

## Foot orthoses affect frequency components of muscle activity in the lower extremity

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### Abstract

The purpose of this study was to quantify the effects of selected foot orthoses on muscle activity in the lower extremity during running. Nine male and 12 female recreational runners, clinically and functionally classified as ‘pronators’, volunteered for this study and performed over-ground running trials at 4 m/s in each of four experimental conditions: control, posting, molding, and posting & molding. Electromyographic (EMG) signals were recorded from seven lower extremity muscles. Wavelet analysis was performed to obtain EMG intensities in two frequency bands that were averaged for the pre-heel-strike and post-heel-strike intervals and for 30–100% of stance phase. Posting and custom-molding of foot orthoses increased the global EMG intensity of most muscles of the lower extremity for the stance phase of running ( $P < 0.05$ ). The increases in EMG intensity were greater in the high- than in the low-frequency bands for some lower extremity muscles ( $P < 0.05$ ). The effects on muscle activity of posting and custom-molding of foot orthoses differed between the three phases of running gait. The three tested foot orthoses did affect lower extremity muscle activity differently and these effects were specific to the phases of running gait. Combinations of increased requirements of controlling joint motion and minimizing soft tissue vibrations may have led to greater increases in shank muscle activity for the posted condition. The substantial changes in EMG due to orthotic interventions found in this study documents the importance of the study of muscle activity as a reaction to shoe inserts and foot orthoses.

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### 1. Introduction

Recreational runners use foot orthoses to prevent injuries, to rehabilitate from injuries, to increase comfort and/or to improve performance. Foot orthoses are typically classified as non-posted or posted and as non-molded or custom-molded, and medial or lateral posts are often added to custom-molded foot orthoses [1].

Foot orthoses are generally believed to align the skeleton and to reduce the loading of biological structures in the

lower extremities. However, results of most kinematic studies (e.g. [2,3]) showed that the effects of foot orthoses/inserts on foot eversion were small and non-systematic. Results of a comprehensive recent study showed that foot orthoses do have small but significant effects on maximum foot eversion, maximum foot inversion during the second half of stance phase, vertical ground reaction forces and vertical loading rate [4]. However, the functional reason for a potential improvement of the loading situation of the musculoskeletal system during running due to foot orthoses is not well understood.

Potential candidates for explaining the effects of foot orthoses are changes in the activation of muscles of the lower extremities. Initial studies have documented substantial subject specific changes in lower extremity muscle activity

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in reaction to foot orthoses [5]. To explain these changes, it was proposed that an orthosis supporting the natural joint motion (determined by the geometry of the articular surface and the ligaments) will reduce muscle activation, and that an orthosis counteracting natural joint motion will increase muscle activation to maintain natural joint motion [6].

Changes in muscle activity may occur with respect to intensity and/or frequency. In addition to changes in intensity, which have been quantified traditionally, substantial changes in the frequency content of muscle activation have been demonstrated during prolonged running activities [7] and for running with shoes with different midsole constructions [8]. Thus, it is speculated that foot orthoses may cause a change in intensity and frequency of the EMG signals of lower extremity muscles.

The primary functions of muscle activity vary throughout the stance phase of running. It has been suggested [9], that before and immediately after heel-strike, muscles are activated to stabilize the joints and to minimize possible soft tissue vibrations. After heel strike, muscle may also be activated due to stretch-reflex-related responses [10,11]. Muscle activation during the rest of stance phase is related to muscle forces to support and to accelerate the body and muscle forces that provide stability during locomotion. It is speculated that the effects of foot orthoses on EMG signals may vary for these time intervals. However, to date no evidence has been provided to support this speculation.

The purpose of this study was to quantify the effects of custom molded and posted foot orthoses on muscle activity in the lower extremity during running. It was hypothesized that (a) posting and custom-molding of foot orthoses affect both the intensity and frequency content of the EMG signal in lower extremity muscles similarly for pronating runners and (b) the effects of posting and custom-molding of foot orthoses are specific to different intervals before and within the stance phase of running.

## 2. Methods

### 2.1. Subject population

Nine men ( $27.4 \pm 1.8$  yr;  $174.2 \pm 2.6$  cm;  $65.0 \pm 2.4$  kg) and 12 women ( $23.9 \pm 1.6$  yr;  $167.2 \pm 1.3$  cm;  $63.7 \pm 2.2$  kg) participated in this study. All subjects gave informed written consent according to the guidelines of the University of Calgary Ethics Committee prior to their participation.

All subjects were recreational runners classified as “pronators” with a weekly running distance of 15–40 km. Subjects were only included in the study when their foot eversion (determined from 2-dimensional high-speed video pictures) was greater than  $13^\circ$  during running at 4 m/s on a treadmill [12]. All subjects were clinically assessed by a podiatrist to have a normal range of motion of the joints and normal strength and flexibility of the muscles of the lower extremities [13]. Leg length discrepancy between the left

and right leg was required to be less than 0.5 cm. The detailed results of the clinical assessments have been published earlier [14].

### 2.2. Experimental conditions

Three orthotic and one control condition were used in this study. The top layer of all orthotic conditions was composed of 3 mm Spenco (Spenco Medical Corporation, Waco, TX). The bottom layer of the control condition consisted of 3 mm flat ethylene vinyl acetate (EVA; Solflex [Shore C: 50–55], Phoenix, AZ). The bottom layer of the posted condition consisted of a 6 mm full-length EVA wedge. Plaster casts of both feet in a subtalar neutral position were taken from each subject. Polypropylene shells were fabricated to positive molds obtained from the negative casts. The molded condition consisted of the polypropylene shell with no extrinsic posting, while a 6 mm extrinsic EVA post was added to the medial rearfoot and forefoot areas of the polypropylene shell to obtain the posted & molded condition. The control and all experimental conditions were similar in mass. Running sandals were used for all experiments (Model: Bryce Canyon; The Rockport Company, Canton, MA). The original inserts of the running sandals were removed and replaced by each of the four experimental conditions: (a) control, (b) posted, (c) molded and (d) posted & molded conditions. A more detailed description of the casting and fabrication techniques has been published earlier [14].

### 2.3. Testing procedure

Subjects completed two weeks of their regular running schedule in the control condition (running sandal plus control insert). Following this initial phase, each subject was tested three times per week for three weeks (nine sessions per subject). In each of the nine sessions, subjects ran 200 m on an indoor running track with each of the four insert conditions. Subjects were then set up for biomechanical testing at the Human Performance Laboratory at the University of Calgary. The four experimental conditions were tested in randomized order in each session. Before testing each of the three orthotic conditions, subjects ran 50 m in the control condition. Electromyographic and ground reaction force data were collected for 12 over-ground running trials at  $4.0 \pm 0.2$  m/s per experimental condition (heel-toe running; 48 trials per subject per session). Running trials were only accepted if the subject's speed was within  $4.0 \pm 0.2$  m/s. Subjects required 12–14 trials to obtain 12 trials within this range. This experimental design allowed for a comparison of values for each variable for the orthotic conditions to values for the control condition within each session and, thus, possible variability between sessions due to, for instance, electrode placement was eliminated. Although fatigue is unlikely to occur within a 30-min sub-maximal running protocol, this study design using

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