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Effects of foot orthoses on patellofemoral load in recreational runners

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The most common chronic injury in recreational runners is patellofemoral pain. Whilst there is evidence to suggest that orthotic intervention may reduce symptoms in runners who experience patellofemoral pain the mechanism by which their clinical effects are mediated is currently poorly understood. The aim of the current investigation was to determine whether foot orthoses reduce the loads experienced by the patellofemoral joint during running. Patellofemoral loads were obtained from fifteen male runners who ran at 4.0 m·s^{-1}. Patellofemoral loads with and without orthotics were contrasted using paired t-tests. The results showed that patellofemoral joint loads were significantly reduced as a function of running with the orthotic device. The current investigation indicates that through reductions in patellofemoral loads, foot orthoses may serve to reduce the incidence of chronic running injuries at this joint.

Keywords: patellofemoral pain, orthoses, biomechanics

Distance running has been shown to be physiologically beneficial [1]. However despite this, research examining the incidence of running injuries indicates that chronic pathologies are a prominent complaint for both recreational and competitive runners [2], with an incidence rate of around 70% during the course of a year [3].

The most common chronic injury in recreational runners is patellofemoral pain, which is characterized by pain linked to the contact of the posterior surface of the patella with the femur during dynamic activities [4].

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Pain symptoms which develop as a function of patellofemoral disorders can be debilitating and patellofemoral pain may also be a pre-cursor to the progression of osteoarthritis in later life [5,6]. Conservative treatment of patellofemoral disorders is preferable to operative interventions, and the efficacy of a number of conservative approaches has been explored in the literature.

There is evidence to suggest that orthotic intervention may reduce symptoms in runners who experience patellofemoral pain. Collins et al. prospectively examined the efficacy of foot orthoses in the management of patellofemoral pain [7]. Foot orthoses were shown to produce clinically meaningful improvements in pain symptoms. Eng et al. examined the effectiveness of soft foot orthotics in the treatment of patients with patellofemoral pain syndrome [8]. Participants were assigned to either an orthotic or control condition and subjects reported their perceived pain levels over an 8 week period using a visual analogue scale. It was shown that the soft foot orthotics may be an effective treatment mechanism for patellofemoral pain. Batron et al.

investigated the effects of 12 week intervention using of non-custom foot orthoses on self-reported improvements in pain symptoms [9]. It was shown that 25% of participants showed marked improvements in patellofemoral pain symptoms as a function of orthotic intervention. Pitman & Jack monitored the efficacy of foot orthoses as a treatment modality for patellofemoral pain [10]. They found that orthotics produced reductions in pain symptoms, which led to the conclusion that orthotics may be an effective treatment mechanism.

Despite the potential efficacy of foot orthoses in the prevention/treatment of patellofemoral pain symptoms, there is a paucity of research investigating any potential alterations in loading at this joint that may be mediated through orthotic intervention. The aim of the current investigation was therefore to determine whether foot orthoses reduce the loads experienced by the patellofemoral joint during the stance phase of running. This study tests the hypothesis that orthoses will reduce patellofemoral load during running.

Methods

Participants

Fifteen male participants (Age 25.76 ± 5.21 years; height 1.74 ± 0.06 m; mass 71.15 ± 4.84 kg) took part in the current study. Participants were all recreational runners who engaged in training at least three times per week. Ethical approval for this project was obtained from the University and each participant provided informed consent in written form in accordance with the declaration of Helsinki.

Orthotic device

Commercially available orthotics (Sorbothane, shock stopper sorbo Pro; Nottinghamshire UK) were examined in the current investigation. Although the right side was selected for analysis orthotic devices were placed inside both shoes.

Procedure

Participants completed five trials running at 4.0 $m \cdot s^{-1}$ with and without orthotics. The order in which participants ran in each condition was counterbalanced. Participants ran over an embedded piezoelectric force platform (Kistler Instruments, Model 9281CA) operating at 1000 Hz [11]. Running velocity was controlled using infra-red timing gates (SmartSpeed Ltd UK). A deviation of ±5% from the pre-determined velocity was allowed. Participants struck the force platform with their right (dominant) limb and five trials were obtained from each footwear condition. Three-dimensional (3-D) kinematics and ground reaction forces data were collected synchronously. The stance phase was defined as the duration over which >20 N of vertical force was applied to the force platform [12]. Kinematic information was obtained using an eight camera optoelectric motion capture system (Qualisys Medical AB, Goteburg, Sweden) using a capture frequency of 250 Hz. Dynamic calibration of the motion capture system was conducted prior to data collection.

The current investigation used the calibrated anatomical systems technique (CAST) to model the lower extremity segments in six degrees of freedom [13]. To define the anatomical frame of the right shank and thigh, retroreflective markers were positioned unilaterally to the medial and lateral malleoli, medial and lateral epicondyle of the femur and greater trochanter. Rigid technical tracking clusters were positioned on the shank and thigh segments. Static trials were conducted in order for the positions of the anatomical markers to be referenced in relation to the tracking markers/clusters, following which those not required for tracking were removed.

Data processing

Ground reaction force and kinematic data were smoothed using cut-off frequencies of 50 Hz and 12 Hz with a low-pass Butterworth 4th order filter using Visual 3-D (C-Motion, Germantown, MD, USA). Newton-Euler inverse-dynamics were used which allowed knee joint moments to be calculated. Knee loading was examined through extraction of peak knee extensor moment, peak knee abduction moment, patellofemoral contact force (PTCF) and patellofemoral contact pressure (PTCP).

A previously utilized algorithm was used to quantify PTCF and PTCP [14]. This method has been utilized previously to resolve differences in PTCF and PTCP when using different footwear [15,16,17] and between those with and without patellofemoral pain [18]. PTCF (B.W) was estimated using knee flexion angle (KFA) and knee extensor moment (KEM) through the biomechanical model of Ho et al [19]. The moment arm of the quadriceps (QMA) was calculated as a function of KFA using a non-linear equation, based on cadaveric information presented by van Eijden et al. [20]:

$$QMA = 0.00008\ KFA^{3} - 0.013\ KFA^{2} + 0.28\ KFA + 0.046$$

Quadriceps force (FQ) was calculated using the below formula:

$$FQ = KEM / QMA$$

PTCF was estimated using the FQ and a constant (C):

$$PTCF = FQ\ C$$

The C was described in relation to KFA using the equation described by van Eijden et al. [20]:

$$C = (0.462 + 0.00147\ KFA^{2} - 0.0000384\ KFA^{2}) / (1 - 0.0162\ KFA + 0.000155\ KFA^{2} - 0.000000698\ KFA^{3})$$

PTCP (MPa) was calculated using the PTCF divided by the patellofemoral contact area. The contact area was delineated by fitting a 2nd-order polynomial curve to the data of Powers et al., [21] showing patellofemoral contact areas at varying levels of KFA.

$$PTCP = PTCF / contact\ area$$

PTCF loading rate (B.W/s) was also calculated as a function of the change in PTFC from initial contact to peak force divided by the time to peak force.

Statistical Analyses

The data were tested for normality using a Shapiro-Wilk test which confirmed that the data were suitable for parametric testing. Means and standard deviations were calculated for each running condition. Differences in the outcome 3D kinematic parameters were examined using paired samples t-tests. The alpha level required for statistical significance was adjusted to $p \leq 0.008$ based on the number of comparisons being made. Effect sizes for all significant observations were calculated using a Cohen's *D* statistic. All statistical analyses were conducted using SPSS v21.0 (SPSS Inc, Chicago, USA).

Results

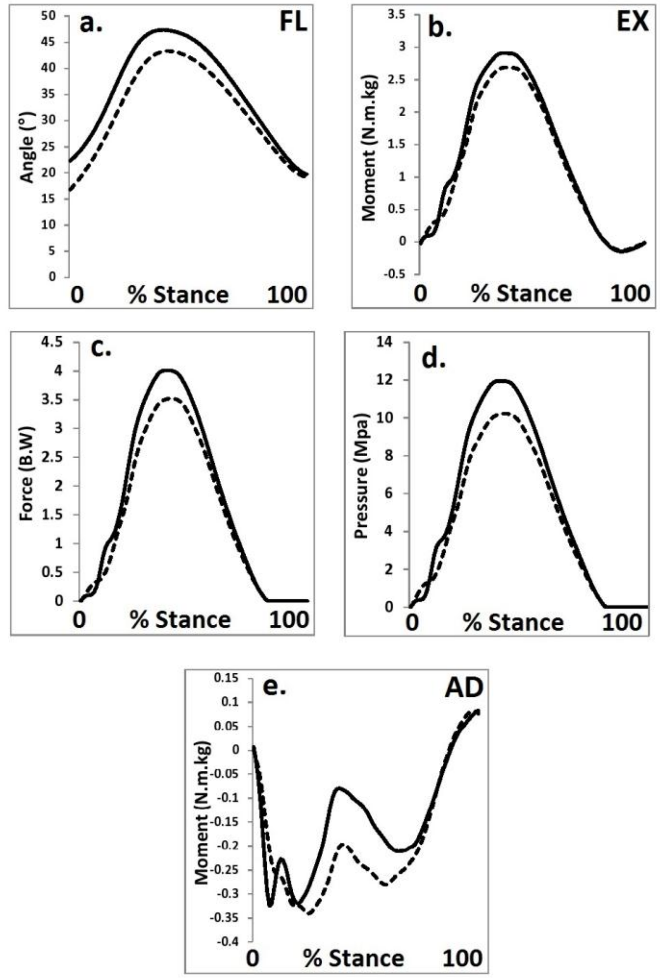

Figure 1 Knee kinetics and kinematics as a function of orthotic intervention, black = no-orthotic and dash = orthotic, (a= knee angle, b = sagittal knee moment c = PTCF, d = PTCP, e = coronal knee moment) (FL = flexion, EX = extension, AD = adduction).

Peak knee extensor moment was significantly ($t_{(14)}$ = 4.11, $p<0.008$, *D* = 2.20) greater in the non-orthotic condition compared to running with orthotics (Table 1, Figure 1a). In addition PTFC ($t_{(14)}$ = 3.96, $p<0.008$, *D* = 2.12) and PTCP ($t_{(14)}$ = 4.57, $p<0.008$, *D* = 2.44) were also shown to be significantly greater in the non-orthotic condition compared to running with orthotics (Table 1, Figure 1bc). Finally PTCF loading rate was shown to be significantly ($t_{(14)}$ = 3.88, $p<0.008$, *D* = 2.07) higher when running without orthotics (Table 1).

	No-orthotic		Orthotic		
	Mean	*SD*	*Mean*	*SD*	
Peak knee extensor moment (N.m.kg)	3.05	0.72	2.75	0.80	*
PTFC (B.W)	4.16	0.95	3.71	1.05	*
PTCP (Mpa)	12.21	2.81	10.80	3.04	*
Time to PTFC (s)	0.08	0.01	0.09	0.02	
PTFC load rate (B.W/s)	56.28	23.92	42.17	14.19	*
Peak knee abductor moment (N.m.kg)	-0.68	0.26	-0.56	0.29	

Table 1 Knee loads as a function of orthotic intervention. Notes: * = significant difference $p<0.008$.

Discussion

This study aimed to determine whether foot orthoses reduce the loads experienced by the patellofemoral joint during the stance phase of running. Previous analyses have examined the efficacy of orthotic devices in the treatment of patellofemoral disorders, but this represents the first investigation to examine the effects of orthotic devices on the loads experienced by the joint itself.

In support of our hypothesis, the key observation from the current investigation is that patellofemoral load parameters were significantly reduced with the presence of orthotic intervention when compared to running without orthotic inserts. This finding may have relevance clinically and serve to provide further insight into the mechanisms by which foot orthoses serve to attenuate the symptoms of patellofemoral pain Ho et al. [19]. The aetiology and pathogenesis of patellofemoral disorders are a function of habitual and excessive loads experienced by the patellofemoral joint itself, which could account for the high incidence of patellofemoral disorders in runners. This current investigation shows that using foot orthoses may be a potential mechanism by which runners are able to attenuate their risk of injury through reductions in knee joint loading.

It is hypothesized that the reductions in patellofemoral kinetics observed in the current study are linked to the additional midsole cushioning associated with the orthotic device. When running with increased midsole cushioning runners typically utilize reduced knee flexion angle at footstrike and throughout the stance phase (Figure 1a). Reductions in knee flexion are associated with lengthening of the quadriceps moment arm, which serves to reduce the load experienced by the patellofemoral joint as PTFC and PTCP are governed by the force generated in the quadriceps [19].

In conclusion, the findings from the current study show that running with foot orthotics are associated with significant reductions in patellofemoral loading parameters when compared to running without orthotic intervention. Given the proposed relationship between the magnitude of patellofemoral loading and the aetiology of patellofemoral pathology, it is proposed that the risk of the developing running related injuries at the patellofemoral joint may be attenuated as a function of orthotic intervention.

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References

1. Denvir MA, Gray GA. Run for your life: exercise, oxidative stress and the ageing endothelium. Journal of Physiology 2009 Sep;587(Pt17):4137-4138. PubMed
2. Hreljac A. Impact and overuse injuries in runners. Medicine & Science in Sports & Exercise 2004 May;36(5):845-849. PubMed
3. Marti B, Vader JP, Minder CE, Abelin T. On the epidemiology of running injuries The 1984 Bern Grand-Prix study. American Journal of Sports Medicine 1988 May-Jun;16(3): 285-294. PubMed
4. Besier TF, Gold GE, Beaupre GS, Delp SL. A modeling framework to estimate patellofemoral joint cartilage stress in vivo. Medicine & Science in Sports & Exercise 2005 Nov;37(11):1924–1931. PubMed
5. Crossley KM. Is patellofemoral osteoarthritis a common sequela of patellofemoral pain?. British Journal of Sports Medicine 2014 Mar;48(6):409-410. PubMed

6. Thomas MJ, Wood L, Selfe J, Peat G. Anterior knee pain in younger adults as a precursor to subsequent patellofemoral osteoarthritis: a systematic review. BMC Musculoskeletal Disorders 2010 Sep;11: 201. PubMed
7. Collins N, Crossley K, Beller E, Darnell R, McPoil T, Vicenzino B. Foot orthoses and physiotherapy in the treatment of patellofemoral pain syndrome: randomised clinical trial. British Medical Journal 2008 Oct; 337:1735. link
8. Eng JJ, Pierrynowski MR. Evaluation of soft foot orthotics in the treatment of patellofemoral pain syndrome. Physical Therapy 1993 Feb;73(2):62-68. PubMed
9. Barton CJ, Menz HB, Crossley KM. Clinical predictors of foot orthoses efficacy in individuals with patellofemoral pain. Medicine & Science in Sports & Exercise 2011 Sep;43(9):1603-1610. PubMed
10. Pitman D, Jack D. A clinical investigation to determine the effectiveness of biomechanical foot orthoses as initial treatment for patellofemoral pain syndrome. Journal of Prosthetics & Orthotics 2000;12(4):110–116. link
11. Sinclair J, Hobbs SJ, Taylor PJ, Currigan G, Greenhalgh A. The influence of different force measuring transducers on lower extremity kinematics. Journal of Applied Biomechanics 2014 Jul; 40(3):476-479. PubMed
12. Sinclair J, Edmundson CJ, Brooks D, Hobbs SJ. Evaluation of kinematic methods of identifying gait Events during running. International Journal of Sport Science & Engineering 2011 Aug; 5(3): 188-192. link
13. Cappozzo A, Catani F, Leardini A, Benedeti MG, Della CU. Position and orientation in space of bones during movement: Anatomical frame definition and determination. Clinical Biomechanics 1995 Jun;10(4):171-178. PubMed
14. Ward SR, Powers CM. The influence of patella alta on patellofemoral joint stress during normal and fast walking. Clinical Biomechanics 2004 Dec;19(10):1040–1047. PubMed
15. Bonacci J, Vicenzino B, Spratford W, Collins P. Take your shoes off to reduce patellofemoral joint stress during running. British Journal of Sports Medicine 2014 Mar;48(6):425-428. PubMed
16. Kulmala JP, Avela J, Pasanen K, Parkkari J. Forefoot strikers exhibit lower running-induced knee loading than rearfoot strikers. Medicine & Science in Sports & Exercise 2013 Dec;45(12):2306-2313. PubMed
17. Sinclair J. Effects of barefoot and barefoot inspired footwear on knee and ankle loading during running. Clinical Biomechanics 2014 Apr;29(4):395-399. PubMed
18. Keino BJ, Powers CM. Patellofemoral stress during walking in persons with and without patellofemoral pain. Medicine & Science in Sports & Exercise 2002 Oct;34(10):1582–1593. PubMed
19. Ho KY, Blanchette MG, Powers CM. The influence of heel height on patellofemoral joint kinetics during walking. Gait & Posture 2012 Jun;36(2):271-275. PubMed
20. van Eijden TM, Kouwenhoven E, Verburg J, Weijs WA. A mathematical model of the patellofemoral joint. Journal of Biomechanics 1986;19(3):219–229. PubMed
21. Powers CM, Lilley JC, Lee TQ. The effects of axial and multiplane loading of the extensor mechanism on the patellofemoral joint. Clinical Biomechanics 1998 Dec;13(8):616–624. PubMed