showed significant changes in F2, TF2, F4, TF6, and TF7 after exercise ($P < 0.05$).

Conclusion: A home-based stretching exercise program was effective in reducing pain and some GRF-time variables, with the most noticeable response seen in the mild subgroup.

Keywords: Ground reaction force, Stretching exercise, Plantar fasciitis, Gait

1. Introduction

Plantar fasciitis (PF) is one of the most common foot and lower extremity pathologies (Lopes, Hespanhol Junior, Yeung, & Costa, 2012). The occurrence of PF was reported to be slightly higher in females and those with intermediate or routine manual occupations (Thomas et al., 2019). PF pathogenesis is characterized by a chronic degenerative process within the plantar fascia, causing a repetitive overload, poor lower extremity biomechanics, and soft tissue microtrauma (Cutts, Obi, Pasapula, & Chan, 2012; Waclawski, Beach, Milne, Yacyshyn, & Dryden, 2015). Clinical symptoms of PF present with heel pain while standing or walking for a long time. Pain usually presents at the first few steps in the morning after waking up and will be disappeared after rest (Karagounis, Tsironi, Prionas, Tsiganos, & Baltopoulos, 2011). Decreased gait ability is the most important functional limitation in daily life for individuals with PF. If individuals are not treated appropriately, condition can become more severe and develop into a chronic stage (Beeson, 2014).

From the current knowledge, the exact etiology of PF is still unclear. However, several intrinsic and extrinsic risk factors have been proposed to be contributing causes including obesity, prolonged weight-bearing activities, or sports training with high impact forces such as running and jumping. In addition, abnormal biomechanics such as excessive foot pronation, decreased ankle dorsiflexion, and incorrect foot placement are also suspected to be related causes of PF (Beeson, 2014; Wearing, Smeathers, Urry, Hennig, & Hills, 2006). Increasing the Ground Reaction Force (GRF), which directly transmits and potentially damages the plantar fascia during walking, has been highlighted as an important biomechanical factor of PF progression. Persistent heel pain results in alterations of temporospatial gait and foot kinematic variables (Bovonsunthonchai et al., 2019; Thong-On et al., 2019), which in turn could affect the GRF-time variables during the stance phase of gait through pain avoiding strategies (Phillips & McClinton, 2017). A previous study (Johnson, Tenforde, Outerleys, Reilly, & Davis, 2020), compared the impact-related GRF variables between two groups of runners with and without PF. Impact-related GRF variables included vertical average and instantaneous load rates, posterior and medial/lateral instantaneous load rates, vertical stiffness, and ratio of peak vertical ground reaction force (vGRF) to vertical center of mass (vCOM) displacement at initial loading. The results showed higher vertical average loading rates and vertical instantaneous loading rates in runners with PF. The authors also reported that runners who had a vertical stiffness during loading response of ≥73.1 kN/m were 15 times more likely to have PF than those with a lower vertical stiffness. This suggests that therapists may need to focus on reducing the GRF during the management of injured runners, especially in those with PF. Therefore, GRF variables could be used to represent the abnormal mechanics of plantar fascia loading associated with the risk of injury on the soft tissue, fascia, and other related foot structures.

Alteration of the GRF-time variables in individuals with PF is still ambiguous due to the difference in methodology and variability of participants' characteristics between studies. Comparing the data to those of healthy controls, Chang et al. (Chang, Rodrigues, Van Emmerik, & Hamill, 2014) found the reduced 2nd peak of vertical GRF (v-GRF) and delayed time to midstance in individuals with PF. Consistent with this finding, Katoh et al. (Katoh, Chao, Morrey, & Laughman, 1983) and Wearing et al. (Wearing, Smeathers, & Urry, 2003) also reported the increased 1st peak v-GRF in the same population. However, when controlling the speed of walking, a study conducted by Bovonsunthonchai et al.

(Bovonsunthonchai et al., 2019) reported no difference in the v-GRF and mediolateral GRF (ML-GRF) between individuals with PF and healthy controls, but larger variability was found as observed by the greater standard deviation in individuals with PF when compared to healthy controls.

Tightness of the ankle plantarflexors has been suggested to be the most important impairment associated with biomechanical changes in PF (Riddle, Pulisic, Pidcoe, & Johnson, 2003). The tension of ankle plantarflexors decreases the ankle dorsiflexion angle at heel strike and results in the increased force transmission on the plantar fascia during the stance phase of gait. Force overload on plantar fascia may cause tissue damage, and may also be associated with the inability of GRF absorption function over foot flat to midstance period, which results in altered GRF patterns, creates a risk of injury, and inhibits the tissue healing process (Liddle, Rome, & Howe, 2000).

Non-operative interventions are suggested as an effective treatment in PF. Stretching exercise is the most popular recommendation supported by moderate to high levels of evidence (DiGiovanni et al., 2003; Digiovanni et al., 2006; Porter, Barrill, Oneacre, & May, 2002). Stretching exercise is a low-cost treatment that everyone can easily perform by themselves. Individuals with PF could gain many benefits from exercise, as shown with improvements in clinical symptoms and activities of daily living (Boonchum, Bovonsunthonchai, Sinsurin, & Kunanusornchai, 2020; DiGiovanni et al., 2003; Digiovanni et al., 2006; Thong-On et al., 2019). Importantly, exercise may help with some of the limitations including treatment time, cost of treatment, health-profession consultation demand, and treatment accessibility.

Home-based stretching exercise programs have been suggested as a sustainable management option for this condition (Boonchum et al., 2020), with reported improvements in pain and muscle strength, however no changes in multi-segment foot motion after performing a home-based stretching exercise program were seen. Boonchum et al. demonstrated both the direct and indirect benefits of stretching, i.e, reduced pain. increased muscle strength, increased muscle length, leading to increases in the isometric contraction force through changes in the length-tension relationship. A pilot study was carried out in 39 individuals with PF who were classified into three groups. The first group received manual treatment, exercises, and insoles, the second group received exercises and insoles, and the last group received insoles only. The findings showed moderate improvement in pain and function when compared to baseline in all the three groups but no inter-group difference was found {Yildiz, 2022 #65}. The efficacy of home-based exercise was further supported by a prospective randomized controlled study of Kaiser et al. {Kaiser, 2022 #64}. They compared physical therapy with home-based stretching exercises and found that both groups had significant improvements in visual analog scale (VAS) pain scores, Foot and Ankle Ability Measure (FAAM), and Short Form Health Survey (SF-36) scores at 6 months relative to baseline, but no notable differences in all outcomes were seen between groups {Kaiser, 2022 #64}.

The verifiable response to treatment in this group of patients may be influenced in part by patient characteristics such as severity, pain, duration of disease, etc. Therefore, choosing the appropriate form of treatment should take into account these factors. A previous study has shown a statistically significat correlation between gastrocnemius muscle tightness and heel pain severity in patients with PF {Pearce, 2021 #62}. Factors contributing to the failure of conservative treatment, such as stretching and custom foot orthosis, were also reported. The study found that the first-step pain, ankle dosiflexion limitation, and heel valgus in a relaxed position could predict the treatment failure for patients with PF {Wrobel, 2016 #63}. However, to date, no study has shown the efficacy and effectivenes of such exercises in PF patients with varying degrees of severity.

Therefore, this study aimed to investigate the effect of a home-based stretching exercise program on GRF-time variables and pain, and to determine if the exercise effect varied according to the different pain severity levels in individuals with PF. We hypothesized that the home-based stretching exercise program would produce significantly different GRF-time variables and significant reductions in pain, and that similar effects would be seen in a group with less pain severity.

2. Methods

2.1 Study design and ethical consideration

This was a single cohort with a pre-and post-test design. Data were collected in a 3D motion analysis laboratory, at the Faculty of Physical Therapy, XXX University, COUNTRY. The study was approved by XXX University Central Institutional Research Board (COA no: MU-CIRB 2019/018.2801). The study was conducted in accordance with the Declaration of Helsinki. Participants were informed about the research objectives, benefits and details and signed an informed consent form before participating in the study.

2.2 Participants

The inclusion criteria were; age between 40 – 65 years, ≥1-month duration of clinical symptoms, resting pain ≤4 points, decreased active ankle dorsiflexion of < 30 degrees assessed using a hand-held goniometer with the knee flexed in sitting position, tightness of achilles tendon assessed by passive movement, and negative tarsal tunnel test. Exclusion criteria were; a history of neuromuscular disorders, lower extremity surgery, systemic disease, rheumatoid arthritis, ankylosing spondylitis, Reiter's syndrome, generalized osteoarthrosis, tingling or numbness in the foot, inflammation sign at the ankle, flatfoot deformity assessed by footprint method, peripheral vascular disease, and receiving other physical therapy or treatment during the study.

A flow chart diagram of the recruitment is presented in **Fig. 1**. Fifty-four individuals with PF were recruited from social media and posters advertised within the Physical Therapy Center, Faculty of Physical Therapy, Mahidol University. After screening following the criteria, twenty-six individuals with PF were included in the study. During participation, three individuals withdrew from the program due to sudden pain at the knee (n = 1) and lumbar (n = 1), and admission to the hospital with an unrelated medical problem (n = 1), with the remaining twenty participants completing the study. Age, weight, height, body mass index (BMI), and gender were recorded for demographic data. Additional measures included; disease onset, worst pain score, symptomatic side, physical activity level, gait speed, and cadence. The worst pain was determined using scores between 0 – 100 with a higher value representing greater severity. Physical Activity level was assessed using the Thai version of the International Physical Activity Questionnaire (IPAQ).

The GRF-time variables and worst pain score were evaluated at two-time points, before and after the exercise program. In addition, data were classified according to three subgroups of worst pain score {Turner, 2004 #69}; mild (between 0 to 40, n = 7), moderate (between 41 to 70, n = 7), and severe pain (between 71 to 100, n = 6), and outcome measures were compared between and within these subgroups.

2.3 Data collection protocol

2.3.1 The ground reaction force (GRF)-time

GRF-time data during walking were collected before and after 3 weeks of exercise from two force plates (AMTI-OR67, Advance Mechanical Technologies Inc., USA) which were positiond in the middle of the walkway and synchronized with two video cameras (Vicon^{TM} Bonita, UK) placed infront and at the side of the participants. Before data collection the force plates were zeroed to reduce noise.

Participants walked with bare feet along the 8 m walkway at a self-selected speed. Participants were allowed 2 to 3 practice trials to familiarise themselves with the walkway, and then walking trials were collected. Force data were collected at a sampling rate of 1,000 Hz and were filtered using a fourth-order Butterworth low pass filter with a cut-off frequency of 15. The motion picture obtained by the video cameras was used for inspection along with the force information generated during walking. All data were processed using the Nexus software (version 2.8.1). The averaged successful data of 3 walking trials with the most painful foot of each participant was selected for analysis.

The GRF data were normalized to body weight and the force and time parameters over the stance phase of gait included; 1) vertical (v)-GRF comprised of F1, F2, F3 (N/kg) and TF1, TF2, TF3 (% stance phase), 2) Antero-posterior (AP)-GRF comprised of F4 and F5 (N/kg) and TF4 and TF5 (% stance phase), and 3) Medio-lateral (ML)-GRF comprised of F6 and F7 (N/kg) and TF6 and TF7 (% stance phase) **(Fig. 2)**.

2.3.2 Worst pain score

The worst pain score was verbally rated using the numeric rating scale (NRS) by the participants. The scale ranging from 0 (no pain) to 100 (unimaginary pain) scores over the past week. The more painful side data was used in the analysis for the individuals who had bilateral PF symptoms.

2.4 Intervention program

The home-based exercise program in this study comprised of stepwise progressive stretching exercises for calf and plantar fascia. To ensure individuals with PF were able to follow the program properly, a physiotherapist demonstrated the exercise program until they were able to reproduce the exercises accurately, and participants also received a handbook and video clips of the exercise program. The program consisted of static stretching exercises of the gastrocnemius, soleus, and plantar fascia for 20-30 s, resting between exercises for 10 s. for 10 sets. The total time for each session was 20 min per day, 5 days per week for 3 weeks. Participants were re-checked and were assigned progressive exercises after the 5^{th} and 10^{th} day of the intervention program. Stretching exercise was progressed depending on individual perception of the gastrocnemius and soleus tension to prevent injury and maximize efficiency. The tension during stretching was re-assessed every week to ensure a sequential rehabilitation program was provided. Further details of the exercise program have been previously published (Boonchum et al., 2020).

2.5 Statistical analyses

Non-parametric statistics were used in this study due to the small number of participants recruited. Wilcoxon signed rank tests were used to compare the GRF-time and pain measures between before and after exercise for all participants (n = 20). Further analysis using Kruskal Wallis tests compared the differences of GRF-time variables between mild (n = 7), moderate (n = 7), and severe (n = 6) subgroups before and after exercise, and Wilcoxon signed rank tests were used to compare the data between before and after exercise within each subgroup. The alpha level was set at 0.05 for all comparisons.

For the data that showed significant differences, effect sizes were calculated based on the formula ($r = |z|/\sqrt{N}$) {Fritz, 2012 #70}. The Cohen's guideline for *r* indicates that a large effect is 0.5 or greater, a medium effect is between 0.3 and 0.49, and a small effect is less than 0.1 {Cohen, 1988 #71}. All data were analyzed using SPSS version 23.0 (SPSS Inc, Chicago, IL, USA).

2.6 Sample size calculation

Sample size was estimated based on the first objective which was to determine the effect of a home-based exercise program in individuals with PF. The G*Power program version 3.1.9.4 was used to determine the sample size based on our own pilot data (n = 5) on the F2 variable. A priori method using the Wilcoxon signed rank test (match paired) function was selected with alpha set to 0.05 and power of 0.80. The effect size obtained was calculated using the formula{Fritz, 2012 #70}: $r = |z|/\sqrt{N}$ = 0.78, and the resulting estimated total sample size required was found to be 16.

3. Results

3.1 Characteristics of the participants

Table 1 shows the characteristics of all participants and in each severity subgroup. Twenty individuals with PF completed the research protocol, who were classified into a mild (n = 7), moderate (n = 7), and severe (n = 6) pain subgroup. The total participants' median and interqualtile range (IQR) of age, weight, height, and BMI were 58 (53 – 61) years, 61.8 (53.2 – 72.3) kg, 159.0 (153.2 – 169.9) cm, and 24.6 (21.8 – 27.5) kg/m^2, respectively. Seventy percent of the participants were female (n = 14) and 60% (n = 12) had chronic onset of PF for more than 12 months, with a median and IQR of worst pain at baseline of 50.0 (40.0 – 77.7). The majority of participants (n = 11) fell into the high level of physical activity category using the Thai IPAQ. No significant differences were seen between the three pain subgroups in all variables at baseline, except for the worst pain score. Further Bonferroni correction for multiple test revealed significant differences (*P* <0.001) in the worst pain score between mild vs severe subgroups only.

3.2 Comparisons of GRF-time variables and worst pain between before and after 3 weeks of exercise in individuals with PF and sub-group analysis

Table 2 shows the comparisons of GRF-time variables and worst pain between before and after 3 weeks of exercise in all participants. The results revealed significant differences in F2 (P = 0.019, effect size *(r)* = 0.53) and TF2 (P = 0.026, r = 0.50), TF3 (P = 0.035, r = 0.47), TF5 (P = 0.032, r = 0.48) and worst pain (P = 0.001, r = 0.78) while the other GRF-time variables showed no difference (P >0.05).

Tables 3 and 4 show the effect of a home-based exercise on the vertical and the shear GRF-time variables between the three pain subgroups and within group comparison. The findings demonstrated no significant differences between the three subgroups before nor after exercise (P >0.05) in all GRF-time variables. However, the within-group comparison showed significant differences were seen for F2 (P = 0.043, r = 0.77), TF2 (P = 0.006, r = 0.89), F4 (P = 0.018, r = 0.77), TF6 (P = 0.018, r = 0.89) and TF7 (P = 0.043, r = 0.77) between before and after exercise in mild subgroup.

4. Discussion

4.1 Comparisons of GRF-time variables and worst pain between before and after 3 weeks of exercise in individuals with PF

Our results showed that the combined stretching exercise program for gastrocnemius, soleus, and plantar fascia in individuals with heel pain reduced the worst pain scores, F2, and TF2 with a large effects size and reduced TF3 and TF5 with a medium effect size, with the force during midstance F2 being higher than that previously reported in healthy individuals (Katoh et al., 1983), which could be an indication of a cause or compensation as a result of PF (Wearing et al., 2006). A study done by Erdemir et al. (Erdemir, Hamel, Fauth, Piazza, & Sharkey, 2004), investigated the effect of achilles tendon stimulation on plantar fascia load during gait in cadaver feet. They found the increase of achilles tendon load had a strong association with increasing tension in the plantar fascia over the stance phase of gait ($r = 0.76$). This association yielded greater forces in late midstance in order to counterbalance the higher midstance v-GRF in preparation for the change from stance to swing phase (Dananberg, 1993). This strategy may produce a higher tension in gastrocnemius and soleus muscles, as well as plantar fascia. The changes of these soft tissue properties resulted in higher forces during midstance and were attributed to overload stress on the plantar facia in individuals with PF (Katoh et al., 1983).

Physiological effect of stretching exercise can reduce muscle stiffness and enhance appropriate actin-myosin attachment leading to improvement of viscoelastic property of the muscles (Malliaropoulos, Papalexandris, Papalada, & Papacostas, 2004). Consequently, responsiveness to gain normal movement and appropriate muscle force production (Herzog, Joumaa, & Leonard, 2010). A possible explanation for the lower F2 and slightly earlier timing of TF2 in our study may indicate an improvement in the progression of the body over the stance leg as a result of the stretching exercise program. A stretching exercise program for gastrocnemius and soleus in the closed chain position with weekly progression by increasing the body load position may enhance the absorbing and loading function during gait. Stretching the plantar fascia in the open-chain position could also reduce joint stiffness as well as allowing the calf muscles to generate an appropriate force to stabilize the arch of the foot during midstance. Another explanation for the relationship between muscle and fascia function after the stretching exercises was the reduction in the worst pain which may lead to less compensatory movements. This finding was comparable to a previous RCT study (Hsu, Lai, Chang, & Hsu, 2013), that reported a significant reduction in F2 after 3 weeks of receiving shockwave therapy in individuals with PF. The authors explained that the reduction of force was partly due to the pain being decreased. For the delayed time to the minimum v-GRF at midstance or TF2 in individuals with PF, we found similar results of a previous study (Wearing et al., 2003). It was suspected that individuals with PF had a delayed timing of movement over the stance limb due to pain in the plantar fascia which interrupted loading and weight transfer.

For the TF3 or time to the second peak v-GRF and TF5 or time to peak propulsive force, both occurring over the push-off phase. Nevertheless, none of the previous studies directly determined these variables in individuals with PF before. However, alteration of these timings may be implied from previous studies which investigated the peak v-GRF during push-off (Chang et al., 2014; Katoh et al., 1983; Wearing et al., 2003). As the operational definition of the timing of this force is the percentage of stance time related to v-GRF during push-off phase. Many studies reported significant reductions in the peak v-GRF during push-off in individuals with PF (Chang et al., 2014; Katoh et al., 1983; Wearing et al., 2003). This has been previously hypothesized to be associated with the reduction of stress and strain within the plantar fascia (Phillips & McClinton, 2017). Fessel et al. (Fessel et al., 2014), used elongation measurement in vivo during the stance phase of gait, in combination with measurement of mechanical properties in vitro, to explore the mechanical function of the plantar aponeurosis. They found elongation of the fascia was

Commented [JR<oS&HS1]: Sorry I don't know what point you are trying to make here

associated with F3 or the peak v-GRF during push-off. Consistent with Chen et al.'s study (Chen, Chang, Li, Chang, & Lin, 2015), who reported that peak plantar fascia tension correlated with F3 in healthy subjects. Individuals with PF may have a delay of TF3 to avoid excessive force, which causes stress and pain within the fascia. Thus, an earlier TF3 after stretching exercises may come from a decrease in plantar fascia tension and pain response to the treatment program, which is also likely to be associated with the alterations of TF5 or time to peak propulsive force during push-off.

This current study found no significant differences in F1 and F3 or the 1st and 2nd peak of the v-GRF after completing the exercise program in individuals with PF. According to a previous report (Wearing et al., 2003), individuals with PF showed an increase in F1 when compared to healthy controls. The changes in force generation in the early phase can have a lasting effect on the propulsive forces that occur at the end of the stance phase. Some supporting data showed a reduction of F3 in individuals with PF compared to healthy (Chang et al., 2014; Katoh et al., 1983; Wearing et al., 2003). Hence, we expected to observe a decrease in F1 and an increase in F3 after exercise in individuals with PF. Possible explanations of no change may be attributed to the diversity of sample selection criteria, experimental protocol, testing tool, and computation method between studies.

4.2 Sub-group analysis

When considering the pain severity subgroup analysis, the results showed no difference in all variables between the mild, moderate, and severe subgroups both at before and after exercise (P >0.05). However, for within-group analysis, significant differences were seen in F2, TF2, F4, TF6, and TF7 with large effect sizes in a mild pain subgroup only.

Demographic and clinical characteristics could affect the comparative results among subgroups, however, no differences were seen in those data, except pain which was used as a segmentation factor to assign groups. From the results, it could be implied that a home-based stretching exercise in our study was appropriate for individuals with PF who had a mild pain level only. This may be due to a stretching program that was progressive by using the body weight in a closed chain position, which may be too difficult for individuals with moderate to severe pain levels and led to poor adherence. Another possible reason to support this issue may relate to the fear. Pain catastrophizing and kinesiophobia were believed to be associated with pain severity in individuals with PF (Cotchett, Lennecke, Medica, Whittaker, & Bonanno, 2017). Pain catastrophizing and kinesiophobia may act as the threads and made individuals avoid weight bearing on the symptomatic foot and resulting in the stretching exercise being not effective. However, this fear issue was not documented in this study. In addition, the exercise program was designed as a home-based. Weekly phone calls were performed to check symptoms and encouraged participants to follow the protocol. So, the position and degree of stretching was properly or not cannot be checked in this situation.

The significant reduction of F2 and TF2 in a mild group found in this study could be explained similarly to those of the overall analysis. The results emphasized the exercise effect on the arch of foot improvement to protect load on the fascia over midstance. For the significant increase in F4 after exercise in our study, this may in part be explained by the previous finding (Katoh et al., 1983). This aberrant walking pattern links with a compensatory mechanism to avoid excessive anterior shear force on the symptomatic side during heel strike. So, the effect of stretching exercise could alleviate pain symptoms which potentially allow improvement in braking function. Both time reductions of TF6 and TF7 may be due to the improvement of plantar fascia and gastrosoleus flexibility along with reduced pain. It can be seen that the within group analysis showed the changes only in the mild subgroup, while the moderate and severe subgroups had no change after performing the home-based stretching exercise for 3 weeks. This may be implied that the duration of exercise may not be sufficient to alter the soft tissues, resulting in no visible changes for the moderate and severe subgroups.

No significant differences were seen in all GRF-time variables between the three subgroups. The possible reasons may relate to a small number of participants in our study and the duration of the exercise program being too short to induce any change. A previous study (Engkananuwat et al., 2018), investigated the combined gastrocnemius and plantar fascia stretching exercise with the same intensity dose as our study but provided a longer duration of 4 weeks in the mild stage of individuals with unilateral PF. The results showed significant reductions in pain and ankle dorsiflexion ROM. In addition, a shorter time of calf muscle stretching exercise of 2 weeks could improve pain and function in individuals with PF but not differ from the control group (Radford, Landorf, Buchbinder, & Cook, 2007).

This study has a number of limitations. Firstly, there was no healthy control group, or untreated control group, which could have been used to compare with individuals with PF who received the intervention. Secondly, the exercise program should include gait training section to correct movement patterns, restore normal muscle function, and prevent injuries caused by repetitive force impact onto the ground when walking. thirdly, considering exercise adherence and kinesiophobia may have helped to understand the non-response of the moderate and severe groups. In addition, a long-term follow-up assessment or longer duration of exercise program may have revealed if a more delayed response was present in the moderate and severe groups. Finally, this study is limited by a small sample size, and future study should include a greater number of participants to increase power, generalizability and treatment effects in different subgroups of people with PF.

5. Conclusion

A home-based stretching exercise program of gastrocnemius and soleus muscles and plantar fascia provided beneficial effects on pain relief and improved gait parameters including some GRF-time variables. A sub-group analysis revealed that a 3 week stretching exercise provided benefits in a mild pain subgroup only. Therapists should take into account the pain severity in order to design an exercise program that is appropriate for different pain subgroups.

References

Beeson, P. (2014). Plantar fasciopathy: revisiting the risk factors. *Foot Ankle Surg, 20*(3), 160-165. doi:10.1016/j.fas.2014.03.003

Boonchum, H., Bovonsunthonchai, S., Sinsurin, K., & Kunanusornchai, W. (2020). Effect of a home-based stretching exercise on multi-segmental foot motion and clinical outcomes in patients with plantar fasciitis. *J Musculoskelet Neuronal Interact, 20*(3), 411-420.

Bovonsunthonchai, S., Thong-On, S., Vachalathiti, R., Intiravoranont, W., Suwannarat, S., & Smith, R. (2019). Alteration of the multi-segment foot motion during gait in individuals with plantar fasciitis: a matched case-control study. *Acta Bioeng Biomech, 21*(4), 73-82. doi:10.37190/ABB-01426-2019-02

Chang, R., Rodrigues, P. A., Van Emmerik, R. E., & Hamill, J. (2014). Multi-segment foot kinematics and ground reaction forces during gait of individuals with plantar fasciitis. *J Biomech, 47*(11), 2571-2577. doi:10.1016/j.jbiomech.2014.06.003

Chen, Y. N., Chang, C. W., Li, C. T., Chang, C. H., & Lin, C. F. (2015). Finite element analysis of plantar fascia during walking: a quasi-static simulation. *Foot Ankle Int, 36*(1), 90-97. doi:10.1177/1071100714549189

Cotchett, M., Lennecke, A., Medica, V. G., Whittaker, G. A., & Bonanno, D. R. (2017). The association between pain catastrophising and kinesiophobia with pain and function in people with plantar heel pain. *Foot (Edinb), 32*, 8-14. doi:10.1016/j.foot.2017.03.003

Cutts, S., Obi, N., Pasapula, C., & Chan, W. (2012). Plantar fasciitis. *Ann R Coll Surg Engl, 94*(8), 539-542. doi:10.1308/003588412X13171221592456

Dananberg, H. J. (1993). Gait style as an etiology to chronic postural pain. Part I. Functional hallux limitus. *J Am Podiatr Med Assoc, 83*(8), 433-441. doi:10.7547/87507315-83-8-433

DiGiovanni, B. F., Nawoczenski, D. A., Lintal, M. E., Moore, E. A., Murray, J. C., Wilding, G. E., & Baumhauer, J. F. (2003). Tissue-specific plantar fascia-stretching exercise enhances outcomes in patients with chronic heel pain. A prospective, randomized study. *J Bone Joint Surg Am, 85*(7), 1270-1277. doi:10.2106/00004623-200307000-00013

Digiovanni, B. F., Nawoczenski, D. A., Malay, D. P., Graci, P. A., Williams, T. T., Wilding, G. E., & Baumhauer, J. F. (2006). Plantar fascia-specific stretching exercise improves outcomes in patients with chronic plantar fasciitis. A prospective clinical trial with two-year follow-up. *J Bone Joint Surg Am, 88*(8), 1775-1781. doi:10.2106/JBJS.E.01281

Engkananuwat, P., Kanlayanaphotporn, R., & Purepong, N. (2018). Effectiveness of the simultaneous stretching of the achilles tendon and plantar fascia in Individuals with plantar fasciitis. *Foot Ankle Int, 39*(1), 75-82. doi:10.1177/1071100717732762

Erdemir, A., Hamel, A. J., Fauth, A. R., Piazza, S. J., & Sharkey, N. A. (2004). Dynamic loading of the plantar aponeurosis in walking. *J Bone Joint Surg Am, 86*(3), 546-552. doi:10.2106/00004623-200403000-00013

Fessel, G., Jacob, H. A., Wyss, C., Mittlmeier, T., Muller-Gerbl, M., & Buttner, A. (2014). Changes in length of the plantar aponeurosis during the stance phase of gait--an in vivo dynamic fluoroscopic study. *Ann Anat, 196*(6), 471-478. doi:10.1016/j.aanat.2014.07.003

Herzog, W., Joumaa, V., & Leonard, T. R. (2010). The force-length relationship of mechanically isolated sarcomeres. *Adv Exp Med Biol, 682*, 141-161. doi:10.1007/978-1-4419-6366-6_8

Hsu, W. H., Lai, L. J., Chang, H. Y., & Hsu, R. W. (2013). Effect of shockwave therapy on plantar fasciopathy. A biomechanical prospective. *Bone Joint J, 95-B*(8), 1088-1093. doi:10.1302/0301-620X.95B8.31497

Irving, D. B., Cook, J. L., Young, M. A., & Menz, H. B. (2008). Impact of chronic plantar heel pain on health-related quality of life. *J Am Podiatr Med Assoc*, *98*(4), 283-289. doi:10.7547/0980283

Johnson, C. D., Tenforde, A. S., Outerleys, J., Reilly, J., & Davis, I. S. (2020). Impact-related ground reaction forces are more strongly associated with some running injuries than others. *Am J Sports Med*, *48*(12), 3072-3080. doi:10.1177/0363546520950731

Karagounis, P., Tsironi, M., Prionas, G., Tsiganos, G., & Baltopoulos, P. (2011). Treatment of plantar fasciitis in recreational athletes: two different therapeutic protocols. *Foot Ankle Spec*, *4*(4), 226-234. doi:10.1177/1938640011407320

Katoh, Y., Chao, E. Y., Morrey, B. F., & Laughman, R. K. (1983). Objective technique for evaluating painful heel syndrome and its treatment. *Foot Ankle*, *3*(4), 227-237. doi:10.1177/107110078300300410

Liddle, D., Rome, K., & Howe, T. (2000). Vertical ground reaction forces in patients with unilateral plantar heel pain - a pilot study. *Gait Posture*, *11*(1), 62-66. doi:10.1016/s0966-6362(99)00053-3

Lopes, A. D., Hespanhol Junior, L. C., Yeung, S. S., & Costa, L. O. (2012). What are the main running-related musculoskeletal injuries? A systematic review. *Sports Med*, *42*(10), 891-905. doi:10.1007/BF03262301

Malliaropoulos, N., Papalexandris, S., Papalada, A., & Papacostas, E. (2004). The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. *Med Sci Sports Exerc*, *36*(5), 756-759. doi:10.1249/01.mss.0000126393.20025.5e

Patel, A., & DiGiovanni, B. (2011). Association between plantar fasciitis and isolated contracture of the gastrocnemius. *Foot Ankle Int, 32*(1), 5-8. doi:10.3113/FAI.2011.0005

Phillips, A., & McClinton, S. (2017). Gait deviations associated with plantar heel pain: A systematic review. *Clin Biomech (Bristol, Avon), 42*, 55-64. doi:10.1016/j.clinbiomech.2016.12.012

Pohl, M. B., Hamill, J., & Davis, I. S. (2009). Biomechanical and anatomic factors associated with a history of plantar fasciitis in female runners. *Clin J Sport Med, 19*(5), 372-376. doi:10.1097/JSM.0b013e3181b8c270

Porter, D., Barrill, E., Oneacre, K., & May, B. D. (2002). The effects of duration and frequency of Achilles tendon stretching on dorsiflexion and outcome in painful heel syndrome: a randomized, blinded, control study. *Foot Ankle Int, 23*(7), 619-624. doi:10.1177/107110070202300706

Radford, J. A., Landorf, K. B., Buchbinder, R., & Cook, C. (2007). Effectiveness of calf muscle stretching for the short-term treatment of plantar heel pain: a randomised trial. *BMC Musculoskelet Disord, 8*, 36. doi:10.1186/1471-2474-8-36

Riddle, D. L., Pulisic, M., Pidcoe, P., & Johnson, R. E. (2003). Risk factors for Plantar fasciitis: a matched case-control study. *J Bone Joint Surg Am, 85*(5), 872-877. doi:10.2106/00004623-200305000-00015

Siriphorn, A., & Eksakulkla, S. (2020). Calf stretching and plantar fascia-specific stretching for plantar fasciitis: A systematic review and meta-analysis. *J Bodyw Mov Ther, 24*(4), 222-232. doi:10.1016/j.jbmt.2020.06.013

Thomas, M. J., Whittle, R., Menz, H. B., Rathod-Mistry, T., Marshall, M., & Roddy, E. (2019). Plantar heel pain in middle-aged and older adults: population prevalence, associations with health status and lifestyle factors, and frequency of healthcare use. *BMC Musculoskelet Disord, 20*(1), 337. doi:10.1186/s12891-019-2718-6

Thong-On, S., Bovonsunthonchai, S., Vachalathiti, R., Intiravoranont, W., Suwannarat, S., & Smith, R. (2019). Effects of strengthening and stretching exercises on the temporospatial gait parameters in patients with plantar fasciitis: A randomized controlled trial. *Ann Rehabil Med, 43*(6), 662-676. doi:10.5535/arm.2019.43.6.662

Waclawski, E. R., Beach, J., Milne, A., Yacyshyn, E., & Dryden, D. M. (2015). Systematic review: plantar fasciitis and prolonged weight bearing. *Occup Med (Lond), 65*(2), 97-106. doi:10.1093/occmed/kqu177

Wearing, S. C., Smeathers, J. E., & Urry, S. R. (2003). The effect of plantar fasciitis on vertical foot-ground reaction force. *Clin Orthop Relat Res*(409), 175-185. doi:10.1097/01.blo.0000057989.41099.d8

Wearing, S. C., Smeathers, J. E., Urry, S. R., Hennig, E. M., & Hills, A. P. (2006). The pathomechanics of plantar fasciitis. *Sports Med, 36*(7), 585-611. doi:10.2165/00007256-200636070-00004

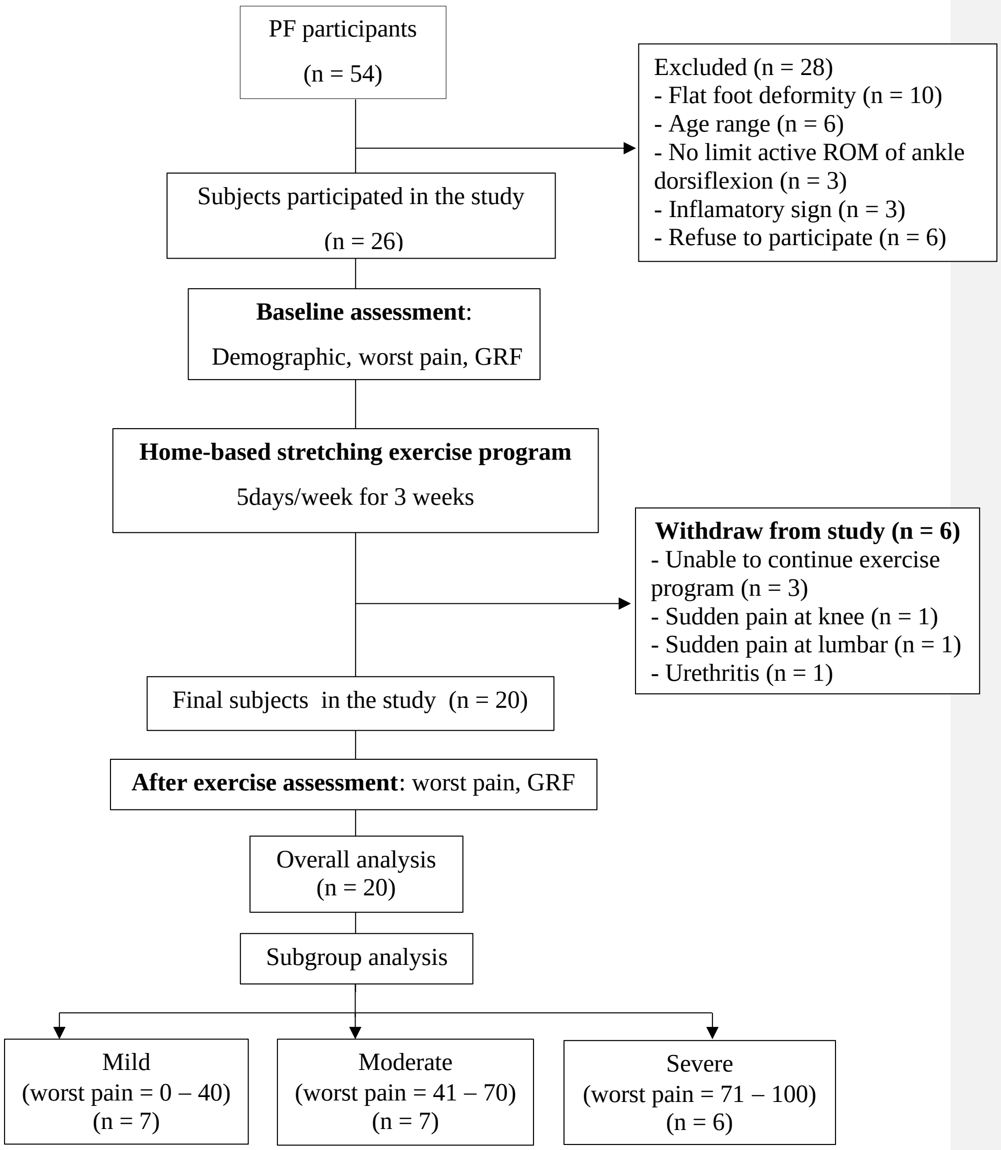

Fig. 1 Flow chart of the study.

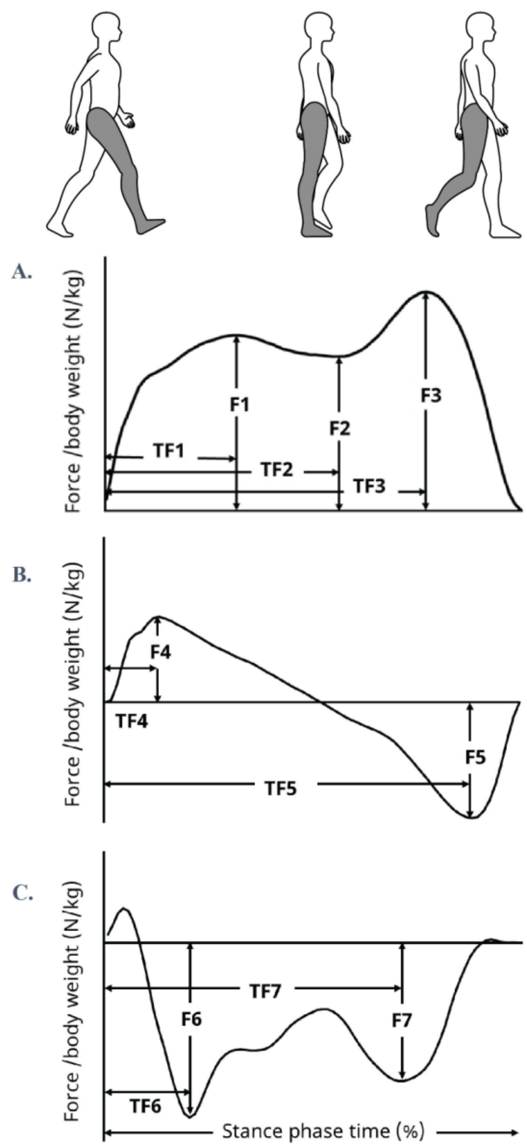

Fig. 2. Ground reaction force (GRF)-time variables [A) vertical (v)-GRF, B) antero-posterior (AP)-GRF, and C) medio-lateral (ML)-GRF].

Table 1 Baseline participant characteristics.

Variables	Total (n = 20)	Mild pain (n = 7)	Moderate pain (n = 7)	Severe pain (n = 6)	*P*-value
Age (years)	58.00 (53.00 – 61.00)	55.00 (52.00 – 59.00)	60.00 (53.00 – 65.00)	59.50 (50.00 – 64.25)	0.394[a]
Weight (kg)	61.83 (53.21 – 72.31)	61.65 (53.00 – 63.85)	58.00 (52.40 – 77.00)	67.80 (58.24 – 96.89)	0.513[a]
Height (cm)	159.00 (153.25 – 169.88)	154.00 (150.00 – 161.50)	158.00 (153.00 – 171.00)	166.40 (159.25 – 174.75)	0.100[a]
BMI (kg/m^2)	24.63 (21.84 – 27.50)	24.48 (22.64 – 26.00)	24.78 (20.99 – 26.33)	26.07 (20.89 – 32.07)	0.833[a]
Gender					
Male (n, %)	6, 30	2, 28.57	3, 42.86	2, 33.33	0.857[a]
Female (n, %)	14, 70	5, 71.34	4, 57.14	4, 66.67	
Disease onset (months)					
1-3 (n, %)	5, 25	3, 42.86	2, 28.57	1, 16.67	0.410[a]
3-6 (n, %)	2, 10	-	1, 14.29	-	
6-9 (n, %)	1, 5	1, 14.29	-	-	
>12 (n, %)	12, 60	3, 42.86	4, 57.14	5, 83.33	
Worst pain (scores)	50.00 (40.00 – 77.68)	35.00 (30.00 – 40.00)	50.00 (50.00 – 65.00)	80.00 (77.68 – 90.00)	**<0.001**[a,b]
Type					
Unilateral (n, %)	8, 40	4, 57.14	2, 28.57	2, 33.33	0.527[a]
Bilateral (n, %)	12, 60	3, 42.86	5, 71.43	4, 66.67	
Physical activity level					
High (n, %)	11, 55	3, 42.86	2, 28.57	2, 33.33	0.790[a]
Moderate (n, %)	1, 5	-	1, 14.29	-	
Low (n, %)	8, 40	4, 57.15	4, 57.14	4, 66.67	
Arch of foot type					
Normal (n, %)	19, 95	7, 100	6, 85.70	6, 100	0.395[a]
High (n, %)	1, 5	-	1, 14.30	-	

Gait speed (m/s)	0.98 (0.96 – 1.07)	0.97 (0.95 – 1.02)	0.98 (0.88 – 1.08)	1.03 (0.98 – 1.19)	0.254[a]
Cadence (steps/min)	105.19 (100.76 – 109.26)	104.58 (106.83 – 97.07)	103.96 (102.72 – 105.81)	108.15 (100.00 – 118.76)	0.332[a]

BMI: Body Mass Index; PF: Plantar Fasciitis. Data expressed as n, % or mean ± standard deviation.

[a]Significant difference tested by the Kruskal-Wallis test at $P<0.05$;

[b]Significant value adjusted by the Boferroni correction for multiple test at $P<0.05$ between mild vs severe subgroups

Table 2 Comparison of the ground reaction force (GRF)-time variables and worst pain between before and after exercise in all participants (n = 20).

Variables	**Before exercise** **Median (IQR)**	**After exercise** **Median (IQR)**	***P*-value***
Worst pain (scores)	50.00 (57.90 – 77.75)	31.00 (20.00 – 58.75)	**0.001**
F1 (N/kg)	101.52 (97.06 – 106.60)	101.47 (97.66 – 107.30)	0.351
F2 (N/kg)	81.34 (77.53 – 83.88)	77.88 (74.31 – 81.95)	**0.019**
F3 (N/kg)	105.69 (98.86 – 108.74)	106.15 (102.27 – 107.97)	0.575
TF1 (%)	19.10 (18.20 – 20.48)	18.10 (17.05 – 19.75)	0.080
TF2 (%)	33.60 (32.23 – 36.31)	32.96 (31.00 – 34.15)	**0.026**
TF3 (%)	52.58 (51.47 – 56.58)	51.70 (50.30 – 54.10)	**0.035**
F4 (N/kg)	14.43 (12.64 – 16.76)	15.20 (13.62 – 17.31)	0.135
F5 (N/kg)	-18.06 (-19.89 – -15.28)	-18.27 (-19.94 – -16.21)	0.100
TF4 (%)	12.53 (11.40 – 13.48)	12.30 (11.76 – 13.10)	0.778
TF5 (%)	62.10 (59.23 – 65.88)	60.77 (57.40 – 62.30)	**0.032**
F6 (N/kg)	-6.44 (-8.25 – -5.33)	-6.52 (-7.87 – -5.74)	0.841
F7 (N/kg)	-7.00 (-7.71 – -6.21)	-6.76 (-7.35 – -5.53)	0.247
TF6 (%)	19.90 (18.00 – 21.15)	17.78 (17.05 – 19.58)	0.073
TF7 (%)	55.45 (52.05 – 57.90)	54.60 (51.45 – 57.10)	0.059

P-value* tested by the Wilcoxon signed ranks test; IQR: Interquatile range; F: peak force; TF: time to peak force; N/kg: newton per kilogram; %: percent of stance phase

Table 3 Comparison of the vertical ground reaction force (GRF)-time variables between the three pain subgroups (mild, moderate, and severe) and within-group (before and after) comparisons.

Variables	Plantar fasciitis severity, median (IQR)						Between-group (B) *P*-value[a]	Between-group (A) *P*-value[a]
	Mild (n = 7)		Moderate (n = 7)		Severe (n = 6)			
	Before (B)	After (A)	Before (B)	After (A)	Before (B)	After (A)		
F1 (N/kg)	100.97 (97.75 – 103.20)	101.10 (98.14 – 106.75)	101.22 (97.04 – 106.14)	107.22 (100.73 – 107.49)	107.15 (91.41 – 111.43)	99.04 (95.91 – 109.82)	0.542	0.357
***P*-value[b]**	0.310		0.310		0.917			
F2 (N/kg)	82.56 (78.09 – 86.01)	77.06 (74.28 – 82.24)	81.31 (75.34 – 86.22)	78.65 (74.18 – 82.49)	79.91 (75.20 – 81.68)	78.16 (72.28 – 82.49)	0.909	0.999
***P*-value[b]**	**0.043**		0.128		0.600			
F3 (N/kg)	107.55 (101.16 – 109.02)	104.86 (101.56 – 108.06)	102.62 (97.60 – 114.63)	106.58 (104.58 – 107.40)	106.26 (97.16 – 109.67)	105.79 (97.61 – 111.95)	0.346	0.255
***P*-value[b]**	0.612		0.735		0.917			
TF1 (%)	18.80 (18.50 – 20.67)	17.40 (16.60 – 19.80)	19.20 (18.20 – 20.50)	18.00 (17.20 – 19.60)	18.85 (16.93 – 20.61)	19.18 (17.48 – 20.63)	0.639	0.677
***P*-value[b]**	0.063		0.310		0.892			
TF2 (%)	33.40 (32.00 – 34.00)	31.80 (30.25 – 33.33)	34.40 (33.00 – 38.33)	34.00 (31.00 – 34.00)	34.00 (31.04 – 38.69)	34.43 (31.48 – 37.74)	0.459	0.671
***P*-value[b]**	**0.018**		0.128		0.600			
TF3 (%)	51.80 (51.67 – 58.00)	51.50 (50.67 – 52.40)	56.33 (51.80 – 56.60)	51.80 (49.67 – 49.67)	51.90 (49.63 – 57.06)	53.18 (48.65 – 55.04)	0.422	0.176
***P*-value[b]**	0.091		0.310		0.400			

P-value[a] tested by the Kruskall Wallis test; *P*-value[b] tested by the Wilcoxon signed ranks test; N/kg: newton per kilogram; %: percent of stance phase; B: Before exercise; A: After exercise

Table 4 Comparison of the shear ground reaction force (GRF)-time variables between three subgroups and within-group comparison.

Variables	Plantar fasciitis severity, median (IQR)						Between-group (B) *P*-value[a]	Between-group (A) *P*-value[a]
	Mild (n = 7)		Moderate (n = 7)		Severe (n = 6)			
	Before (B)	After (A)	Before (B)	After (A)	Before (B)	After (A)		
F4 (N/kg)	13.76 (12.63 – 17.10)	15.81 (13.57 – 17.63)	14.24 (12.39 – 16.67)	14.88 (12.42 – 19.06)	16.36 (12.13 – 18.74)	14.81 (12.64 – 16.66)	0.748	0.662
***P*-value[b]**	**0.043**		0.237		0.116			
F5 (N/kg)	-17.64 (-19.96 – -14.76)	-18.76 (-19.95 – -16.17)	-18.43 (-19.38 – -15.27)	-17.40 (-20.87 – -16.27)	-19.29 (-20.15 – -15.79)	-18.85 (-20.59 – -16.03)	0.542	0.357
***P*-value[b]**	0.091		0.310		0.753			
TF4 (%)	13.00 (10.80 – 13.00)	12.60 (11.80 – 12.75)	12.25 (11.67 – 14.00)	12.20 (11.80 – 13.80)	11.60 (10.69 – 13.43)	11.88 (11.37 – 13.50)	0.909	0.999
***P*-value[b]**	0.204		0.463		0.463			
TF5 (%)	59.75 (59.20 – 67.00)	60.00 (57.60 – 61.80)	63.50 (62.20 – 64.75)	60.33 (57.20 – 61.80)	60.20 (56.51 – 66.75)	62.20 (56.47 – 63.44)	0.346	0.255
***P*-value[b]**	0.176		0.128		0.528			
F6 (N/kg)	-7.22 (-8.69 – -5.87)	-7.19 (-8.19 – -6.35)	-6.23 (-8.49 – -4.89)	-5.72 (-8.49 – -4.42)	-6.00 (-7.13 – -5.13)	-6.02 (-6.93 – -5.74)	0.639	0.677
***P*-value[b]**	0.735		0.345		0.753			
F7 (N/kg)	-7.40 (-8.74 – -6.37)	-6.93 (-7.61 – -6.34)	-6.58 (-7.70 – -6.49)	-6.52 (-7.78 – -4.83)	-6.44 (-7.68 – -5.54)	-6.63 (-7.31 – -4.90)	0.459	0.671
***P*-value[b]**	0.499		0.398		0.753			
TF6 (%)	20.33 (18.00 – 22.40)	17.40 (16.00 – 20.00)	19.80 (18.20 – 20.60)	17.80 (17.20 – 18.40)	19.00 (16.75 – 21.10)	18.25 (17.10 – 23.55)	0.422	0.176
***P*-value[b]**	**0.018**		0.176		0.600			

Variables	Plantar fasciitis severity, median (IQR)						Between-group (B) P-value[a]	Between-group (A) P-value[a]
	Mild (n = 7)		Moderate (n = 7)		Severe (n = 6)			
	Before (B)	After (A)	Before (B)	After (A)	Before (B)	After (A)		
TF7 (%)	55.50 (55.33 – 57.60)	54.80 (51.60 – 57.20)	55.60 (52.00 – 59.20)	54.20 (50.80 – 58.33)	51.90 (50.63 – 58.06)	55.08 (51.93 – 56.75)	0.748	0.662
***P*-value[b]**	**0.043**		0.150		0.598			

P-value[a] tested by the Kruskall Wallis test; *P*-value[b] tested by the Wilcoxon signed ranks test; N/kg: newton per kilogram; %: percent of stance phase; B: Before exercise; A: After exercise