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Effects of medial and lateral orthoses on kinetics and tibiocalcaneal kinematics in male runners

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Background: The aim of the current investigation was to examine the effects of foot orthotic devices with a 5° medial and lateral wedge on kinetics and tibiocalcaneal kinematics during the stance phase of running.
Material and methods: Twelve male participants ran over a force platform at 4.0 m/s in three different conditions (5° medial orthotic, 5° lateral orthotic and no-orthotic). Tibiocalcaneal kinematics were collected using an 8 camera motion capture system and axial tibial accelerations were obtained via an accelerometer mounted to the distal tibia. Biomechanical differences between orthotic conditions were examined using one-way repeated measures of analysis of variance (ANOVA).
Results: The results showed that no differences (P>0.05) in kinetics/tibial accelerations were evident between orthotic conditions. However, it was revealed that the medial orthotic significantly (P<0.05) reduced peak ankle eversion and relative tibial internal rotation range of motion (-10.75 & 4.98°) in relation to the lateral (-14.11 & 6.14°) and no-orthotic (-12.37 & 7.47°) conditions.
Conclusions: The findings from this study indicate, therefore, that medial orthoses may be effective in attenuating tibiocalcaneal kinematic risk factors linked to the etiology of chronic pathologies in runners.

Keywords: running, biomechanics, orthoses, kinetics, kinematics

Distance running is associated with a significant number of physiological and psychological benefits [1]. However, epidemiological analyses have demonstrated that pathologies of a chronic nature are extremely common in both recreational and competitive runners [2] and as many as 80% of runners will experience a chronic injury as a consequence of their training over a one-year period [2].

Given the high incidence of chronic pathologies in runners, a range of strategies have been investigated and implemented in clinical research in an attempt to mitigate the risk of injury in runners. Foot orthoses are very popular devices that are used extensively by runners [3]. It has been proposed that foot orthoses may be able to attenuate the parameters linked to the etiology of injury in runners, thus they have been cited as a mechanism by which injuries can be prophylactically avoided and also retrospectively treated [4]. The majority of research investigating the biomechanical effects of foot orthoses during running has examined either impact loading or rearfoot eversion parameters which have been linked to the etiology of running injuries. Sinclair et al, [5] showed that an off the shelf orthotic device significantly reduced vertical rates of loading and axial tibial

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accelerations, but did not alter the magnitude of rearfoot eversion. Butler et al, [6] examined three-dimensional (3D) kinematic/ kinetic data alongside axial tibial accelerations during running, using dual-purpose and a rigid orthoses. Their findings revealed that none of the experimental parameters were differed significantly between the different orthotic conditions. Laughton et al, [7] showed that foot orthoses significantly reduced the loading rate of the vertical ground reaction force but did not significantly influence rearfoot eversion parameters. Dixon, [8] examined the influence of off the shelf foot orthoses placed inside an military boot on kinetic and 3D kinematic parameters during running. The findings from this investigation revealed that the orthotic device significantly reduced the vertical rate of loading, but no alterations in ankle eversion were reported.

Further to this, because the mechanics of the foot alter the kinetics/kinematics of the proximal lower extremity joints, biomechanical control of the foot with in-shoe orthotic wedges has wide-ranging applications for the treatment of a variety chronic lower extremity conditions. Different combinations of wedges or posts have therefore been used in clinical practice/ research to treat a multitude of chronic pathologies [9]. Both valgus (lateral) and varus (medial) orthoses have been proposed as potentially important low-cost devices for the conservative management of chronic pathologies [10].

Lateral orthoses are utilized extensively in order to reduce the loads experienced by the medial tibiofemoral compartment [10]. Lateral orthoses cause the center of pressure to shift medially thereby moving the medial-lateral ground reaction force vector closer to the knee joint center [11]. This serves to reduce the magnitude of the knee adduction moment which is indicative of compressive loading of the medial aspect of the tibiofemoral joint and its progressive degeneration [12]. Kakihana et al, investigated the biomechanical effects of lateral wedge orthoses on knee joint moments during gait in elderly participants with and without knee osteoarthritis [13]. The lateral wedge significantly reduced the knee adduction moment in both groups when compared with no wedge. Butler et al, examined the effects of a laterally wedged foot orthosis on knee mechanics in patients with medial knee osteoarthritis [14]. The laterally wedged orthotic device significantly reduced the peak adduction moment and also the knee adduction excursion from heel strike to peak adduction compared to the non-wedged device. Kakihana et al, examined the kinematic and kinetic effects of a lateral wedge insole on knee joint mechanics during gait in healthy adults [15]. The wedged insole significantly reduced the knee adduction moment during gait in comparison to the no-wedge condition, although no changes in knee kinematics were evident.

The influence of medially oriented foot orthoses has also been frequently explored in biomechanical literature. Boldt et al, examined the effects of medially wedged foot orthoses on knee and hip joint mechanics during running in females with and without patellofemoral pain syndrome [16]. The findings from this study showed that the peak knee adduction moment increased and hip adduction excursion decreased significantly when wearing medially wedged foot orthoses. Sinclair et al., explored the effects of medial foot orthoses on patellofemoral stress during the stance phase of running using a musculoskeletal modelling approach [17]. Their findings showed that medial foot orthoses significantly reduced peak patellofemoral stress loading at this joint during running.

Although the effects of medial/lateral foot orthoses have been explored previously, they have habitually been examined during walking in pathological patients and thus their potential prophylactic effects on the kinetics and tibiocalcaneal kinematics of running have yet to be examined. Therefore, the aim of the current investigation was to examine the effects of foot orthotic devices with a 5° medial and lateral wedge on kinetics and tibiocalcaneal kinematics the during the stance phase of running. A clinical investigation of this nature may provide further insight into the potential efficacy of wedged foot orthoses for the prevention of chronic running 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. The order that participants ran in each orthotic condition was counterbalanced.

Procedure

Participants completed five running trials at 4.0 m/s ± 5%. The participants struck an embedded piezoelectric force platform (Kistler Instruments, Model 9281CA) sampling at 1000 Hz with their right foot. Running velocity was monitored using infrared timing gates (SmartSpeed Ltd UK). The stance phase of the running cycle was delineated as the time over which > 20 N vertical force was applied to the force platform. Kinematic information was collected using an eight-camera optoelectric motion capture system with a capture frequency of 250 Hz. Synchronized kinematic and ground reaction force data were obtained using Qualisys track manager software (Qualisys Medical AB, Goteburg, Sweden).

The calibrated anatomical systems technique (CAST) was utilized to quantify tibiocalcaneal kinematics (18). To define the anatomical frames of the right foot, and shank, retroreflective markers were positioned onto the calcaneus, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral epicondyle of the femur. A carbon fiber tracking cluster was attached to the shank segment. The foot was tracked using the calcaneus, and first and fifth metatarsal markers. 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.

Tibial accelerations were measured using an accelerometer (Biometrics ACL 300, Units 25-26 Nine Mile Point Ind. Est. Cwmfelinfach, Gwent United Kingdom) sampling at 1000 Hz. The device was attached to the tibia 0.08 m above the medial malleolus in alignment with its longitudinal axis (19). Strong adhesive tape was placed over the device and the lower leg to prevent artifact in the acceleration signal.

Processing

The running trials were digitized using Qualisys Track Manager (Qualysis, Sweden) and then exported as C3D files. Kinematic parameters were quantified using Visual 3-D software (C-Motion, USA) after the marker data was smoothed using a low-pass Butterworth 4th order zero-lag filter at a cutoff frequency of 12 Hz. Three-dimensional kinematic parameters were calculated using an XYZ cardan sequence of rotations where X represents the sagittal plane, Y represents the coronal plane and Z represents the transverse plane rotations (Sinclair et al., 2013). Trials were normalized to 100% of the stance phase then processed and averaged. In accordance with previous studies, the foot segment coordinate system was referenced to the tibial segment for ankle kinematics, whilst tibial internal rotation (TIR) was measured as a function of the tibial coordinate system in relation to the foot coordinate axes [21]. The 3-D kinematic tibiocalcaneal measures which were extracted for statistical analysis were: (1) angle at foot strike, (2) peak angle during stance and (3) relative range of motion (ROM) from footstrike to peak angle.

The tibial acceleration signal was filtered using a 60 Hz Butterworth zero lag 4th order low pass filter to prevent any resonance effects on the acceleration signal. Peak tibial acceleration (g) was defined as the highest positive axial acceleration peak measured during the stance phase. Average tibial acceleration slope (g/s) was quantified by dividing peak tibial acceleration by the time taken from footstrike to peak tibial acceleration and instantaneous tibial acceleration slope (g/s) was quantified as the maximum increase in acceleration between frequency intervals. From the force platform all parameters were normalized by dividing the net values by body weight. Instantaneous loading rate (BW/s) was calculated as the maximum increase in vertical force between adjacent data points.

Statistical analyses

Means, standard deviations and 95 % confidence intervals were calculated for each outcome measure for all orthotic conditions. Differences in kinetic and tibiocalcaneal kinematic parameters between orthoses were examined using one-way repeated measures ANOVAs, with significance accepted at the P≤0.05 level. Effect sizes were calculated using partial eta^2 ($p\eta^2$). Post-hoc pairwise comparisons were conducted on all significant main 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

Tables 1-3 and Figure 1 present differences in kinetics and tibiocalcaneal kinematics as a function of the different orthoses. The results indicate that the experimental orthoses significantly affected orthoses tibiocalcaneal kinematic parameters.

Kinetics and tibial accelerations

No significant (P>0.05) differences in kinetics/tibial acceleration parameters were observed between orthotic conditions.

Tibiocalcaneal kinematics

In the coronal plane a significant main effect ($F_{(2, 22)}$ = 25.58, P<0.05, $p\eta^2$ = 0.70) was found for the magnitude of peak eversion. Post-hoc pairwise comparisons showed that peak eversion was significantly larger in the lateral in relation to the medial (P=0.0000007) and no-orthotic (P=0.01) conditions. In addition, it was also revealed that peak eversion was significantly greater in the no-orthotic (P=0.008) in comparison to the medial orthotic condition. In addition, a significant main effect ($F_{(2, 22)}$ = 25.58, P<0.05, $p\eta^2$ = 0.74) was noted for relative eversion ROM. Post-hoc pairwise comparisons showed that relative eversion ROM was significantly larger in the lateral (P=0.0000006) and no-orthotic (P=0.00001) in relation to the medial condition.

In the transverse plane a significant main effect ($F_{(2, 22)}$ = 116.11, P<0.05, $p\eta^2$ = 0.91) was noted for relative transverse plane ankle ROM. Post-hoc pairwise comparisons showed that relative transverse plane ankle ROM was significantly larger in the lateral (P=0.0000001) and no-orthotic (P=0.0000008) in relation to the medial condition.

In addition, a significant main effect ($F_{(2, 22)}$ = 5.99, P<0.05, $p\eta^2$ = 0.36) was found for the magnitude of peak TIR. Post-hoc pairwise comparisons showed that peak TIR was significantly larger in the lateral in relation to the medial (P=0.007) and no-orthotic (P=0.025) conditions. Finally, a significant main effect ($F_{(2, 22)}$ = 7.55, P<0.05, $p\eta^2$ = 0.41) was noted for relative TIR ROM. Post-hoc pairwise comparisons showed that relative TIR ROM was significantly larger in the lateral (P=0.04) and no-orthotic (P=0.007) in relation to the medial condition.

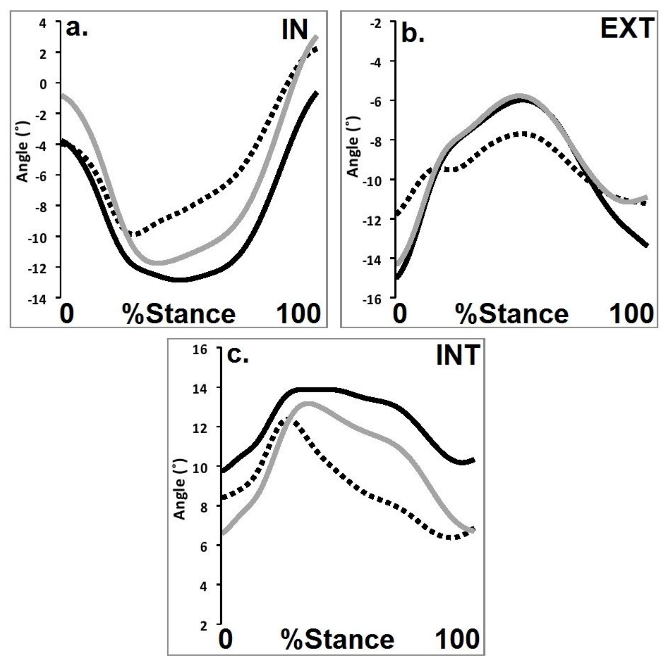

Figure 1 Tibiocalcaneal kinematics as a function of the different orthotic conditions; a= ankle coronal plane angle, b= ankle transverse plane angle & c = tibial internal rotation, (black = lateral, dash = medial & grey = no-orthotic), (IN = inversion, EXT = external & INT = internal).

	Medial				**Lateral**				**No-orthotic**			
	Mean	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*
Coronal plane (+ = inversion & - = eversion)												
Angle at footstrike (°)	-3.98	5.65	-7.57	-0.39	-3.77	5.64	-7.35	-0.19	-0.66	5.91	-4.41	3.09
Peak eversion (°)	-10.75	5.7	-14.38	-7.13	-14.11	6.48	-18.22	-9.99	-12.37	5.43	-15.82	-8.92
Relative ROM (°)	6.77	2.78	5.00	8.54	10.34	3.44	8.15	12.53	11.71	3.26	9.64	13.78
Transverse plane (+ = external & - = internal)												
Angle at footstrike (°)	-11.78	2.72	-13.51	-10.05	-15.01	2.81	-16.80	-13.22	-14.41	2.97	-16.29	-12.52
Peak rotation (°)	-6.80	3.10	-8.78	-4.83	-5.6	3.94	-8.10	-3.09	-5.05	3.33	-7.17	-2.93
Relative ROM (°)	4.97	0.86	4.43	5.52	9.41	1.33	8.56	10.26	9.35	1.44	8.44	10.27

Table 1 Ankle kinematics (mean, SD & 95% CI) in the coronal and transverse planes as a function of the different orthotic conditions.

	Medial				**Lateral**				**No-orthotic**			
	Mean	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*
Transverse plane (+ = internal & - =external)												
Angle at footstrike (°)	8.57	3.16	6.56	10.57	9.74	4.01	7.20	12.29	6.51	3.98	3.98	9.04
Peak TIR (°)	13.54	4.28	10.82	16.27	15.89	5.65	12.30	19.48	13.98	4.58	11.07	16.89
Relative ROM (°)	4.98	2.68	3.28	6.68	6.14	3.54	3.89	8.39	7.47	3.75	5.09	9.85

Table 2 Tibial internal rotation parameters (mean, SD & 95% CI) as a function of the different orthotic conditions.

	Medial				**Lateral**				**No-orthotic**			
	Mean	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*	**Mean**	SD	*95% CI (Lower)*	*95% CI (Upper)*
Peak tibial acceleration (g)	9.83	4.50	6.98	12.69	9.97	4.88	6.87	13.07	9.41	4.76	6.38	12.44
Average tibial acceleration slope (g/s)	362.73	196.31	238.01	487.46	367.37	219.63	227.83	506.91	369.52	257.85	205.69	533.35
Instantaneous tibial acceleration slope (g/s)	866.20	459.40	574.31	1158.09	867.71	554.16	515.61	1219.81	776.85	529.86	440.20	1113.51
Instantaneous load rate (BW/s)	156.17	58.72	118.86	193.48	161.77	71.57	116.30	207.25	134.49	44.62	106.14	162.84

Table 3 Kinetic and tibial acceleration parameters (mean, SD & 95% CI) as a function of the different orthotic conditions.

Discussion

The aim of the current investigation was to examine the effects of foot orthotic devices with a 5° medial and lateral wedge on kinetics and tibiocalcaneal kinematics the during the stance phase of running. This is, to the authors' knowledge, the first investigation to concurrently examine the influence of different orthotic wedge configurations on the biomechanics of running. An investigation of this nature may, therefore, provide further insight into the potential prophylactic efficacy of wedged foot orthoses for the prevention of chronic running injuries.

The current study importantly confirmed that no significant differences in impact loading or axial tibial accelerations were evident as a function of the experimental orthotic conditions. This observation opposes those of Sinclair et al., Laughton et al. and Dixon, who demonstrated that foot orthoses significantly reduced the magnitude of axial impact loading during the stance phase of running [5,7,8]. However, the findings are in agreement with those noted by Butler et al, who similarly observed that the magnitude of axial impact loading did not differ significantly whilst wearing rigid orthoses [6]. Although not all of the aforementioned investigations have published hardness ratings, at a shore A grade of 65 it is likely that the orthoses examined in the current explanation were more rigid than those utilized by Sinclair et al., Laughton et al. and Dixon [5,7,8]. It is proposed that the divergence between investigations relates to differences in hardness characteristics of the experimental orthoses. The magnitude of impact loading is governed by the rate of change in momentum of the decelerating limb as the foot strikes the ground [22]; as such, it appears that the orthoses examined in this analysis were not sufficiently compliant to provide any reduction in impact loading.

Of further importance to the current investigation is that the medial orthoses significantly reduced eversion and TIR parameters in relation to the lateral and no-orthotic conditions. It is likely that this observation relates to the mechanical properties of the medial wedge which is designed specifically to rotate the foot segment into a more inverted position. This finding has potential clinical significance as excessive rearfoot eversion and associated TIR parameters are implicated in the etiology of a number of overuse injuries such as tibial stress syndrome, plantar fasciitis, patellofemoral syndrome and iliotibial band syndrome [23-25]. This observation therefore suggests that medial orthoses may be important for the prophylactic attenuation of chronic running related to excessive eversion/ TIR.

The findings from the current study importantly show that whilst lateral orthoses are effective in attenuating pain symptoms [9] and reducing the magnitude of the external knee adduction moment [13-15] in patients with medial compartment tibiofemoral osteoarthritis, they may concurrently place runners at risk from chronic pathologies distinct from the medial aspect of the tibiofemoral joint. It appears based on the findings from the current investigation that caution should be exercised when prescribing lateral wedge orthoses without a thorough assessment of the runners' individual characteristics.

A limitation, in relation to the current investigation, is that only the acute effects of the wedged insoles were examined**.** Therefore, although the medial orthoses appear to prophylactically attenuate tibiocalcaneal risk factors linked to the etiology of injuries, it is currently unknown whether this will prevent or delay the initiation of injury symptoms. Furthermore, the duration over which the orthoses would need to be utilized in order to mediate a clinically meaningful change in patients is also not currently known. A longitudinal examination of medial/lateral orthoses in runners would therefore be of practical and clinical relevance in the future. A further potential limitation is that only male runners were examined as part of the current investigation. Females are known to exhibit distinct tibiocalcaneal kinematics when compared to male recreational runners, with females being associated with significantly greater eversion and TIR parameters compared to males [26]. Furthermore, females are renowned for being at increased risk from tibiofemoral joint degeneration in comparison to males [27], and experimental findings have shown that degeneration may also be more prominent at different anatomical aspects of the knee in females in relation to males [28]. This suggests that the requirements of females, in terms of wedged orthotic intervention, may differ from those of male runners, thus it would be prudent for future biomechanical investigations to repeat the current study using a female sample.

In conclusion, despite the fact that the biomechanical effects of wedged foot orthoses have been examined previously, current knowledge with regards to the effects of medial and lateral orthoses on the kinetics and tibiocalcaneal kinematics of running have yet to be explored. This study adds to the current literature in the field of biomechanics by giving a comprehensive comparative examination of kinetic and tibiocalcaneal kinematic parameters during the stance phase of running whilst wearing medial and lateral orthoses. The current investigation importantly showed that medial orthoses significantly attenuated eversion and TIR parameters in relation to the lateral and no-orthotic conditions. The findings from this study indicate therefore that medial orthoses may be effective in attenuating tibiocalcaneal kinematic risk factors linked to the etiology of chronic pathologies in runners**.**

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