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Original Research

Effects of three gait retraining techniques in runners with patellofemoral pain

Ana F. dos Santos [a,*], Theresa H. Nakagawa [b], Giovanna C. Lessi [a], Bruna C. Luz [a], Heitor T.M. Matsuo [a], Giovana Y. Nakashima [c], Carlos D. Maciel [c], Fábio V. Serrão [a]

[a] Physical Therapy Department, Federal University of São Carlos, São Carlos, Brazil
[b] Fundação Oswaldo Cruz, Manaus, Brazil
[c] Department of Electrical Engineering, University of São Paulo, São Carlos, Brazil

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ABSTRACT

Objectives: Analyze the effects of 3 gait retraining: forefoot landing (FFOOT), 10% step rate increase (SR10%) and forward trunk lean (FTL) on lower limb biomechanics and clinical measurements in patellofemoral pain (PFP) runners.
Design: Case series report.
Settings: Biomechanical laboratory and treadmill running.
Participants: Eighteen recreational PFP runners randomized in 3 groups.
Main outcome measures: Lower limb kinematics and muscle activation were assessed at baseline and 2-week post-training. Pain intensity and function limitation, measured by AKPS (Anterior Knee Pain Scale) and LEFS (Lower Extremity Functional Scale) assessed at baseline, post-training and 6-month follow-up. Repeated measures analysis of variance was used to compare the effects of gait retraining.
Results: FFOOT and FTL increased the AKPS score at post-training($P = .001$; $P = .008$) and 6-month follow-up($P < .001$; $P < .001$). SR10% increased the AKPS score from baseline to 6-month follow-up($P = .006$). Pain and LEFS score were improved after gait retraining regardless group. FFOOT presented greater gastrocnemius($P = .037$) and rectus femoris pre-activation($P = .006$) at post-retraining session. Gait retraining reduced the muscle activity during stance phase and increased during the late-swing regardless group.
Conclusion: The three techniques presented clinical benefits, improvement of pain symptoms and functional scores, was not accompanied with significant biomechanics differences that could entirely explain this clinical improvement after the intervention.

1. Introduction

Running is one of the most popular physical activities in the world. Associated with a moderate evidence shows improvements in aerobic fitness and cardiovascular function due to running (Oja et al., 2015). Every year, 19.4–79% of runners experience a musculoskeletal injury (Van Gent et al., 2007). Forty-two percent of all injuries involve the knee joint and patellofemoral pain (PFP) is the most common injury (Taunton et al., 2002).

PFP etiology is described as a multifactorial (Collins et al., 2018; Powers, 2003), possibly coupling structural abnormalities with altered knee, hip and pelvis biomechanics (Witvrouw et al., 2014) which could consequently increase patellofemoral joint stress (Petersen et al., 2014; Teng, MacLeod, Link, Majumdar, & Souza, 2015). A recent systematic review (Neal, Barton, Gallie, Halloran, & Morrissey, 2016) had shown that an increased hip adduction in female runners presented a very limited evidence for PFP development, although there was a correlation between PFP in runners and excessive hip adduction, internal rotation and contralateral pelvic drop supported by cross-sectional moderate evidence. Considering the association of pain-related symptoms and strength, Rathleff, Rathleff, Crossley, and Barton (2014) suggested hip muscles weakness following the injury development. Moreover, when compared to asymptomatic runners, females with PFP showed differences of gluteal muscles neuromuscular control

* Corresponding author. Washington Luis, km 235, Departamento de Fisioterapia, São Carlos, SP, CEP 13565-905, Brazil.
E-mail addresses: santosaf@live.com, laiot.ufscar@gmail.com (A.F. dos Santos).

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during running (J D; Willson, Kernozek, Arndt, Reznichek, & Scott Straker, 2011).

It has been shown that running technique modifications may have the potential to improve lower limb biomechanics with simple instructions (Agresta & Brown, 2015; C J; Barton et al., 2016). These interventions could improve the altered biomechanics and consequently lower the load on the patellofemoral joint. In fact, previous study conducted with healthy runners (Crowell & Davis, 2011) and runners with PFP (Bonacci, Hall, Saunders, & Vicenzino, 2017; Noehren, Scholz, & Davis, 2011; J. D.; Willson, Sharpee, Meardon, & Kernozek, 2014; Willy, Scholz, & Davis, 2012) showed significant reduction on tibial acceleration, vertical force loading rate, contralateral pelvic drop, hip adduction, patellofemoral joint stress, lower knee pain and improvement in function. In addition, transitioning from a rearfoot to forefoot strike pattern (FFOOT) (Cheung & Davis, 2011; Kulmala, Avela, Pasanen, & Parkkari, 2013; Lieberman et al., 2010; Roper et al., 2016), step rate increase by 10% (SR10%) (Chumanov, Wille, Michalski, & Heiderscheit, 2012; Hafer, Brown, DeMille, Hillstrom, & Garber, 2015; Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011; Neal, Barton, Birn-jeffrey, Daley, & Morrissey, 2018; Schubert, Kempf, & Heiderscheit, 2014) and, forward trunk lean (FTL) (dos Santos et al., 2016; Teng & Powers, 2014) are some of the gait patterns described in the literature that have biomechanical potential to benefit PFP runners.

Despite the popularity increase of gait retraining approach, the effects of these modifications on lower limb kinematics and muscle pattern activity should be better investigated (Agresta & Brown, 2015). The majority of studies was focused in the immediate effects of these interventions and the effects on healthy runners (Napier, Cochrane, Taunton, & Hunt, 2015). The muscle activation pattern play an important role in load absorption during the stance phase of weight bearing activities (Zhang, Bates, & Dufek, 2000) and according to the author's knowledge, excepted for Giandolini et al. (2013) and Chumanov et al. (2012) which evaluated the muscle activity alterations after acute interventions, no study proposed to analyze these effects. Moreover, the effects of gait retraining in pain and function in PFP runners remains unclear (Collins et al., 2018).

The aim of this study was to quantify the post-training and moderate term effects of FFOOT, SR10% and FTL after a gait retraining program on clinical outcomes (knee pain intensity and function); and the post-training effects on ankle, knee, hip and trunk kinematics; and lower limb muscle activity in PFP runners. We hypothesized that the gait retraining would result in pain and functional improvement accompanied with greater lower limb kinematic alignment and electromyography (EMG) modifications for all three running techniques.

2. Methods

2.1. Subjects

Participants were recruited through flyers posted in the university, running recreational centers, parks, running events and social network websites. To be included in the study, runners had to be natural rearfoot strikers, run a minimum of 15 km per week in the last 3 months, self-report PFP symptoms during and/or after their running training in the last 3 months unrelated to any traumatic event, between the ages of 18 and 35 years, report anterior or retropatellar knee pain during at least 2 of the following functional activities besides running: squatting, isometric quadriceps contraction, ascending/descending stairs, kneeling, jumping, prolonged sitting. Finally, they had to present the worst knee pain experienced in the previous week of “3” or greater using a 10-cm visual analogue scale (VAS) (“0” indicating no pain and “10” indicating extremely intense pain). Runners were excluded if they had any lower limb surgery, neurological, cardiovascular or orthopaedic condition except PFP. A licensed physical therapist screened all potential participants for inclusion and exclusion criteria.

Seventy-eight runners responded to the recruitment attempt. Most were not eligible for inclusion due to associated lower limb injuries, age criteria, low weekly training distance, short PFP symptoms duration or did not agree to participate in the gait retraining sessions. Eighteen runners met inclusion criteria and accepted to participated in this study (9 females and 9 males). A post-hoc analysis was conducted to verify that the study was powered appropriately using peak hip adduction values, which resulted in power greater than 0.9 (effect size = 0.218; $\alpha = 0.05$).

All participants provided informed consent as approved by the University Ethics Committee for Human Investigations (735.596).

2.2. Procedures

To assess pain and function on the day of testing, two validated self-reported questionnaires widely used in clinical assessments of lower limb injuries and PFP were applied. The Anterior Knee Pain Scale (AKPS) (Kujala et al., 1993) is composed by 13 multiple-choice questions to assess the PFP symptoms severity and participant's functional limitations. The score ranges from 0 (worst condition) to 100 (normal knee condition, no symptoms and no daily functional restrictions). The Lower Extremity Functional Scale (LEFS) (J. Binkley, Stratford, Lott, & Riddle, 1999) graduates the participant's ability to perform twenty everyday tasks. The score for each task is separated in 5 categories “0” (extreme difficulty or unable to perform activity), “1” (quite a bit of difficulty), “2” (moderate difficulty), “3” (a little bit of difficulty) and “4” (no difficulty). The maximal function is 80 points. The runners also reported the worst pain intensity in the last week in the 10-cm VAS scale. The AKPS, LEFS and VAS were used to assess pain and function before and after the retraining program and at the 6-month follow-up.

Runners included in this study were invited to perform 2 biomechanical testing sessions, a baseline and a post-retraining session, held at most 3 days after the end of the retraining program. Nine runners reported bilateral symptoms, in these cases, the lower extremity reported to be most affected was tested (8 left, 10 right). Firstly, a baseline kinematic (7-camera, Qualisys Motion-Capture System, Qualisys Medical-AB, Sweden) and electromyographic (EMG) (TrignoTM Wireless System, Delsys Inc., USA) analysis were performed during runner's preferred running pattern without any instruction at a comfortable self-selected speed on a treadmill. The comfortable speed was determined by asking the common speed in a 30 min run for each participant. The speed did not change between sessions.

Three-dimensional motion analysis of ankle, knee, hip and trunk were recorded at 240 Hz using anatomical and tracking reflective markers placed on each participant as described in a previous study (dos Santos et al., 2016). The EMG data were simultaneously recorded with the kinematics at 2400 Hz sample rate. The activity of seven lower limb muscles was recorded during running: medial gastrocnemius (MG), tibialis anterior (TA), vastus lateralis (VL), rectus femoris (RF), gluteus medius (GMED), biceps femoris (BF) and gluteus maximus (GMAX). The participant's skin was shaved and cleaned with alcohol, then wireless surface electrodes were applied to the according to the SENIAM recommendations (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Each electrode pre-amplified the signal and was interfaced to an amplifier unit (Delsys Inc., USA, operating range 40 m, transmission frequency 2.4 GHz, CMRR >80 dB; bandwidth of 450 Hz at >80 dB/s). The EMG signals were digitized using a 16-bit analog-to-digital board synchronized with the motion analysis data. The same researcher placed the markers and electrodes on all participants.

All biomechanical procedures were repeated at the post-retraining session. Runners were encouraged to execute the learned technique during the post-retraining assessment. For both days, the participant started the session with a warm up on a treadmill (5 min walking at 1.38 m s^{-1}). Each participant wore the same shoes (Asics Gel-Equation5, ASICS, Kobe, Japan) to standardize footwear condition. The step rate was visually determined by counting the number of right foot strikes over a 30-s period and multiplying by 4. The footstrike pattern was confirmed using a real-time visual analysis of plantar pressure distribution using insole sensors (Pedar-System, Novel, Munich, Germany) operating at 100 Hz. The participants were instructed to run for 2 min and 30-s samplings of data were performed in the end of this period.

2.3. Gait retraining

Participants were randomized in 3 groups:1) FFOOT group; 2) SR10% group and 3) FTL group. Randomization was performed by a second independent researcher blinded to the participant information (concealed allocation) using a random numbers generator to either 3 groups using blocked randomization so that there were an equal number (n = 6) of participants in each group. The sealed and opaque envelopes were kept in a locked filing cabinet in the laboratory and opened once the participant agreed to participate in the study. Participants were not blinded to what group they were in. The examiner researcher was not blinded to the participant gait retraining condition during the post training session.

Each group performed a 2-week gait retraining in one of three running techniques on a treadmill. The program was composed by 8 sessions (4 sessions/week). Running time increased progressively from 15 to 30 min and verbal instructions to keep the new running pattern decreased progressively (Cheung & Davis, 2011; Crowell & Davis, 2011; Roper et al., 2016; Willy et al., 2012) (Fig. 1). Treadmill speed was the same as the baseline session for each runner. Participants wore their own shoes during the retraining sessions and were instructed not to run outside retraining sessions. For FFOOT group, runners were instructed to "strike with the forefoot", touching the ground with the metatarsal joints, and rearfoot contact after foot strike was optional after the first contact. For SR10% technique, runners were instructed to keep a 10% higher cadence controlled by a digital audio metronome. For the FTL condition, the runners were asked to "run with an increase in flexed trunk posture". No changes to trial outcomes after the trial commenced was done.

2.4. Data processing

The average of 10 successive strides was analyzed for each running trial for kinematic and EMG variables. Visual 3D software (Version 3.9; C-Motion Inc., Rockville, USA) was used to calculate anatomical joint coordinate system and filter marker trajectory (4th-order, zero-lag, low-pass Butterworth at 12 Hz). The Cardan angles were calculated using the joint coordinate system definitions recommended by the International Society of Biomechanics (Wu et al., 2002) relative to the static standing trial. Footstrike and toe off events were identified using a custom Matlab (MathWorks Inc., Natick, USA) algorithm. Footstrike was identified by the instant that distal heel marker anteroposterior velocity changed from positive to negative (Zeni, Richards, & Higginson, 2008). Toe-off was determined by the second knee extension peak (Fellin, Rose, Royer, & Davis, 2010). All kinematic data (averages and peak angles) were analyzed during the stance phase.

Using a custom Matlab code, raw EMG signals were band-pass filtered at 20–450 Hz. After that, the data were full-wave rectified and low-pass filtered using a bidirectional, 4-th order Butterworth filter with a cut off frequency of 50 Hz (Chumanov et al., 2012). The EMG data was normalized by the mean of the respective muscle activity across the entire gait cycle considering 10 steps as suggested by Chumanov et al. (2012). The study considered the average EMG data for each of the 3 running specific phases: stance phase (0 ≅ 45% of gait cycle), first half of late-swing (80–90% of gait cycle) and second half of late-swing (90–100% of gait cycle).

2.5. Data analysis

Data normality and variance homogeneity were tested using the Shapiro-Wilk and Levene tests, respectively. Repeated measures analysis of variance (ANOVA) with a 3-by-3 mixed-model (time x group) (baseline, post-retraining and 6-month follow-up x 3 groups) design was used to compare the effects of gait retraining on

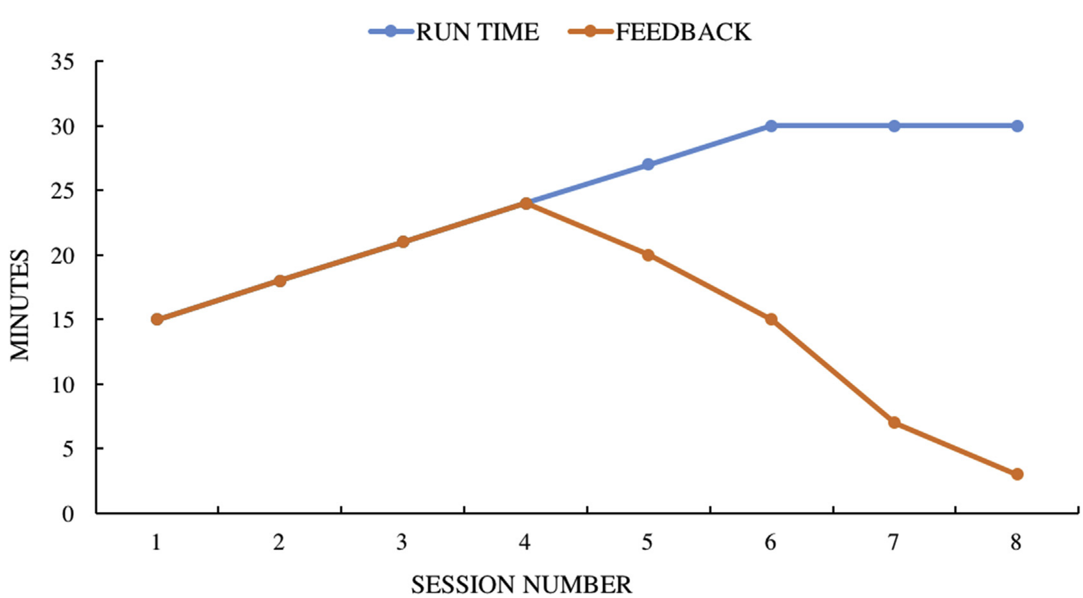

Fig. 1. Gait retraining protocol.

pain intensity and function (AKPS and LEFS Scales) with group (FFOOT, SR10% and FTL) as independent factor and time as a repeated factor.

For biomechanics analysis, a 2-by-3 ANOVA (baseline and post-retraining x 3 groups) with time as a repeated factor was performed. The dependent variables were: lower limb kinematics (ankle and knee sagittal angle at initial contact, average and peak knee flexion, peak knee abduction, peak knee external rotation, hip flexion at initial contact, peak hip adduction, peak hip internal rotation and average trunk flexion) and average muscle activity from MG, TA, VL, RF, GMED, BF and GMAX during 3 phases of gait cycle. Separated models for running condition were used for each outcome. If the assumption of sphericity was violated, Greenhouse-Geisser correction were used. If there were significant group-by-time interaction, univariate effects were analyzed. Tukey's post hoc tests were used to determine significant pairwise differences when there was a significant interaction. In the absence of a significant interaction, the main effect of time and group were reported. Effect size reported is partial eta-squared (η^2_p). Statistical analyses were made using SPSS version 17.0 (SPSS Inc, Chicago, USA). The significance level for all analyses was set at 0.05.

3. Results

Participants demography characteristics and the PFP information can be found in Table 1. No significant difference was observed between groups in terms of the age, mass, running distance trained per week, worst pain intensity in the last week, AKPS and LEFS scores (P > .05). Running experience in years was greater for SR10% group compared to others (P = .027). All randomized participants completed all trials. The groups were similar at baseline for pain intensity, function, joint angles and EMG measurements (P > .05).

For clinical measurements, there was a significant group-by-time interaction for AKPS score (P = .023; effect size = 0.306) (Fig. 2). FFOOT (P = .001; mean difference [MD]: −16.50 points; 95% confidence interval [CI]: −26.31, −6.68) and FTL (P = .008; MD: −13.00 points; 95% CI: −22.81, −3.18) gait retraining improved AKPS when comparing baseline to post-training and; baseline to 6-month follow-up scores (P < .001; MD: −18.73 points, 95% CI: −26.54, −10.92) (P < .001; MD: −15.50; 95% IC: −23.31, −7.68). SR10% condition increased the AKPS from baseline to 6-month follow-up (P = .006; MD: −10.83 points; 95% CI: −18.64, −3.02) and from post-training to 6-month follow-up (P = .007; MD: −9.33 points; 95% CI: −16.26; −2.40). No difference was shown between baseline and post-training values (P = 1.00; MD: −1.50 points; 95% CI: −11.31, 8.31).

However, regardless of group, there were significant main effects of time for worst knee pain in previous week (P < .001; effect size = 0.190) and LEFS questionnaire score (P < .001; effect size = 0.269). There was a reduction of pain intensity from baseline to post-training session (P = .002; MD: 2.75; 95% CI: 1.05, 4.44) and from baseline to 6-month follow-up (P < .001, MD: 3.77; 95% CI: 1.96, 5.58) (Fig. 3). The same results were observed for LEFS score (Fig. 4). The gait retraining increased the participants' ability to perform functional activities compared baseline to post-training value (P = .001; MD: −8.16 points; 95% CI: −12.89, −3.44) and baseline to 6-month follow up (P < .001; MD: −8.74 points; 95% CI: −13.30, −4.17).

Kinematic results are shown in Table 2. The specific gait pattern modification after retraining for each running technique was achieved considering a significant group-by-time interaction for ankle sagittal angle at initial contact (P < .001) and average trunk flexion angle (P < .001). Planned pairwise comparisons showed that FFOOT group exhibited greater plantarflexion angle post-retraining (P < .001; MD: 21.54°; 95% CI: 15.44, 27.64) and it was significantly greater when compared to SR10% (P = .001, MD: −15.44°; 95% CI: −24.56, −6.31) and FTL (P < .001; MD: −22.15°; 95% CI: −31.27, −13.03). The runners trained in the FTL condition exhibited greater trunk flexion (P < .001; MD: −8.23°; 95% CI: −11.17, −5.28) compared to their baseline and also greater angle than the other groups post training (P = .004; MD: 9.69°; 95% CI: 3.02, 16.36 compared to FFOOT; P < .001; MD: 14.29°; 95% CI: 7.62, 20.97 compared to SR10%). A significant group-by-time interaction was found for running cadence (P < .001). The number of steps per minute was greater for SR10% group between sessions (P < .001).

EMG muscle activity results are reported in Table 3. There was a significant group-by-time interaction during the first late-swing phase (80–90% of gait cycle) for medial gastrocnemius (P = .037) and, a significant interaction during the second late-swing phase (90–100% of gait cycle) for rectus femoris (P = .006). The pairwise comparison showed greater medial gastrocnemius activation during the post-training session between FFOOT and FTL groups (P = .022 during 80–90% of gait of cycle and P = .038 during 90–100% of gait cycle). Participants who trained at FFOOT technique demonstrated greater rectus femoris activity compared to SR10% (P = .002, MD: 0.52; 95% CI: 0.18, 0.85) and FTL (P = .030, MD: 0.36; 95% CI: 0.03, 0.70) post-training sessions. Regardless of group, gait retraining decreased medial gastrocnemius (P = .024; MD: 0.20; 95% CI: 0.03, 0.37), vastus lateralis (P = .027; MD: 0.97; 95% CI: 0.01, 0.18) and gluteus medius (P = .003; MD: 0.12; 95% CI: 0.05, 0.19) activation during the stance phase of running. A significant main effect was also found during late-swing phase for medial gastrocnemius (P = .003; MD: −0.34; 95% CI: −0.54, −0.13) and rectus femoris (P = .049; MD: −0.11; 95% CI: −0.22, 0), the gait retraining increased the activity of these muscles.

4. Discussion

The purpose of this study was to determine if a 2-week gait retraining in FFOOT, SR10% or FTL techniques would be able to reduce pain intensity and improve function accompanied with lower limb kinematics and EMG alterations in PFP runners. Also, if the clinical measurements would be maintained in a moderate-term. The results of this case series partially support our

Table 1
Participants demographics at baseline.

	Age (years)	Height (m)	Mass (kg)	PFP symptoms duration (years)	Average running distance (km/week)	Running experience (years)	AKPS score	LEFS score	Gender
FFOOT	28.50 (2.74)	1.69 (0.03)	66.33 (13.60)	0.70 (0.69)	21.17 (5.85)	1.76 (1.86)	75.67 (6.86)	63.83 (8.93)	2 M/4 F
SR10%	26.50 (5.43)	1.75 (0.05)§	74.83 (10.07)	4.06 (3.65)	25.67 (7.39)	4.58 (3.32)*,§	81.33 (6.95)	70.83 (2.04)	4 M/2 F
FTL	26.83 (2.71)	1.66 (0.06)	64.33 (10.98)	2.19 (3.83)	22.00 (6.93)	0.79 (0.50)	75.50 (9.63)	65.50 (9.27)	3 M/3 F

Values are mean (SD); PFP: Patellofemoral Pain; AKPS: Anterior Knee Pain Scale; LEFS: Lower Extremity Functional Scale; M: male; F: female; FFOOT: Forefoot landing group; SR10%: step rate increase group; FTL: Forward trunk lean group.
*Significant difference from FFOOT group (*P* < .05).
§Significan difference from FTL group (*P* < .05).

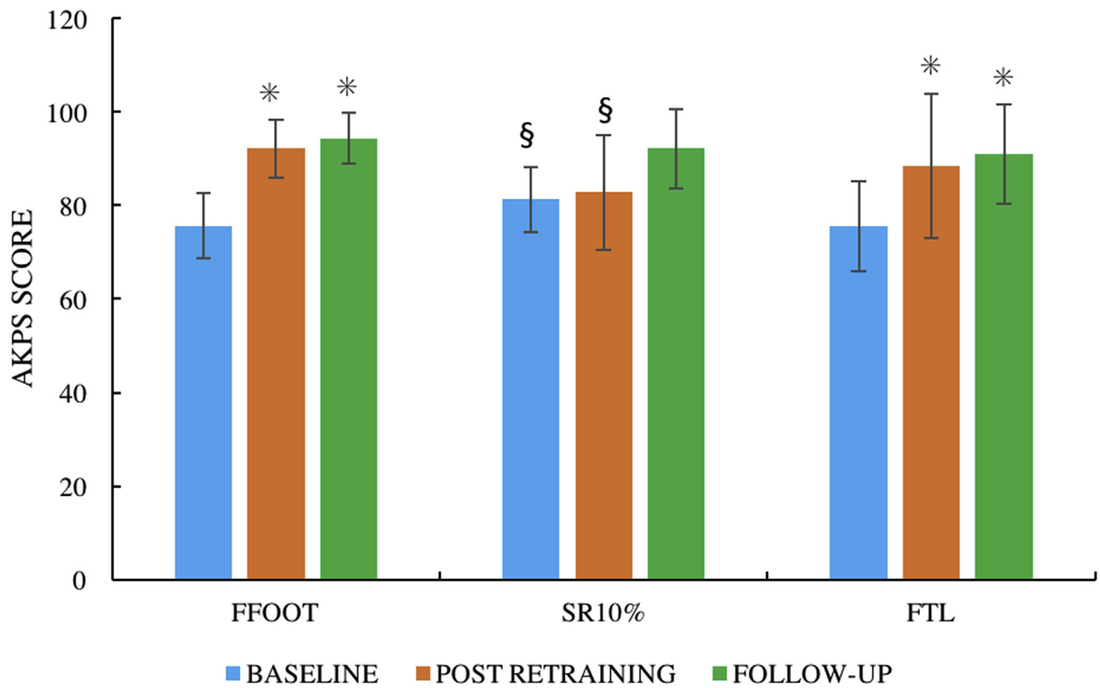

Fig. 2. Mean (standard deviation) of AKPS score at baseline, post-retraining and 6-month follow-up. There was significant group X time interaction. AKPS: Anterior Knee Pain Scale; FFOOT: forefoot strike pattern; SR10%:step rate increase by 10%; FTL: forward trunk lean. *Significantly different from baseline ($p<0.05$). §Significantly different from 6-month follow-up ($p<0.05$).

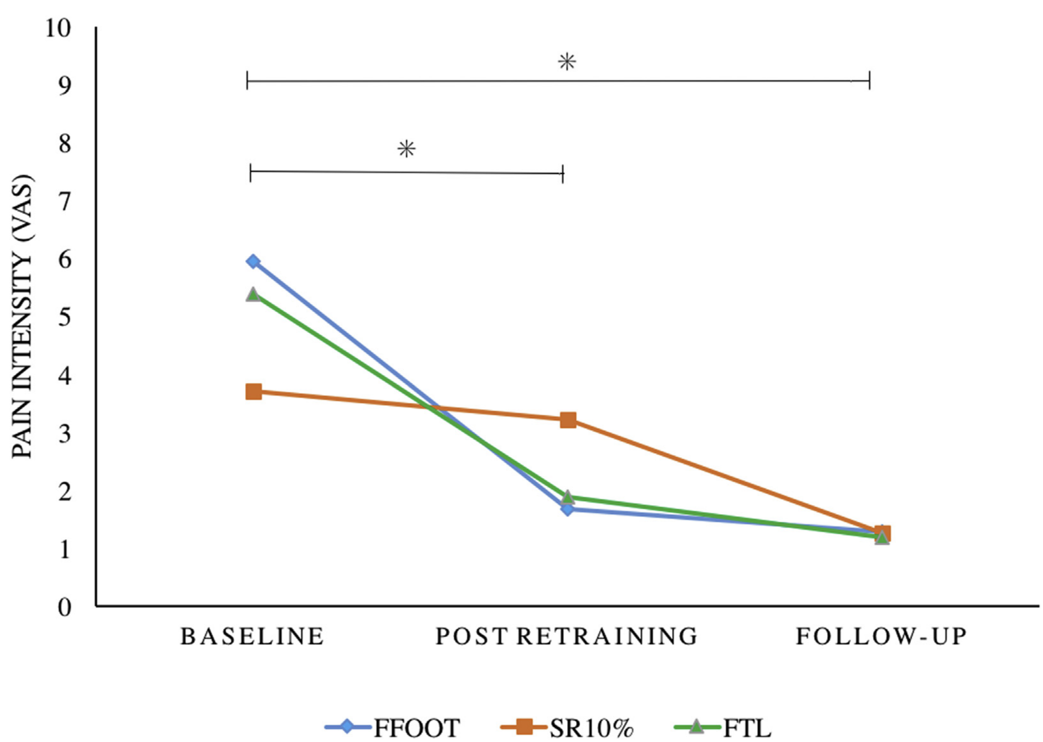

Fig. 3. Mean pain intensity at baseline, post-retraining and 6-month follow-up. There was significant main effect of time. VAS: Visual Analogue Scale; FFOOT: forefoot strike pattern; SR10%: step rate increase by 10%; FTL: forward trunk lean. *Significantly different from baseline ($p<0.05$).

hypothesis. Interestingly, our results showed that clinical benefits, as demonstrated by improvement of pain symptoms and functional scores, was not accompanied with significant kinematic and EMG differences that could explain this clinical improvement after the gait retraining.

The current study showed that FFOOT and FTL running techniques were statistically and clinically important and improved the function after 8-sessions of gait retraining. The minimal clinically important difference (MCID) of AKPS Scale is 8–10 points (Crossley, Bennell, Cowan, & Green, 2004). In both running techniques the

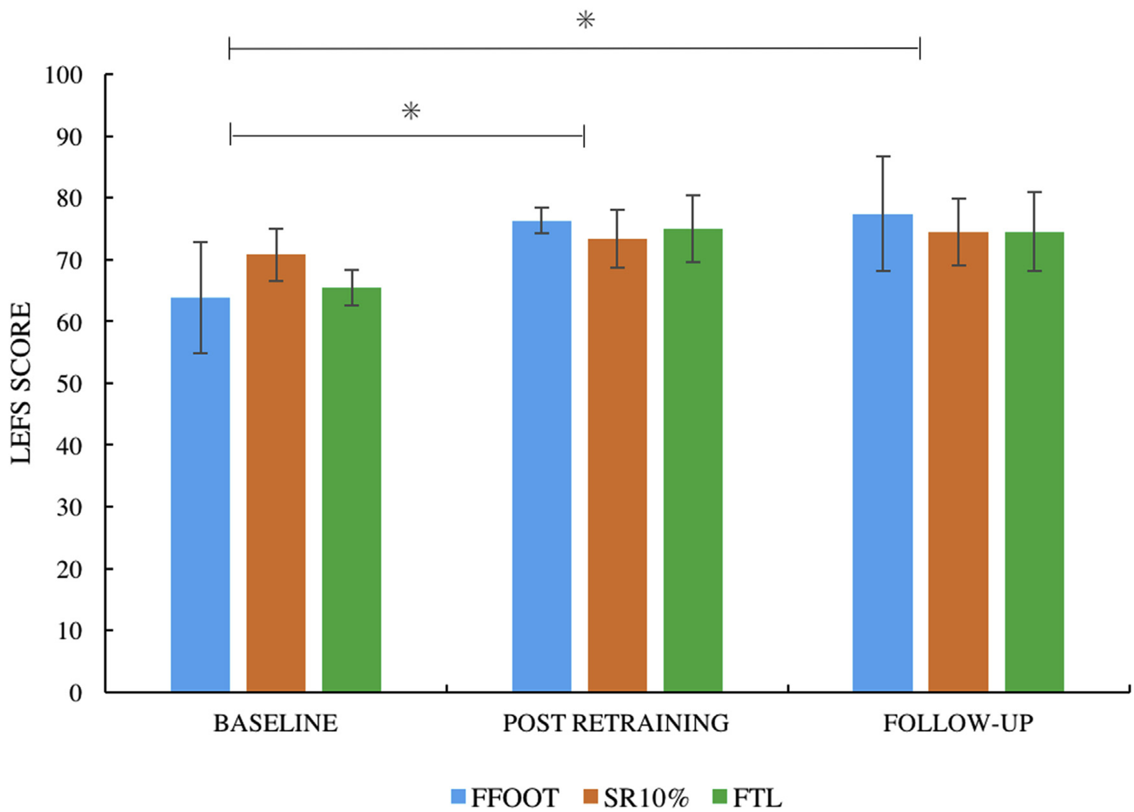

Fig. 4. Mean (standard deviation) of LEFS score at baseline, post-retraining and 6-month follow-up. There was significant main effect of time. LEFS: Lower Extremity Functional Scale; FFOOT: forefoot strike pattern; SR10%: step rate increase.

Table 2
Effects of gait retraining on lower limb and trunk kinematics during running.

	Ankle	Knee					Hip			Trunk
	Dorsi (+)/Plantar flexion (−) at initial contact	Flexion at initial contact	Peak flexion	Average flexion	Peak abduction	Peak external rotation	Flexion at initial contact	Peak adduction	Peak internal rotation	Average flexion
FFOOT										
Baseline	10.26 (2.81)	7.89 (2.47)	35.86 (5.20)	22.23 (3.20)	3.90 (3.86)	21.28 (4.45)	26.66 (3.22)	13.19 (2.76)	17.44 (3.67)	10.04 (4.06)
Post	−11.29 (5.49)*	11.93 (9.57)	34.18 (4.59)	24.26 (5.77)	4.95 (2.59)	23.69 (5.49)	25.13 (5.40)	14.18 (4.24)	17.75 (5.36)	9.36 (4.82)§
SR10%										
Baseline	5.16 (6.66)	6.83 (2.22)	35.59 (3.29)	22.28 (2.93)	4.00 (2.68)	19.70 (5.84)	30.24 (7.77)	11.05 (3.12)	17.66 (5.16)	7.21 (3.23)
Post	4.15 (5.10)§	9.63 (5.05)	32.37 (1.68)	21.83 (3.56)	2.73 (2.60)	16.29 (6.96)	27.57 (5.33)	8.93 (4.16)	16.54 (4.24)	4.75 (3.12)§
FTL										
Baseline	10.26 (2.13)	3.27 (6.17)	33.90 (7.21)	20.57 (6.19)	3.92 (2.69)	22.77 (5.23)	27.86 (6.91)	12.63 (5.88)	15.50 (2.39)	10.82 (4.24)
Post	10.86 (6.86)§	2.15 (5.51)	34.29 (7.07)	20.61 (5.89)	2.91 (2.46)	24.45 (4.47)	28.98 (4.95)	10.71 (4.54)	14.76 (1.71)	19.05 (4.71)*
Effect size (η^2_p)	.713	.143	.074	.047	.323	.244	.114	.218	.032	.697

Values are mean (SD); FFOOT: Forefoot landing group; SR10%: step rate increase group; FTL: Forward trunk lean group.
*Statistically different from baseline ($P < .05$).
§Statistically significant between-group difference at this time point ($P < .05$).

MD values for this Scale were greater than MCID, which indicates that the changes were clinically relevant with greater improvement for FFOOT. The benefits were maintained after 6 months without specific treatment while the runners practiced their usual training. A previous study conducted with 3 PFP runners trained in forefoot strike pattern had shown an average improvement of 10 points at post-training and 12 points of improvement after 3 months follow-up using the same questionnaire. The group trained in the SR10% condition showed longer PFP symptoms duration compared to the other groups, which could explain the lack of clinical differences at the post-training session. However, the SR10% group presented clinical improvement at the 6-month follow-up assessment.

In addition, regardless group, there were a 54% reduction on worst knee pain after training and 75% reduction in 6 months follow-up measurement. This change exceeded the MCID for pain intensity outcome measure (2 cm on the VAS)(Crossley et al., 2004), which indicates a clinically relevant improvement after gait retraining with greater changes at the 6-month follow-up. Previous studies which involved forefoot gait retraining reported 80–86% of pain reduction after intervention (Cheung & Davis, 2011; Roper et al., 2016) and gait retraining using visual feed-back techniques to improve lower limb alignment reduced in 90.5–100% the related pain in PFP runners (Noehren et al., 2011; Willy et al., 2012). For LEFS Scale, the MD values presented after gait retraining did not

Table 3
Effects of gait retraining on lower limb muscle activity.

	MG	TA	VL	RF	GMED	BF	GMAX
Stance Phase							
FFOOT							
Baseline	1.96 (0.45)	1.08 (0.60)	1.80 (0.22)	1.35 (0.18)	1.50 (0.22)	1.08 (0.32)	1.27 (0.29)
Post	1.64 (0.35)	1.14 (0.35)	1.81 (0.11)	1.48 (0.11)	1.43 (0.20)	1.04 (0.37)	1.12 (0.29)
SR10%							
Baseline	1.98 (0.08)	0.56 (0.21)	1.81 (0.12)	1.18 (0.33)	1.56 (0.10)	1.04 (0.21)	1.14 (0.34)
Post	1.96 (0.17)	0.74 (0.23)	1.70 (0.20)	1.12 (0.29)	1.37 (0.15)	0.89 (0.17)	1.15 (0.40)
FTL							
Baseline	2.10 (0.11)	0.75 (0.33)	1.83 (0.15)	1.35 (0.37)	1.56 (0.12)	0.96 (0.11)	1.37 (0.23)
Post	1.83 (0.27)	0.77 (0.29)	1.64 (0.22)	1.16 (0.19)	1.43 (0.18)	1.10 (0.13)	1.35 (0.32)
Effect size (η^2_p)	.148	0.540	0.213	.196	.114	.217	.106
80–90% of gait cycle							
FFOOT							
Baseline	0.23 (0.25)	0.52 (0.35)	0.30 (0.16)	0.46 (0.16)	0.74 (0.40)	2.14 (0.63)	0.78 (0.27)
Post	0.94 (0.34)*	0.56 (0.23)	0.44 (0.19)	0.58 (0.19)	0.80 (0.42)	2.52 (0.42)	0.70 (0.24)
SR10%							
Baseline	0.18 (0.07)	1.20 (0.55)	0.43 (0.32)	0.29 (0.12)	0.67 (0.37)	1.98 (0.54)	0.68 (0.33)
Post	0.44 (0.67)	1.19 (0.58)	0.58 (0.38)	0.35 (0.16)	0.85 (0.61)	2.19 (0.30)	0.71 (0.42)
FTL							
Baseline	0.11 (0.03)	0.79 (0.37)	0.42 (0.23)	0.44 (0.21)	0.85 (0.85)	2.31 (0.59)	0.59 (0.26)
Post	0.16 (0.06)§	0.66 (0.20)	0.41 (0.28)	0.44 (0.20)	0.73 (0.29)	1.97 (0.70)	0.47 (0.12)
Effect size (η^2_p)	.356	0.210	.081	.146	.049	.192	.0.30
90–100% of gait cycle							
FFOOT							
Baseline	0.72 (0.63)	1.60 (0.78)	0.83 (0.32)	0.60 (0.18)	1.22 (0.36)	1.69 (0.41)	1.43 (0.51)
Post	2.10 (0.68)*	1.28 (1.01)	1.23 (0.31)	1.00 (0.34)*	1.31 (0.60)	1.72 (0.48)	1.15 (0.59)
SR10%							
Baseline	0.76 (0.43)	2.03 (0.71)	0.91 (0.38)	0.50 (0.16)	1.05 (0.69)	2.09 (0.65)	1.15 (0.53)
Post	1.19 (0.91)	1.70 (0.36)	1.32 (0.86)	0.48 (0.14)§	1.18 (0.38)	2.37 (0.96)	1.02 (0.40)
FTL							
Baseline	0.42 (0.31)	2.30 (0.69)	1.00 (0.19)	0.68 (0.14)	0.89 (0.52)	2.94 (1.75)	1.07 (0.21)
Post	0.88 (0.63)§	2.01 (0.62)	1.26 (0.74)	0.64 (0.09)§	1.10 (0.68)	2.38 (0.46)	1.11 (0.38)
Effect size (η^2_p)	.315	.001	.010	.491	.010	.118	.138

Values are mean (SD); FFOOT: Forefoot landing group; SR10%: step rate increase group; FTL: Forward trunk lean group; MG: Medial Gastrocnemius; TA: Tibialis Anterior; VL: Vastus Lateralis; RF: Rectus Femoris; GMED: Gluteus Medius; BF: Biceps Femoris; GMAX: Gluteus Maximus.
*Statistically different from baseline ($P < .05$). §Statistically significant between-group difference at this time point ($P < .05$).

reach the MCID for this outcome measure (9 scale points) (J. M. Binkley et al., 1999), contrasting previous studies which reported around 11 points of improvement (Noehren et al., 2011; Willy et al., 2012).

Contrary to our hypothesis, the kinematic time-by-group interactions and the main effects significant results were as expected considering the techniques verbal instructions: greater plantar flexion angle during FFOOT and greater trunk flexion angle exhibited by FTL group. Despite previous studies had shown acute kinematics differences during the same running techniques, such as lower peak knee flexion (Kulmala et al., 2013; Lenhart, Thelen, Wille, Chumanov, & Heiderscheit, 2014; Teng & Powers, 2014), lower knee abduction (dos Santos et al., 2016; Kulmala et al., 2013) and/or lower hip adduction (Heiderscheit et al., 2011; Kulmala et al., 2013) in healthy runners after FFOOT, SR10% and FTL modifications. Also, it has been shown lower hip adduction after SR10% gait training in 6 healthy runners (Hafer et al., 2015). Our results, in PFP runners, did not corroborated with previous studies in healthy runners. Therefore, these gait retraining effects observed in healthy populations should not be assumed for PFP runners. It should be taken into account that PFP participants could present compensatory kinematic strategy due to the knee symptoms and did not present excessive magnitude of altered lower limb movements as reported by Luz et al. (2018) and Souza and Powers (2009) when compared to healthy runners. The kinematic results reported in the literature comparing runners with and without knee symptoms are conflicting and more high-quality prospective studies are needing to better characterizes this population of runners.

Moreover, gait retraining involving real-time visual feedback instructions as mirror training or kinematic feedback at the described 8 sessions protocol had also presented significantly reduction on contralateral pelvic drop and hip adduction angles in PFP runners (Noehren et al., 2011; Willy et al., 2012). The authors believe that the difference could be explained since these studies directly encouraged the runners to improve lower limb alignment in order to reduce the excessive angles related to PFP development, that was not done in the current study. As a multifactorial injury, the interpretation of the present results compared to previous findings in the literature could be practical and useful for clinicians, coaches and athletes in order to choose or not choose one running technique by considering the effectiveness of each condition and the runner's previous injury history.

The EMG interaction analysis showed that FFOOT was the most sensitive technique to change the mean muscle activation. The landing pattern modification increased medial gastrocnemius and rectus femoris muscles activation of the PFP runners during the late-swing compared to other techniques after gait retraining. Giandolini et al. (2013) and Shih, Lin, and Shiang (2013) also reported acute greater gastrocnemius lateralis activation during the pre-contact phase and no differences during the stance phase when healthy runners switch the rearfoot strike to a midfoot strike pattern. The gastrocnemius pre-activation could be associated to the foot plantar flexed posture and the generation of a dorsiflexor moment during the initial contact (Chumanov et al., 2012; Giandolini et al., 2013). Also, the muscle pre-activation could influence leg stiffness (Gollhofer & Kyröläinen, 1991) and the lower limb stabilization to receive the impact load (Chumanov et al., 2012). Contrary to our results, Shih et al. (2013) reported greater acute gastrocnemius activation during stance phase at FFOOT. Possibly, PFP runners of the current study executed the technique with lower plantar flexors overload after gait retraining.

Different from expected, no gluteal muscles activation after gait retraining for any condition were found, contrary to the results demonstrated by Chumanov et al. (2012) during SR10% running. Methodological differences could explain the differences between studies. The previous study assessed healthy runners and, only the immediate effects of SR10%. Chumanov et al. (2012) and Heiderscheit et al. (2011) reported greater gluteus muscles activity accompanied with lower hip adduction angle and, lower hip adduction and internal rotation moment during the SR10% technique. Thus, it is possible that the lack of hip muscles activity differences of our study could be explained by the absence of hip kinematics alterations after the gait retraining. Moreover, the absence of these changes could be partially explained by the results of Barton, Lack, Malliaras, and Morrissey (2013) who reported moderate evidence of no difference in gluteus medius activity during running and also presented conflicting evidence related to gluteus maximus activity between healthy and PFP runners.

Previous studies showed that FFOOT could improve shock attenuation during running (Delgado et al., 2013). It is known that increasing knee flexion at initial contact allows better load dissipation (Lieberman, 2012). Roper et al. (2016) in a similar protocol of FFOOT gait retraining with 8 PFP runners, demonstrated a significant increase of 6.00 degree of the knee flexion at initial contact. However, in the current study, the FFOOT runners presented a non-significant 4.04° increase in knee flexion during landing. In addition, the participants of this study showed greater gastrocnemius and rectus femoris pre-activation after gait-retraining; which could have helped to dampen the impact forces.

The pain pathways involved in PFP remains unclear and a variety of local structures could contribute to nociception (Crossley et al., 2016; Witvrouw et al., 2014). Considering the pain and functional improvements observed in our results, we hypothesized that a greater muscle pre-activation may have a contribution on the patellofemoral joint stabilization and/or it is possible that small kinematic modifications even without statistical significance could affect the kinematics and kinetics of the patellofemoral joint, reducing the clinical symptoms. The 2-weeks gait retraining protocol (78 min at the 1st week and 117 min at the 2nd week) was relative lower than participants average running distance weekly (Table 1) and could contributed to the clinical improvements. We also believe that other factors not evaluated in this study could explain the substantial clinical effects of the gait retraining. For example, the analysis of the forces acting on the patella measured by the patellofemoral joint stress, which is directly associated with the etiology or exacerbation of PFP symptoms due to an increase on subchondral tissue pressure (Fulkerson & Shea, 1990).

There are limitations to the present study, which need to be considered. First, the inclusion criteria were very strict, and the sample size used in the study was small to detect significant effects. There was no control group who experienced no intervention. The group randomization did not take into account the running experience and weekly distance, pain symptoms duration and gender. The gait retraining was performed on a treadmill while most of the runners used to practice their usual running training in open places. There was not biomechanical evaluation in the 6-month or 1-year follow-up; therefore, it is not possible to know if the participants maintained the gait pattern trained or sustained other injuries. The placebo effect by interaction of participants and researchers can not be ignored in the clinical settings. In order to reduce these limitations, future studies should be developed as randomized clinical trials to compare gait retraining interventions to gold standard rehabilitation programs focused on PFP runners.

5. Conclusion

Forefoot landing, increase step rate by 10% and forward trunk lean running techniques were able to reduce PFP symptoms and improve function after a 2-week of supervised gait retraining and the benefits were maintained in the 6-month follow-up. However, the clinical improvement was not accompanied with significant kinematic and EMG differences that could entirely explain this clinical improvement after the gait retraining.

Ethical statement

All participants provided informed consent as approved by the Federal University of São Carlos.

Ethics Committee for Human Investigations (protocol number 735.596).

Conflict of interest disclosure

The authors have no conflicts of interest to report.

Financial disclosure

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Appendix A. Supplementary data

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