Baltic Journal of Health and Physical Activity

Volume 8 | Issue 4 Article 1

2016

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Recommended Citation
Sinclair J, Richards JD, Shore H. Effects of semi-custom and off-the-shelf orthoses on Achilles tendon and patellofemoral kinetics in female runners. Balt J Health Phys Act. 2016; 8(4): 7-15. doi: 10.29359/BJHPA.08.4.01

Baltic Journal of Health and Physical Activity 2016;8(4):7-15
Journal of Gdansk University of Physical Education and Sport in Gdansk
e-ISSN 2080-9999

ORIGINAL

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Effects of semi-custom and off-the-shelf orthoses on Achilles tendon and patellofemoral kinetics in female runners

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abstract

Background The aim of the current investigation was to examine the effects of semi-custom and off-the-shelf orthotics on the loads experienced by the patellofemoral joint and the Achilles tendon in female runners.

Material/Methods Twelve female recreational runners ran at 4.0 m.s 1 whilst wearing no orthotics, semi-custom orthotics and off-the-shelf orthotics. Kinetics and kinematics of running were obtained via a force platform and a motion capture system. Differences between orthotic conditions were contrasted using one-way repeated measures ANOVA.

Results The results showed that both patellofemoral contact force and pressure were significantly lower in the no-orthotic (force = 3.21 B.W & pressure = 8.18 MPa) condition in comparison to the off-the-shelf (force = 3.60 MPa & pressure = 9.07 B.W) and semi-custom orthoses (force = 3.69 B.W & pressure = 9.30 MPa).

Conclusions The current investigation indicates that foot orthoses such as those examined in the current investigation may place female runners at increased risk from patellofemoral disorders, although future prospective research is required before this can be substantiated.

Key words Biomechanics, Achilles tendon, patellofemoral, orthoses

article details

Article statistics **Word count:** 2,578; **Tables:** 2; **Figures:** 2; **References:** 31
Received: October 2015; **Accepted:** October 2016; **Published:** December 2016

Full-text PDF: http://www.balticsportscience.com

Indexation: AGRO, Celdes, CNKI Scholar (China National Knowledge Infrastructure), CNPIEC, De Gruyter - IBR (International Bibliography of Reviews of Scholarly Literature in the Humanities and Social Sciences), De Gruyter - IBZ (International Bibliography of Periodical Literature in the Humanities and Social Sciences), DOAJ, EBSCO - Central & Eastern European Academic Source, EBSCO - SPORTDiscus, EBSCO Discovery Service, Google Scholar, Index Copernicus, J-Gate, Naviga (Softweco, Primo Central (ExLibris), ProQuest - Family Health, ProQuest - Health & Medical Complete, ProQuest - Illustrata: Health Sciences, ProQuest - Nursing & Allied Health Source, Summon (Serials Solutions/ProQuest, TDOne (TDNet), Ulrich's Periodicals Directory/ulrichsweb, WorldCat (OCLC)

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest: Authors have declared that no competing interest exists.

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INTRODUCTION

Runners are known to be highly susceptible to chronic injuries; as many as 80% of all who participate in running training will suffer from a chronic pathology over the course of one year [1]. The knee and ankle joints have been shown to be the most common injury sites and are associated with up to one fifth of all running injuries[1]. Female runners have been shown to be at much higher risk of experiencing a chronic running injury in comparison to age-matched males [2]. Conservative management of injuriesis preferable to surgical intervention; therefore, a number of different mechanisms have been examined in clinical/biomechanical literature. Shoe orthoses are frequently employed in an attempt to manage running injuries [3] and have thus received considerable attention.

Sinclair et al. [4] showed that using an off-the-shelf orthotic served to significantly reduce the loading rate and tibial acceleration parameters. Laughton et al. [5] investigated the influence of custom-moulded foot orthoses on the loading rate of the vertical ground reaction force. Their findings also indicated that foot orthoses reduced the vertical rate of loading. Fong et al. [6] investigated the influence of an off-the-shelf orthotic on rearfoot kinematics during running. Their findings show that the magnitude of peak ankle eversion was significantly reduced when wearing orthoses. Telfer et al. [7] examined the effects of a custom orthotic device with different medial wedge angles on tibiocalaneal kinematics during running. Their results indicated that the magnitude of peak eversion and tibial internal rotation were reduced with increases in medial wedge angle. The results of Sinclair et al. [4] showed however that an off-the-shelf orthotic device did not significantly influence the peak angle of ankle eversion or tibial internal rotation compared to running with no orthotic device. Similarly Laughton et al. [5] demonstrated using a custom-moulded foot orthoses that the angle of peak ankle eversion was not significantly influenced.

A large range of foot orthoses are available which are typically classified either as off-the-shelf or custom devices. Off-the-shelf devices are prefabricated by the manufacturer and thus the design and fit of the devices are predetermined and thus cannot be altered. Custom orthoses conversely allow the shape, design and fit of the orthotic to be specifically tailored to the individual needs of the wearer. Typically, custom orthoses are very expensive, however, and can take several weeks to manufacture. Therefore, a large number of runners select off-the-shelf orthoses which are not tailored to the individual requirements and fit of each user. In response to this, orthotic manufacturers have introduced semi-custom devices which the user can heat mould to fit each runners feet more readily. This allows the user to fit the orthoses more closely to their own foot but at a much lower cost in relation to fully custom devices. The biomechanical effects of semi-custom orthoses have received little attention however.

Ferber & Benson [8] investigated the influence of a semi-custom orthotic on multi-segment foot kinematics and plantar fascia strain during walking. Their results indicate that the semi-custom device significantly reduced plantar fascia strain, but did not affect multi-segment foot kinematics. Zifchock & Davis [9] examined the influence of both custom and semi-custom orthoses on foot eversion during walking. They showed that both devices were effective at reducing eversion velocity and excursion in comparison to no orthotic, but no differences between orthoses were shown.

The effects of foot orthoses on the loads experienced by the patellofemoral joint have been examined previously. Sinclair et al. [10] examined the effects of off-the-shelf orthoses on the forces experienced by the patellofemoral joint in males. Their findings showed that orthoses mediated significant reductions in patellofemoral loading. Similarly, the influence of foot orthoses on the forces imposed on the Achilles tendon have been examined in previous work. Sinclair et al. [11] investigated the effects of off-the-shelf orthoses on the forces experienced by the Achilles tendon in male runners. Their observations indicated that orthoses were able to significantly reduce the load experienced by the Achilles tendon during running. However, current research with regards to the influence of semi-custom orthoses on the knee and ankle kinetic parameters linked to the aetiology of injury are not yet known. In addition,the effects of orthotic intervention on the loads experienced by the patellofemoral joint and Achilles tendon have not been investigated.

Therefore, the aim of the current investigation was to examine the effects of running in semi-custom and off-the-shelf orthotics on the loads experienced by the patellofemoral joint and Achilles tendon in female runners. The findings from the current study may provide important information to female runners regarding the conservative management of Achilles tendon and patellofemoral pathologies.

METHODS

PARTICIPANTS

Twelve female recreational runners (age 21.19 ±3.05 years, height 1.68 ±0.09 m and body mass 61.44 ±3.25 kg) took part in the current investigation. Ethical approval was obtained from the Universities STEMH ethical panel, and the procedures outlined in the declaration of Helsinki were followed.

PROCEDURE

All runners completed five successful trials in which they ran through a 22 m walkway at an average velocity of 4.0 $m.s^{-1}$ in each running shoe condition. The participants struck an embedded piezoelectric force platform (Kistler Instruments) with their right foot [12]. The force platform was collected with a frequency of 1000 Hz. Running velocity was controlled using timing gates (SmartSpeed Ltd UK) and a maximum deviation of 5% from the pre-determined velocity was allowed. 3-D kinematic information from the stance phase of the running cycle was obtained using an eight-camera motion capture system (Qualisys Medical AB, Goteburg, Sweden) with a capture frequency of 250 Hz. The order in which participants performed in each footwear condition was counterbalanced. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform [13].

The calibrated anatomical systems technique was utilised to quantify lower extremity kinematics [14]. In order to define the anatomical axes of the right thigh, shank and foot segments 19 mm circular retroreflective markers were positioned unilaterally at the calcaneus, 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral epicondyle of the femur and contralaterally to the greater trochanter and iliac crest positions. The pelvis segment was defined using markers attached to the left and right anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS). The knee and ankle joint centres were delineated as the mid points between the femoral epicondyle and malleoli markers [15, 16]. The hip joint centre was estimated by equations based on the position of the ASIS markers [17]. To track the shank and thigh segments rigid carbon fibre clusters were utilized. The pelvis and foot segments were tracked using the ASIS and PSIS markers and the calcaneus, 1st and 5th metatarsal markers respectively. Static calibration trials were conducted with participants in the anatomical position allowing the anatomical markers to be referenced in relation to the tracking markers/clusters.

PROCESSING

GRF and marker data were filtered at 50 and 12 Hz using a low pass Butterworth 4th order zero-lag filter and analysed using Visual 3D (C-Motion, Germantown, MD, USA). Kinematics of the knee and ankle joints were quantified using an XYZ cardan sequence of rotations (where X = sagittal plane; Y = coronal plane and Z = transverse plane). Kinematic curves were normalized to 100% of the stance phase then processed trials were averaged. Joint moments were computed using Newton-Euler inverse-dynamics. To quantify net joint moments anthropometric data, ground reaction forces and angular kinematics were used [18]. The net joint moments were subsequently normalized to participants' body mass and (Nm/kg).

To determine patellofemoral contact force and pressure, a previously utilized model was employed [19]. This technique has been adopted previously to resolve differences in patellofemoral force (PTF) and patellofemoral pressure (PP) when wearing different footwear [20, 21] and when running with and without orthoses [10]. Patellofemoral joint contact force (B.W) was estimated as a function of the knee flexion angle (kfa) and the knee extensor moment (ME), according to the biomechanical model described by Ho et al. [22]. The moment arm of the quadriceps muscle (mq) was calculated as a function of the knee flexion angle using non-linear equation, based on cadaveric information presented by van Eijden et al. [23]:

$$mq = 0.00008\ kfa^3 - 0.013\ kfa^2 + 0.28\ kfa + 0.046$$

Quadriceps force (QF) was then calculated using the formula below:

$$QF = ME / mq$$

PTF was estimated using the QF and a constant (K):

$$PTF = QF * K$$

The constant was described in relation to the kfa using a curve fitting technique based on the non-linear equation described by van Eijden et al. [23]:

$$K = (0.462 + 0.00147\ kfa^2 - 0.0000384\ kfa^2) / (1 - 0.0162\ kfa + 0.000155\ kfa^2 - 0.000000698\ kfa^3)$$

PP (MPa) was calculated as a function of the PTF divided by the patellofemoral contact area. The contact area was described in accordance with the Ho et al. [22] recommendations by fitting a second-order polynomial curve to the data of Powers et al. [24], who documented patellofemoral contact areas at varying levels of knee flexion.

PP = PTF / contact area

Achilles tendon force (ATF) (B.W) was also determined using a previously described model [25]. This procedure has also been used previously to resolve differences in ATF between different footwear [21, 26] and also between running with and without orthotics [11]. ATF was calculated by dividing the plantarflexion moment (MPF) by the estimated Achilles tendon moment arm (mat). The moment arm was quantified as a function of the ankle sagittal plane angle (ak):

ATF = MPF / mat

$$mat = -0.5910 + 0.08297\ ak - 0.0002606\ ak^2$$

In addition, both PTF and ATF average loading rate (B.W/s) were calculated by dividing the peak force by the time taken from footstrike to peak force. As changes in midsole interface have been shown to influence the stride characteristics of runners, the total PTF and ATF impulse (BW x s) were also quantified by multiplying the PTF and ATF estimated during the stance phase by the stance time [27].

STATISTICAL ANALYSES

Means and standard deviations were calculated for each outcome measure for all conditions. Differences in the Achilles tendon and patellofemoral parameters between orthotic conditions were examined using one-way repeated measures ANOVAs, with significance accepted at the $p \leq 0.05$ level [27]. Effect sizes were calculated using partial eta^2 (pη^2). Post-hoc pairwise comparisons were conducted on all significant main effects. The data werescreened for normality using a Shapiro-Wilk test which confirmed that the normality assumption was met. All statistical actions were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

RESULTS

Tables 1–2 and Figures 1–2 present Achilles tendon and patellofemoral kinetics as a function of orthotic and no-orthotic conditions. The results indicate that patellofemoral kinetics were significantly influenced as a function of orthotic intervention.

Table 1. Achilles tendon kinetics as a function of orthotic intervention

	No-orthotic		Off-the-shelf		Semi-custom	
	Mean	SD	Mean	SD	Mean	SD
Peak Achilles tendon force (B.W)	5.23	1.20	5.42	0.94	5.52	0.94
Time to Achilles tendon force (s)	0.12	0.02	0.13	0.02	0.12	0.02
Average loading rate (B.W/s)	45.72	17.00	45.19	13.35	47.17	12.77
Impulse (B.W.s)	0.60	0.17	0.63	0.15	0.63	0.13

Table 2. Patellofemoral kinetics as a function of orthotic intervention

	No-orthotic		Off-the-shelf		Semi-custom	
	Mean	SD	Mean	SD	Mean	SD
Peak patellofemoral force (B.W)	3.21	1.05	3.60	1.12	3.69	1.14
Time to patellofemoral force (s)	0.08	0.02	0.08	0.01	0.09	0.02
Peak patellofemoral pressure (B.W)	8.18	2.43	9.07	2.57	9.30	2.56
Average loading rate (B.W/s)	43.64	17.42	44.18	14.74	45.33	16.37
Impulse (B.W.s)	0.29	0.09	0.33	0.10	0.35	0.11

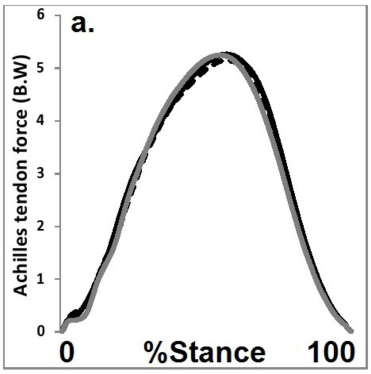

Fig. 1. Achilles tendon kinetics as a function of orthotic intervention, a. = Achilles tendon force (Black = no-orthotic, grey = semi-custom, dash = off-the-shelf)

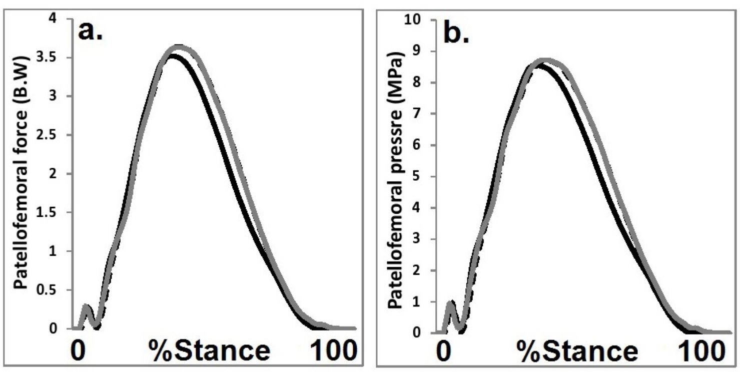

Fig. 2. Patellofemoral kinetics as a function of orthotic intervention, a. = patellofemoral force, b. = patellofemoral pressure (Black = no-orthotic, grey = semi-custom, dash = off-the--shelf)

ACHILLES TENDON FORCES

No significant differences (p > 0.05) in Achilles tendon kinetics were observed between footwear conditions (Table 1; Figure 1b).

PATELLOFEMORAL FORCES

A significant main effect (p <0.05, $p\eta^2$ = 0.54) was found for peak PTF. Post-hoc pairwise comparisons showed that peak PTF was significantly greater in the off-the-shelf and semi-custom orthoses in comparison to running with no orthotics (Table 2; Figure 2b). In addition a significant main effect (p < 0.05, $p\eta^2$ = 0.38) was shown for time to peak PTF. Post-hoc pairwise comparisons showed that time to peak PTF was significantly longer in the off-the-shelf and semi-custom orthoses in comparison to running with no orthotics. A significant main effect ($p < 0.05$, $p\eta^2 = 0.55$) was also shown for peak PP. Post-hoc pairwise comparisons showed that peak PP was significantly greater in the off-the-shelf and semi-custom orthoses in comparison to running with no orthotics (Table 2; Figure 2). Finally, a significant main effect ($p < 0.05$, $p\eta^2 = 0.55$) was shown for PTF impulse. Post-hoc pairwise comparisons showed that PTF impulse was significantly greater in the off-the-shelf and semi-custom orthoses in comparison to running with no orthotics.

DISCUSSION

The aim of the current investigation was to examine the effects of running in semi-custom and off-the-shelf orthotics on the loads experienced by the patellofemoral joint and the Achilles tendon in female runners. To the authors knowledge, this represents the first study to examine the influence of semi-custom orthoses on the loads experienced by the patellofemoral joint and the Achilles tendon.

The first key finding from the current investigation is that both foot orthoses significantly increased the loads experienced by the patellofemoral joint in comparison to running without orthoses. This observation opposes those of Sinclair et al. [10] who demonstrated that off-the-shelf orthoses significantly reduced the loads experienced by the patellofemoral joint in males. This observation may be an important one with regards to the effects of orthoses in female runners. Given the proposed relationship between patellofemoral loading and the aetiology of patellofemoral disorders [22, 29, 30], the current investigation indicates that off-the-shelf and semi-custom orthoses may actually increase runners' susceptibility to knee pathologies. The clinical efficacy of orthoses for the treatment of patellofemoral pain remains equivocal; it appears based on these findings that a prospective analysis regarding the effects of both off-the-shelf and semi-custom orthoses in runners with knee pain is warranted.

A further important observation from this work is that orthoses did not significantly influence the magnitude of the loads experienced by the Achilles tendon. Once again, this observation opposes those found previously by Sinclair et al. [11] who showed that off-the-shelf orthoses significantly reduced the forces borne by the Achilles tendon in males. Achilles tendonitis in runners is considered to be mediated by excessive and habitual loading of the tendon itself [31]. Therefore, the findings from the current investigation indicate that both off-the-shelf and semi-custom orthotics provide female runners with protection from Achilles tendon pathologies.

CONCLUSION

In conclusion, whilst the influence of foot orthoses on running biomechanics have been examined previously, the effects of semi-custom and off-the-shelf orthoses on the loads experienced by the Achilles tendon and patellofemoral joint are unknown. The current investigation, therefore, provides new information describing the influence of semi-custom and off-the-shelf orthoses on the loads borne by these specific musculoskeletal structures in female runners.

On the basis of the fact that increased loading of the patellofemoral joint was observed when running with both off-the-shelfand semi-custom orthotics, the current investigation may provide insight into the clinical efficacy of orthotic intervention in females. Clinically, the current investigation indicates that foot orthoses, such as those examined in the current investigation, may place female runners at increased risk from patellofemoral disorders, although future prospective research is required before this can be substantiated.

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Cite this article as:
Sinclair J, Richards JD, Shore H. Effects of semi-custom and off-the-shelf orthoses on Achilles tendon and patellofemoral kinetics in female runners. Balt J Health Phys Act. 2016;8(4):7-15.