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Effects of medial and lateral orthoses on Achilles tendon kinetics during running

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The aim of the current investigation was to determine the effects of medial and lateral foot orthoses on Achilles tendon kinetics. Achilles tendon kinetics were obtained from twelve male runners who ran at 4.0 m/s, in lateral, medial and no-orthotic conditions. Achilles tendon loading parameters in the three orthotic conditions were examined using one-way repeated measures analysis of variance (ANOVA). The results showed that peak Achilles tendon force was significantly reduced in the medial (49.96 N/kg) in relation to the lateral (54.32 N/kg) and no-orthotic (53.90 N/kg) conditions. In addition, it was also shown that Achilles tendon load rate was significantly reduced in the medial (400.25 N/kg/s) in relation to the lateral (444.11 N/kg/s) and no-orthotic (431.30 N/kg/s) conditions. The current investigation therefore indicates that that medial orthoses can significantly attenuate Achilles tendon loading parameters linked to the etiology of Achilles tendon pathologies. Further study is required to determine whether reductions in Achilles tendon load as a function of medial orthoses also serve to reduce the risk of developing Achilles tendon pathology.

Keywords: biomechanics, Achilles tendon, orthoses, running, sport

Tendons consist of mostly type I collagen and elastin embedded in a proteoglycan-water matrix with collagen; the comprises 65–80% and elastin and approximately 1–2% of the dry mass of the tendon [1]. The Achilles Tendon (AT) is the strongest and thickest tendon in the human body; it originates from near the middle of the calf and is the conjoint tendon of the gastrocnemius and soleus muscles [2]. The AT is subjected to the highest repetitive loads of any tendon within the body, with tensile loads up to ten times an individual's body weight during running, jumping, hopping, and skipping [3]. The AT can experience loads in excess of 5 body weights (BW) during a standard running gait [4]; whist Achilles tendinopathy represents 9.5% of all running injuries sustained [5]. This can be attributed to degeneration of the collagen and elastin that comprise the structure of the AT through the cyclical nature of loading in physical activities such as running.

In-shoe orthotics designed to adjust the relative position of the calcaneus are traditionally used in rehabilitation methods post AT injury; the elevation of the calcaneus causes increased plantar-flexion and the shortening of the muscle-tendon unit, therefore reducing AT load during gait [6]. Using appropriate and well-fitting orthoses has been shown to improve walking and running function during activities in daily lives [7].

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Lorimer and Hume., [8] identified two variables which showed strong evidence of reduction of loads experienced by the AT during running activities; these were high vertical forces and high medial foot arch. They also identified that surface stiffness may have had an effect on AT load and risk of injury.

The force distribution of the triceps surae coupled with the position of the calcaneus has been theorised to have an effect on the strain differences of the AT between individuals [9]; indicating that manipulation of the calcaneus position could affect the distribution of force through the foot. Functional foot orthoses are intended to aid in the correction of biomechanical abnormalities of an individual and reduce the likelihood of the occurrence of injuries as a result of the abnormality. The effects of orthoses on the reduction of AT loads have been studied extensively in a range of locomotion activities; Hockings and Nester., [10] determined that the use of dorsal ankle orthoses reduced vertical ground reaction force (GRF) during locomotion activities when compared with the same motion without the orthotic insert. However, Fröberg et al., [11] produced results that showed that weight bearing in ankle-foot orthoses which restrict dorsiflexion potentially could result in increased forces in the Achilles tendon compared with barefoot walking. Donoghue et al., [12] found that the use of an orthotic resulted in an average reduction of symptoms brought on by a chronic AT injury of 92%; indicating that orthoses when used correctly can aid in the treatment of chronic AT injuries brought on by repetitive loading activities.

However, there has yet to be any published information concerning the effects of medial and lateral orthoses in the reduction of AT load. Therefore, the aim of the current investigation was to determine the effects of medial and lateral foot orthoses on AT kinetics. This could lead to the assertion as to whether medial or lateral orthoses are a viable method of reducing AT load; potentially reducing the incidence of AT injuries.

Methods

Participants

Twelve male runners (age 26.23 ± 5.76 years, height 1.79 ± 0.11 cm and body mass 73.22 ± 6.87 kg) volunteered to take part in this study. All runners were free from musculoskeletal pathology at the time of data collection and were not currently taking any medications. The participants provided written informed consent in accordance with the principles outlined in the Declaration of Helsinki. The procedure utilized for this investigation was approved by the University of Central Lancashire, Science, Technology, Engineering and Mathematics, ethical committee.

Orthoses

Commercially available orthotics (Slimflex Simple, High Density, Full Length, Algeos UK) were examined in the current investigation. The orthoses were made from Ethylene-vinyl acetate and had a shore A rating of 65. The orthoses were able to be modified to either a 5° varus or valgus configuration which spanned the full length of the device.

Procedure

Participants ran at 4.0 m/s (±5%), striking an embedded piezoelectric force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire) with their right foot [13]. Running velocity was monitored using infrared timing gates (Newtest, Oy Koulukatu, Finland). The stance phase was delineated as the duration over which 20 N or greater of vertical force was applied to the force platform [14]. Runners completed a minimum of five successful trials in each footwear condition. The order that participants ran in each footwear condition was randomized. Kinematics and ground reaction forces data were synchronously collected. Kinematic data was captured at 250 Hz via an eight camera motion analysis system (Qualisys Medical AB, Goteburg, Sweden). Dynamic calibration of the motion capture system was performed before each data collection session.

To define the segment coordinate axes of the right foot and shank. Carbon fiber tracking clusters were positioned onto the shank segment, whilst the foot was tracked using the 1st metatarsal, 5th metatarsal and calcaneus markers. The centers of the ankle and knee joints were delineated as the midpoint between the malleoli and femoral epicondyle markers [15,16].

Static calibration trials were obtained with the participant in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking clusters/markers. A static trial was conducted with the participant in the anatomical position in order for the anatomical positions to be referenced in relation to the tracking markers, following which those not required for dynamic data were removed.

Processing

Dynamic trials were digitized using Qualisys Track Manager in order to identify anatomical and tracking markers then exported as C3D files to Visual 3D (C-Motion, Germantown, MD, USA). Ground reaction force and kinematic data were smoothed using cut-off frequencies of 25 and 12 Hz with a low-pass Butterworth 4th order zero lag filter.

Data during the stance phase of running were exported from Visual 3D into OpenSim software (Simtk.org), which was used give to simulations of muscles forces. Simulations of muscle forces were obtained using the standard gait2392 model within Opensim v3.2. This model corresponds to the eight segments that were exported from Visual 3D and features 19 total degrees of freedom and 92 muscle-tendon actuators.

We firstly performed a residual reduction algorithm (RRA) within OpenSim, this utilizes the inverse kinematics and ground reaction forces that were exported from Visual 3D. The RRA calculates the joint torques required to re-create the dynamic motion. The RRA calculations produced route mean squared errors <2°, which correspond with the recommendations for good quality data. Following the RRA, the computed muscle control (CMC) procedure was then employed to estimate a set of muscle force patterns allowing the model to replicate the required kinematics [17]. The CMC procedure works by estimating the required muscle forces to produce the net joint torques.

Achilles tendon force (ATF) was estimated in accordance with the protocol of Almonroeder et al., [18] by summing the muscle forces of the medial gastrocnemius, lateral, gastrocnemius, and soleus muscles. All Achilles tendon load parameters were normalized by dividing the net values by body mass (N/kg).

Achilles tendon load rate (N/kg/s) was quantified as the peak ATF divided by the time to peak ATF. Finally, Achilles tendon impulse (N/kg·s) during the stance phase was quantified by multiplying the force during the stance phase by the stance phase duration.

Statistical analyses

Means, standard deviations and 95% confidence intervals were calculated for each outcome measure for all footwear conditions. Differences in ATF parameters between footwear were examined using one-way repeated measures ANOVAs, with significance accepted at the $P \leq 0.05$ level [19]. Effect sizes were calculated using partial eta^2 (pη^2). Post-hoc pairwise comparisons were conducted on all significant main effects. In addition to this percentage differences were also calculated for all statistically significant effects. The data was screened for normality using a Shapiro-Wilk which confirmed that the normality assumption was met. All statistical actions were conducted using SPSS v23.0 (SPSS Inc., Chicago, USA).

Results

A significant main effect ($P<0.05$, pη^2 = 0.33) was shown for the peak ATF. Post-hoc pairwise comparisons showed that peak ATF was significantly lower in the medial orthosis in relation to the lateral and no-orthotic condition. In addition a significant main effect ($P<0.05$, pη^2 = 0.31) was observed for ATF load rate. Post-hoc pairwise comparisons showed that ATF load rate was significantly lower in the medial orthosis in relation to the lateral and no-orthotic condition (Figure 1, Table 1).

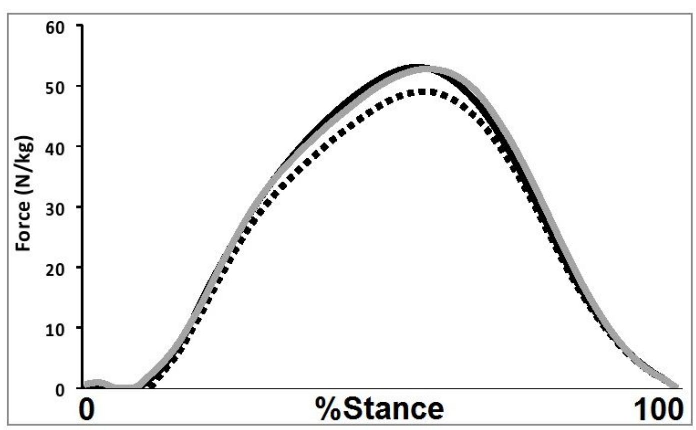

Figure 1 Achilles tendon force during the stance phase (black = lateral, dash = medial, grey = no-orthosis).

	No-orthosis			Medial			Lateral		
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
Maximum ATF (N/kg)	53.90	8.23	48.67-59.13	49.96	9.37	44.01-55.91	54.32	9.56	48.25-60.39
ATF rate (N/kg/s)	431.30	126.84	350.71-511.89	400.25	130.53	321.32-487.19	444.11	139.85	355.25-532.97
ATF impulse (N/kg·s)	5.84	1.21	5.08-6.61	5.61	1.20	4.85-6.37	5.89	1.46	4.96-6.82

Table 1 Achilles tendon kinetics (Mean, SD and 95% CI) as a function of the different orthotic conditions.

Discussion

The aim of the current investigation was to determine the effects of medial and lateral foot orthoses on AT kinematics. To the author's knowledge, this represents the first investigation to examine the biomechanical effects of medial and lateral orthoses on AT kinetics. This investigation provides evidence of potential positive effects on running kinematics of orthoses, focusing on AT load. Results of this study could potentially be used in the treatment of AT pathologies or in the development of more effective orthoses. The first key observation from the current investigation is that medial orthosis produced significantly lower ATF load rate and peak ATF. Findings from this investigation support the proposition of Donoghue et al., [12] who proposed that a high medial foot arch can contribute to the reduction of loads experienced by the AT during running and that orthoses can reduce the symptoms of chronic injuries of the AT as a result of cyclical loading; potentially explaining a component of the load reduction identified when using medial orthoses. Lersch et al., [9] proposed that manipulation of the calcaneus position affected the force distribution of the triceps surae and therefore the AT; given that the insertion points of the medial/ lateral gastrocnemius and soleus muscles increased calcaneal range of motion; this would therefore increase the tensile forces on the AT. This is supported by the OpenSim model for muscle tendon units proposed by Delp et al., [20]. The findings of this investigation would support this proposal due to the effect a medial orthosis has on calcaneus position. Excessive loading of the AT is considered to be a key mechanism linked to the aetiology of AT pathologies in runners [21] as decomposition of the collagen fibers that comprise the structure of the AT exceeds fiber synthesis. Therefore, the key implication of these from this observation is that medial orthoses when compared to lateral and no orthoses; reduce the kinetic parameters linked with the aetiology of AT pathologies.

Lateral orthoses are heavily utilized for the treatment of medial tibiofemoral compartment pathologies [22]. Laterally wedged orthotic devices have been shown to reduce the knee adduction moment which is a measurement of compressive medial knee compartment loading [22, 23]. However, the findings of this investigation indicate that lateral orthoses should perhaps be utilized contextually in that they could potentially increase the likelihood of the development of AT injuries.

Excessive lateral manipulation of the calcaneus could result in restriction of the blood supply to the AT which has been suggested as a cause of increased AT pathologies [24]. Therefore, it can be speculated that medial orthoses may be able to attenuate the risk of development of AT pathologies in runners, although further prospective work is required to fully establish this. It should be noted that this finding was observed when performing fully anticipated and controlled movements in a laboratory setting, therefore the results may not be generalizable to a running specific environment where variables are not controlled to the same level.

In conclusion, the current knowledge with regards to the efficacy of medial/lateral orthoses during locomotion is limited; therefore, the current investigation addresses this by examining the effect AT kinetics during running movements. The current study showed firstly that AT kinetics are significantly affected by the orientation of the orthoses used; with the lateral and no-orthotic conditions presenting significantly increased peak ATF, ATF load rate and AT impulse. Therefore, the current investigation indicates that that medial orthoses significantly attenuated AT loading parameters linked to the aetiology of AT pathologies, although further study is required to determine whether reductions in AT load as a function of medial orthoses serve to attenuate the risk of developing AT pathologies as a result of running.

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