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Footwear characteristics are related to running mechanics in runners with patellofemoral pain

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HIGHLIGHTS

- Footwear characteristics are associated with running mechanics in runners with PFP
- Higher MI score was moderately correlated with lower foot inclination and PFJ force
- Lower shoe mass was indicative of higher step rate and lower peak PFJ force
- Greater flexibility was indicative of lower foot inclination angle
- No significant correlations were found between footwear characteristics and VLR

ABSTRACT

Title. Footwear characteristics are related to running mechanics in runners with patellofemoral pain

Running footwear is known to influence step rate, foot inclination at foot strike, average vertical loading rate (VLR) and peak patellofemoral joint (PFJ) force. However, the association between the level of minimalism of running shoes and running mechanics, especially with regards to these relevant variables for runners with patellofemoral pain (PFP), has yet to be investigated. The objective of this study was to explore the relationship between the level of minimalism of running shoes and habitual running kinematics and kinetics in runners with PFP. Running shoes of 69 runners with PFP (46 females, 23 males, 30.7±6.4 years) were evaluated using the Minimalist Index (MI). Kinematic and kinetic data were collected during running on an instrumented treadmill. **Principal component and** correlation analyses were performed between the MI and its subscales and step rate, foot inclination at foot strike, average VLR, peak PFJ force and peak Achilles tendon force. Higher MI scores were moderately correlated with lower

foot inclination (r= -0.410, *P*<0.001) and lower peak PFJ force (r= -0.412, *P*<0.001). Moderate correlations also showed that lower shoe mass is indicative of greater step rate (ρ=0.531, *P*<0.001) and lower peak PFJ force (ρ= -0.481, *P*<0.001). Greater shoe flexibility was moderately associated with lower foot inclination (ρ= -0.447, *P*<0.001). Results suggest that **greater levels of minimalism are associated with lower inclination angle and lower peak PFJ force in runners with PFP.** Thus, this population may potentially benefit from changes in running mechanics associated with the use of shoes with a higher level of minimalism.

Keywords. Knee pain; Shoes; Kinetics; Kinematics; Gait retraining.

INTRODUCTION

Patellofemoral pain (PFP), defined as pain around or behind the patella that is aggravated by activities loading the patellofemoral joint (PFJ)[1], is among the most common running injuries [2]. It has been suggested that runners with PFP present altered running biomechanics [3], which may contribute to the persistence of symptoms. Lower step rate [4], greater foot inclination at foot strike [4,5] and greater vertical loading rate (VLR)[5] have all been related to increased peak PFJ force during running, and may represent key modifiable factors to address in rehabilitation of runners with PFP.

Running footwear is known to influence step rate [6], foot inclination [6], VLR [7] and peak PFJ force [8] in healthy runners. For example, Squadrone et al.[6] have reported greater step rates and lower foot inclination when wearing minimalist shoes and while barefoot compared with traditional shoes. Interestingly, in that study, foot inclination decreased as the level of minimalism of footwear increased. Similarly, Sinclair et al. [8] reported lower values of peak PFJ force when wearing minimalist compared with cushioned footwear. In addition, a recent

study by Rice et al.[7] suggested that forefoot striking in minimalist shoes induced lower VLR than any foot strike pattern in traditional footwear. To date, no study has explored running mechanics of runners with PFP as they relate to the level of minimalism of running shoes. A recently validated rating scale, the Minimalist Index (MI)[9], allows one to quantify the level of minimalism of running shoes and explore such associations.

Considering that footwear influences running biomechanics, and that runners with PFP may benefit from reduced peak PFJ force [10] and VLR [11], it is important to evaluate if footwear characteristics are associated with running mechanics in this population. The objective of this study was to explore, in a cohort of runners with PFP, the relationship between the level of minimalism of running shoes as determined by the MI and habitual running kinematics and kinetics. We hypothesized that footwear with a greater level of minimalism would be associated with greater step rate and lower foot inclination, VLR and PFJ force.

METHODS

Sixty-nine runners (43 females, 26 males; Table 1) with PFP for at least 3 months, running at least 15 km/week, and aged between 18 and 45 years were included. Exclusion criteria included lower limb injuries other than PFP and any history of neurological, inflammatory or degenerative disease. The local research ethics committee approved the study, and participants provided informed consent.

Data on demographics, symptomatology and running habits were first collected. Then, participants' running shoes were rated using the MI according to standardized guidelines [9]. The

MI, which was developed through a modified Delphi process, is a valid and reliable (ICC=0.84-0.99)[9] rating scale that quantifies the level of minimalism of running shoes. It includes 5 subscales (weight, stack height, heel to toe drop, technologies and flexibility), each rated through 6-point Likert scales **(Appendix 1)**. The sum of sub-scores is converted to a percentage score. A higher score indicates a greater level of minimalism [9].

Thereafter, runners were equipped with triads of retroreflective markers bilaterally on lower limb segments and at the lumbosacral and cervicothoracic junctions to collect kinematic data using a motion analysis system (Vicon motion systems, CA, USA). Anatomically-referenced calibration markers were temporarily positioned according to previously reported methods [12]. Following calibration, runners walked on an instrumented treadmill (Bertec Corp, OH, USA) for one minute, before performing a five-minute warm-up of running at preferred speed between 8 and 10 km/h. Then, during the following three minutes, kinematic and kinetic data were collected at 200 Hz and 1000 Hz, respectively.

Marker trajectories and ground reaction forces were filtered using zero-lag, fourth order, low-pass, Butterworth filters at 12 Hz and 30 Hz, respectively. A 20 N vertical ground reaction force threshold delimited the stance phase. Fifty steps on the symptomatic limb were considered for analyses. Kinematic variables of interest were step rate and foot inclination at foot strike. Kinetic variables included average VLR [13], peak knee extension and ankle plantarflexion moments as well as peak PFJ force and peak Achilles tendon force, which were estimated using commonly reported methods [14]. **Typical symptoms were also considered as variables of interest.**

Principal component analyses (PCA) were used to justify further correlation analyses between MI score and biomechanical variables of interest. Then, individual relationships were analyzed using Pearson correlations (r), while Spearman correlations (ρ) were used for MI subscales. Correlations were described as very weak (0<0.20), weak (0.20<0.39), moderate (0.40<0.59), strong (0.60<0.79) or very strong (0.80-1)[15], and were considered statistically significant when $P \leq 0.05$.

RESULTS

Kaiser-Meyer-Olkin statistic (KMO=0.660) confirmed sampling adequacy, and PCA revealed two main components (62% of MI variance). Component 1 was strongly associated with step rate (0.912) and peak PFJ force (-0.780), while component 2 showed greater associations with peak Achilles tendon force (0.928) and foot inclination (-0.623).

Moderate negative correlations were found between total MI score and foot inclination (r= -0.410, $P<0.001$) as well as with peak PFJ force (r= -0.412, $P<0.001$; Figure 1), suggesting that footwear with a greater level of minimalism were associated with lower foot inclination and lower peak PFJ force (Table 2). Moderate correlations showed that lower shoe mass was indicative of greater step rate (ρ=0.531, $P<0.001$) and lower peak PFJ force (ρ= -0.481, $P<0.001$; Figure 1), while **lower foot inclination angle was indicative of lower peak PFJ force (r=0.55, *P*<0.001)**. Greater footwear flexibility was moderately associated with lower foot inclination (ρ= -0.447, $P<0.001$; Table 2). Average VLR **or symptoms** were not significantly correlated with any footwear-related variable (Table 2).

DISCUSSION

Similar to previous studies in healthy runners, we found that footwear with a greater level of minimalism were linked with lower foot inclination at foot strike [6] and reduced peak PFJ force [8]. However, contrary to our hypothesis and to Rice et al.[7], we did not observe that average VLR was influenced by footwear. **Rice et al's comparison of only two shoe models (highly minimal, highly cushioned) potentially outlined effects that were not consistently associated with the level of minimalism in our sample.** Unlike the above-mentioned studies, the major strength of the current study is the use of a validated rating scale to quantify the level of minimalism, which allows clinicians to generalize findings to runners regardless of habitual footwear. **It must be noted that variations in foot inclination caused by footwear could represent a confounding factor when interpreting the effects of footwear on peak PFJ force, despite PCA classifying both variables in different components**. Since shoes characterized by a greater level of minimalism were indicative of lower foot inclination at foot strike, higher step rate and lower peak PFJ force, it is possible that recommending more minimalist footwear may facilitate implementation and retention of gait retraining interventions in this population. Future studies should consider evaluating the effects of reductions in knee loading through instructed and gradual transition to more minimalist shoes on symptoms, function and running mechanics of runners with PFP.

CONCLUSION

Greater levels of minimalism were associated with lower inclination angle and lower peak PFJ force in runners with PFP. Such findings suggest that this population may potentially

benefit from changes in running mechanics associated with shoes with a greater level of minimalism.

CONFLICT OF INTEREST STATEMENT

The authors do not have any conflict of interest to report.

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FIGURE CAPTIONS

Figure 1: Correlation between total **Minimalist Index (MI) score and peak patellofemoral joint (PFJ) force during running. A greater MI score indicates a greater level of minimalism.**

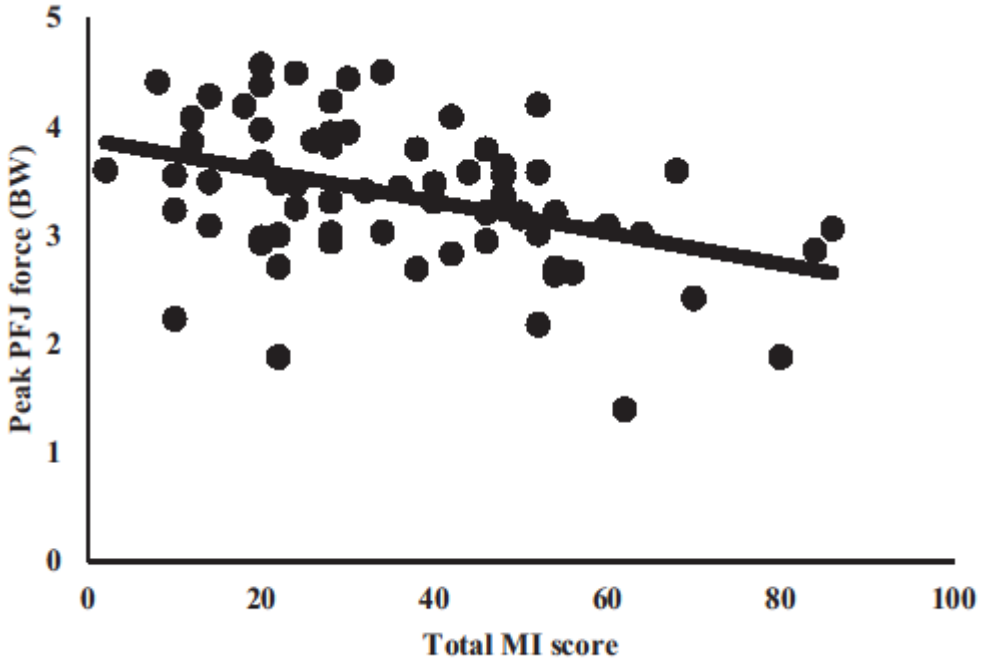

Table 1. Baseline characteristics of runners (n=69)

	Mean ± SD
Age (years)	30.7 ± 6.4
Average weekly mileage (km)	20.3 ± 5.5
Duration of symptoms (months)	28.8 ± 38.9
Score to the Activities of Daily Living Scale of the Knee Outcome Survey (0-100)	70.0 ± 9.6
Typical pain during running (0-10)	6.0 ± 1.9
Minimalist Index score (%)	36.3 ± 19.2
Shoe wear (months)	**10.1 ± 8.1**
Step rate (steps/min)	168.6 ± 10.5

Activities of Daily Living Scale of the Knee Outcome Survey: a score of 100 indicates the absence of symptoms and functional limitations. Typical pain during running: a score of 0 indicates no pain, a score of 10 indicates worst pain imaginable.

Table 2. Correlations between running kinematics and kinetics and the Minimalist Index. Pearson correlation coefficients (r) are reported for total Minimalist Index score, and Spearman correlation coefficients (ρ) for its subscales. A positive foot inclination angle denotes a rearfoot strike.

	Total Minimalist Index score	Shoe mass	Stack height	Heel to toe drop	Technologies	Flexibility
Step rate (steps/min)	**0.395** (*P*=0.001)	**0.531** (*P*<0.001)	**0.337** (*P*=0.005)	0.096 (*P*=0.434)	**0.288** (*P*=0.016)	**0.311** (*P*=0.009)
Foot inclination angle at foot strike (°)	**-0.410** (*P*<0.001)	**-0.370** (*P*=0.002)	**-0.285** (*P*=0.018)	-0.120 (*P*=0.326)	**-0.336** (*P*=0.005)	**-0.447** (*P*<0.001)
Average VLR (BW/s)	0.077 (*P*=0.527)	-0.023 (*P*=0.851)	0.018 (*P*=0.882)	0.076 (*P*=0.535)	-0.128 (*P*=0.293)	-0.150 (*P*=0.219)
Peak knee extension moment (Nm/kg)	**-0.317** (*P*=0.008)	**-0.356** (*P*=0.003)	**-0.256** (*P*=0.034)	-0.115 (*P*=0.345)	-0.180 (*P*=0.140)	**-0.323** (*P*=0.007)
Peak PFJ force (BW)	**-0.412** (*P*<0.001)	**-0.481** (*P*<0.001)	**-0.338** (*P*=0.004)	-0.192 (*P*=0.114)	-0.227 (*P*=0.061)	**-0.339** (*P*=0.004)
Peak ankle plantarflexion moment (Nm/kg)	**0.375** (*P*=0.001)	0.225 (*P*=0.064)	**0.245** (*P*=0.043)	**0.292** (*P*=0.015)	0.227 (*P*=0.061)	**0.389** (*P*=0.001)
Peak Achilles tendon force (BW)	**0.377** (*P*=0.001)	0.214 (*P*=0.078)	0.230 (*P*=0.057)	**0.289** (*P*=0.016)	0.224 (*P*=0.065)	**0.379** (*P*=0.001)
KOS-ADLS score	0.200 (*P*=0.099)	0.182 (*P*=0.135)	0.148 (*P*=0.225)	0.178 (*P*=0.142)	0.155 (*P*=0.204)	0.110 (*P*=0.368)
Typical pain during running	0.132 (*P*=0.278)	0.147 (*P*=0.227)	0.096 (*P*=0.431)	0.044 (*P*=0.720)	0.131 (*P*=0.282)	0.097 (*P*=0.426)

Abbreviations: VLR, Vertical loading rate; BW, Bodyweight; PFJ, Patellofemoral joint.