ORTHOSES CONTROL OF FRONTAL AND SAGITTAL PLANE MOTION IN THE INJURED AND UNINJURED LEGS OF SUBJECTS WITH CHRONIC ACHILLES TENDON INJURY DURING RUNNING

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This study is part of a larger study examining the effectiveness of orthoses in relieving symptoms of injury. Nine subjects with unilateral chronic Achilles tendon injury ran on a treadmill under three conditions: barefoot, with orthoses and without orthoses. Three-dimensional rearfoot and lower leg kinematic data was obtained using eight ProReflex Qualisys MCU240 cameras operating at 200 Hz. An SPSS repeated measures ANOVA was used to examine differences between injured and uninjured legs. Results indicated considerable between subject variation even in this carefully controlled subject group. Orthoses restored the injured leg to a more neutral frontal plane position at heel strike and decreased sagittal plane maximum and ROM angles by more than 2° compared to the no orthoses condition. There was a significant leg*condition interaction effect for Achilles tendon angle at heel strike ($p = 0.003$) illustrating different effects of conditions for both legs.

KEY WORDS: pronation, chronic Achilles tendon injury, treadmill running

INTRODUCTION: Chronic Achilles tendon injury is common especially in older endurance athletes. It is speculated that the mechanisms involved may be either excessive pronation of the rearfoot or excessive eccentric contraction of the gastrosoleus complex (Smart et al., 1980). The condition is very resistant to treatment and conventional methods often only have short-term and limited success in relieving the symptoms. Orthoses are widely used in addition to conventional treatments in the treatment of chronic Achilles tendon injury as well as many other lower limb pathologies (Stacoff et al., 2000). Anecdotal evidence indicates that orthoses prescribed to alter a specific movement pattern are often effective in relieving the symptoms of injury but the scientific evidence to validate this is lacking (Heiderscsheit et al., 2001). Several researchers have attempted to quantitatively examine if orthoses control the kinematics of the foot and lower limb movement. The majority of the results have been inconsistent and equivocal often due to lack of control in the experimental design (Heiderscheit et al., 2001). Several external factors influence the kinematics of rearfoot and lower leg motion, which makes it important to incorporate a significant amount of control into the study to detect the small and subtle changes which may occur. In this study, running speed and subject population were controlled in order to minimise sources of variation in the experiment. This study is part of a larger investigation examining the effect of orthoses in controlling rear foot and lower limb motion in subjects with chronic Achilles tendon injury during running. This aspect of the research programme compared the effect of orthoses on injured and uninjured legs of subjects with chronic Achilles tendon injury.

METHODS: Ethical approval was obtained for this study from the Ethics Committee in the University of Salford. Nine subjects (8 male, 1 female, mean age: 42 ± 8.5 years; mass: 71 ± 8.6 kg; height: 1.75 ± 0.05 m) provided written, informed consent to participate in the study. Selection criteria required that subjects had a chronic, low grade Achilles tendon injury, which was not a tear and not degenerative. All subjects were classified as excessive pronators exhibiting lateral bowing of the Achilles tendon based on 2-D movement analysis. All subjects were involved in various sports (running, football), had good fitness levels, no injuries at the time of testing and no unusual running patterns.
Subjects underwent a full podiatric examination assessing the soft tissue and bony structures of the foot, joint alignment, leg length discrepancy, ROM of the joints of the foot, navicular

drop, subtalar joint neutral alignment and static 3-D Achilles tendon angle (Root et al., 1971). The same podiatrist provided all subjects with individually designed orthoses to alleviate pain and symptoms of injury. This ensured consistency across the examination, diagnosis and manufacture procedures for the devices used in the study. Subjects also completed a questionnaire providing details of the injury, aggravating factors, training activities, treatment received, follow-up on pain relief and improvements following treatment.

Retroreflective markers were placed on the posterior and lateral aspects of both lower extremities as follows: two markers on the posterior aspect of the shoe bisecting the heel, two bisecting the posterior shank (one on the Achilles Tendon, one below the belly of the gastrocnemius), one on each of the 5th metatarsal, lateral malleolus, fibular head and greater trochanter (Figure 1). These were used to define 3-D sagittal and frontal plane movements of the foot and lower leg during stance (Table 1). All angles were measured relative to subtalar neutral position taken by the podiatrist prior to each dynamic condition. Subjects completed a habituation period running on a Make-Vision Fitness T9450HRT treadmill prior to testing. For data collection, subjects ran at a comfortable self selected speed.

Figure 1 Marker setup as used in this study.

Eight ProReflex Qualisys MCU240 cameras operating at a frequency of 200 Hz and a shutter duration of 0.00833s were placed in an arc around the side and rear of the treadmill to obtain three-dimensional coordinates data of rearfoot and lower leg markers during barefoot (BF), orthoses (O) and no orthoses (NO) conditions. Marker tracking of the video data completed using Qualisys Track Manager (Gothenburg, Sweden). The heelstrike and toe off events of the individual footfalls were determined from the displacement of a marker placed on the front of the treadmill. Five footfalls (trials) for each leg and condition were obtained for analysis from each subject's data. These trials were then exported for smoothing and angle calculation using the Peak Motus™ Analysis System (Peak Performance Technologies, Englewood, CO, USA). A repeated general linear model (GLM) ANOVA in SPSS was used to determine if significant differences existed between the injured and uninjured legs. The ANOVA involved three within subjects factors, namely, leg (with two levels (injured and uninjured), condition (with 3 levels: BF, shod with an orthoses and shod without an orthoses) and trials (with five levels). The interaction between leg and condition was also examined. All measures were tested at a significance level of $\alpha = 0.05$. The dependent variables were joint angle measurements as described in Table 1. All joint angle measurements were obtained relative to relaxed stance position. For each angle, measures were obtained for heelstrike (HS), maximum angle (max) during stance and range of motion (ROM).

Table 1 Defined angles to describe frontal and sagittal plane motion.

Medial lower leg (MLL) angle	Angle between the lower leg and ground on medial side from posterior
Rearfoot (Rft) angle	Angle between the rearfoot and ground on medial side from posterior
Achilles Tendon (AT) angle	In/eversion position of rearfoot relative to the lower leg
Ankle DF angle (ADF)	Anatomical joint angle between fibular head, ankle and 5th metatarsal
Knee flexion angle (KF)	Anatomical joint angle between greater trochanter, fibular head and ankle

RESULTS AND DISCUSSION: Significant differences were found for max AT, max MLL and AT ROM angles ($p < 0.001$, $p = 0.046$ and $p < 0.001$ respectively) between running conditions irrespective of leg. This confirms reports from previous studies of lower values in BF running compared to shod (Stacoff *et al.*, 1991). AT angle at HS was found to be significant ($p = 0.003$) when the leg×condition interaction effect was examined. It was noteworthy that the pattern of the shoe and orthoses effects across conditions was not consistent for injured and uninjured legs. For example, AT angle at HS and ROM angles were reduced in the injured leg towards those seen in BF running, while they were increased away from the BF values in the uninjured leg (see Figure 2).

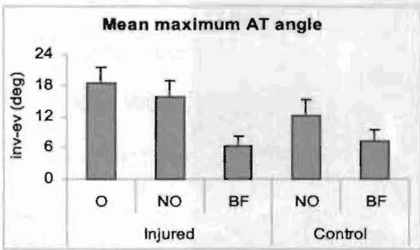

Figure 2 Average maximum AT angle at HS for injured and control legs (-ve = inversion, +ve = version).

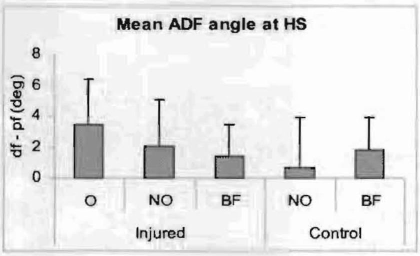

Figure 3 Average ADF angle at HS for injured and control legs (-ve = dorsiflexion,+ve = plantar-flexion).

The range of standard deviations for HS, max and ROM angles varied from 5° for Rft angle and 20° for KF angle, illustrating considerable variation between subjects despite having a similar mechanism of injury and movement pattern. This made it difficult to detect several changes as being significant. However, for any measure across conditions, the standard deviations were often very similar suggesting that the same relative changes and effects may have been occurring. This indicates that the initial angles and positions of the foot may differ between subjects but the pattern of movement that the foot undergoes is similar.

It was hypothesised that the orthoses would reduce excessive maximum and ROM values of sagittal and frontal plane motion during stance. Barefoot running typically results in fewer injuries than shod running (Warburton, 2001), so this condition was used as an indication of what desirable kinematics would be. Situations where an orthoses altered a measure by more than 2° compared to the no orthoses condition were selected. A value of 2° was chosen to allow for measurement error and as anything less may not be clinically significant.

Despite not being statistically significant, some trends regarding the effects of orthoses in the injured leg did emerge. Orthoses tended to reduce the average AT angle at HS, max ankle and knee flexion angles and ankle and knee ROM. The orthoses also decreased AT and KF angles at HS, max AT and KF angles in the uninjured leg. This supports the suggestion that there may be excessive movements present with injury and that an orthoses may decrease these towards values seen in the uninjured leg and BF running condition. This also highlights the importance of HS and ROM angles as well as max angle in the occurrence of AT injury. For max ADF and ADF, KF and MLL ROM angles, the orthoses had a greater decreasing

effect in the injured leg compared to the uninjured leg (see Figure 3). This could be attributed to the fact that injured legs display more excessive values providing a greater need for change so the response to a device may be dependent on the initial presenting kinematics. However it is also possible that the injured legs have a lower tolerance for certain kinematic angles due to the injury and have a greater need for adjustment. Instead of drastically changing the kinematics in both limbs, the injured leg may be prioritised and the uninjured may be influenced in a corresponding manner to ensure balance between both limbs.
There were clear asymmetries between the injured and uninjured legs in all conditions for the angles measured. However subjective reports based on the questionnaire indicated that subjects found the orthoses were on average 93% successful in relieving the symptoms of their injury. This suggests that it may not be necessary to have kinematic symmetry between the injured and uninjured legs for comfortable and effective locomotion. So despite promoting an asymmetrical movement pattern, the orthoses may still restore optimal function to the limbs.

CONCLUSION: Orthoses research rarely examines the effect of devices in a specific subject population such as those with chronic Achilles tendon injury. This study recruited subjects with a similar movement pattern to ensure consistency in the kinematics of rearfoot motion. The magnitude of angles showed some differences illustrating that each subject still displayed considerable variation despite this. In contrast to previous studies which found inconsistent effects, the results show that orthoses do have systematic effects in reducing the factors related to Achilles tendon injury. While orthoses often reduced measures in both injured and uninjured legs, this was not always the case and effects often differed between legs. This provides some evidence to support the anecdotal reports of the success of orthoses. Further analysis of controls to examine if they display symmetrical movements patterns should be carried out.

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