Deformable Foot Orthoses Redistribute Ankle-foot Energetics in Healthy Individuals

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Summary

This study evaluated if deformable foot orthoses (DFOs) can store and return energy during gait to modulate ankle-foot energetics. When used in flexible footwear, DFOs added energy to the metatarsophalangeal joint, and healthy individuals adjusted their midtarsal energetics so net combined positive ankle-foot energetics remained similar with and without orthosis use.

Introduction

The ankle-foot system plays a critical role in the mechanical energetics of gait, including driving forward propulsion in late stance [1]. Energy-storing-and-returning orthoses have often focused on the ankle to enhance patients' ankle-foot energetics. However, with the foot's important role in gait energetics being better understood [2], this study sought to evaluate if deformable foot orthoses (DFOs) can store and return energy during gait to modulate ankle-foot energetics. This initial study focused on healthy individuals to probe a "work substitution" hypothesis, which predicted a DFO can increase late-stance positive metatarsophalangeal (MTP) joint work (H1), and this added work will substitute for some of the individual's ankle-foot work, resulting in reduced late stance net ankle work (H2) and no change in work of the combined ankle-foot system (distal-to-shank work, H3). Further, this study evaluated if responses were modulated by DFO stiffness.

Methods

16 participants (7M/9F; 28.9 ±5.4 years; 1.70±0.1 m; 74.9±16.6 kg) free of musculoskeletal injury or disease visited the lab. Foot shape and MTP location were measured to customize the DFOs. Afterwards, three sets of DFOs were manufactured for each participant (Figure 1). All DFOs had 13 carbon fiber layers for the stiffer, posterior region then plies were dropped to create a deformable toe region. The three DFO stiffness levels in this study contained 5, 7, and 9 carbon fiber layers in the region anterior to the metatarsal head axis, respectively.

Figure 1: Left - Modified minimalist shoes. Right - DFO from side (top) and top-down (bottom).

Once DFOs were ready, participants returned to the lab to collect kinematic (200 Hz) and kinetic (1200 Hz) data as they walked overground at 0.8 statures/sec under four randomly presented conditions: minimalist shoes (MS), and three stiffness DFOs placed bilaterally in the minimalist shoes (DFO 5L, 7L, 9L). Pelvis, thigh, shank, and three foot segments [3] were identified and tracked. Data were processed with forces assigned to foot segments using the COP-cross method [4]. Joint powers and works plus distal-to-shank power and work were calculated for all conditions, averaged across limbs and participants. Hypotheses were assessed via repeated-measure ANOVAs. Post hoc pairwise comparisons with Bonferroni corrections were conducted as appropriate.

Results and Discussion

When used in flexible footwear, DFOs substantially impacted MTP and midtarsal joints, with small impacts at the ankle (Figure 2). DFO stiffness modulated energetics, although not always systematically (Figure 2). Supporting H1, MTP positive work was significantly different across conditions ($p<0.001$). This energy return at the MTP joint caused a redistribution of energy within the foot, with healthys reducing positive midtarsal work ($p<0.001$) instead of reducing ankle work ($p=0.72$, refuting H2). Supporting H3, these changes resulted in no significant differences in distal-to-shank positive work ($p=0.32$). When comparing the three DFO stiffnesses, the 9L condition had the most favorable positive to negative work ratio at the MTP joint but the least favorable at the midtarsal joint. Post hoc analyses revealed significant differences amongst all pairwise comparisons for MTP positive work and varying pairs for other metrics.

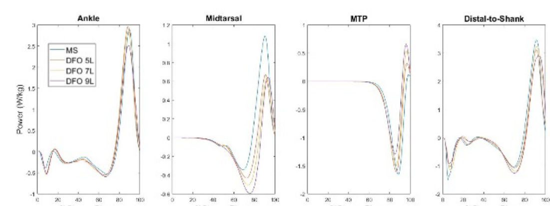

Figure 2: Foot and ankle joint powers along with combined ankle-foot system (distal to shank) power.

Conclusions

This study demonstrated that DFO use during gait returned positive energy to the MTP joint, which substituted for some work typically done by the midtarsal joint. DFO stiffness impacted the response. With this study demonstrating work substitution in healthys, future work should evaluate if DFOs can enhance ankle-foot energetics for patients with ankle-foot impairments and how DFO stiffness impacts those responses.

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References

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