Effect of Foot Plate Length on Foot Segment Movement

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INTRODUCTION

Exoskeletons and assistive orthotics often utilize a foot plate to actuate the foot during rehabilitation. [1] showed that a foot plate in a shoe restricted ankle movement but did not change ground reaction forces or hip or knee kinematics. They used a single foot segment, although it is likely footwear stiffness alters foot kinematics. Supporting this, a study using sandals of increasing stiffness showed that shod conditions restrict the abduction/adduction (ABD/ADD) and inversion/eversion (INV/EV) of the foot but do not affect plantarflexion/ dorsiflexion (PF/DF) [2]. This abstract quantifies the effects of very rigid foot plates on foot and toe kinematics.

METHODS

For this pilot study, one subject walked on a treadmill at a self-selected speed while kinematic data was collected for 1 min per condition. The subject wore a modified ballet slipper with a strap that held the foot plate to the foot and allowed markers to be placed. The Oxford foot model [3] was used to generate hindfoot, forefoot, and toe segments. For this work, joint angles were defined as the relative angle between the segment and the next most proximal segment. Three conditions were tested – a foot plate ending just before the metatarsal joints (three quarters), a foot plate equal to the length of the foot (full), and the ballet slipper alone (control). The foot plates were made of 5 mm thick Delrin. For the three quarters condition, foam was used under the toes to maintain a constant insole height. Range of motion (ROM) data were tested for statistical differences via t-tests with $\alpha = 0.05$. All reported differences have $p < 0.05$.

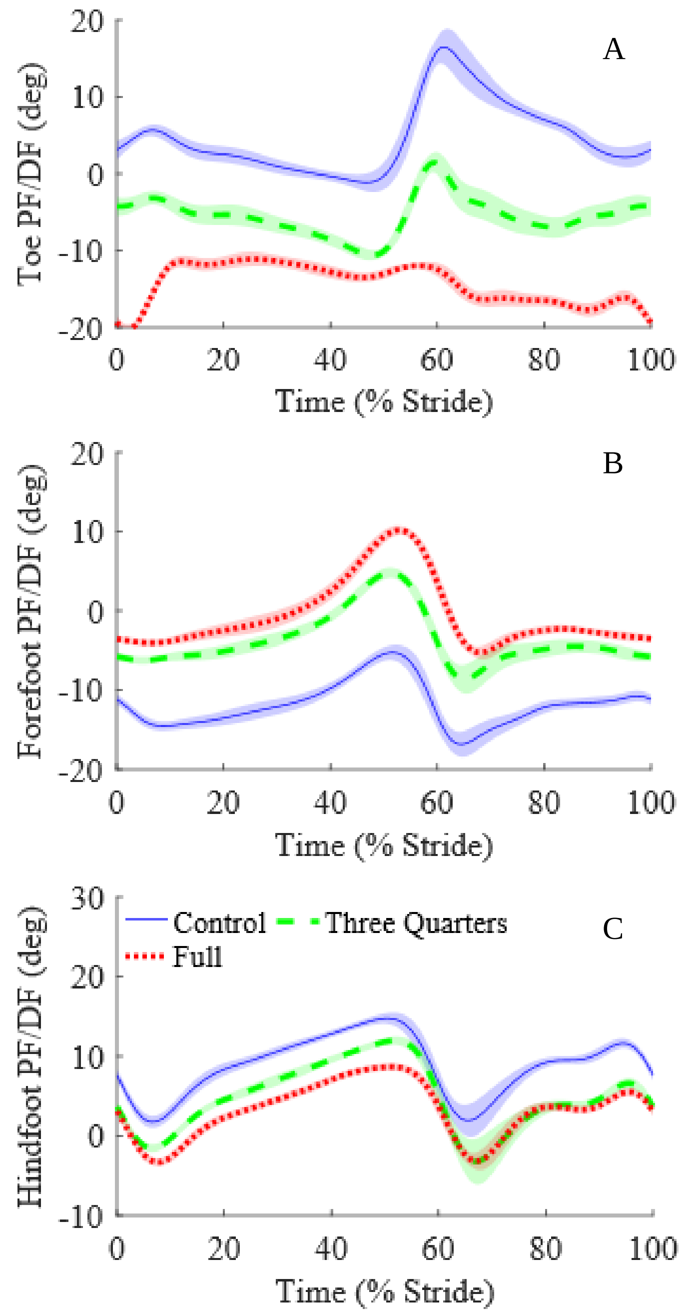

Figure 1: PF/DF for (A) the toe relative to the forefoot, (B) the forefoot relative to the hindfoot, and (C) the hindfoot relative to the tibia (this is the closest measure to typical ankle angle).

RESULTS AND DISCUSSION

In general, as the foot plate lengthens, the foot kinematics become less similar to the control condition (Fig. 1). The toe is the most effected by the foot plate condition (Tab. 1). PF/DF experienced the greatest decrease in ROM as the foot plate lengthened. While the three-quarter plate ended before the toe joint, the toe kinematics were still restricted, although to a lesser extent than for the full plate condition. Toe INV/EV also decreased, while the change in ABD/ADD was inconclusive. This indicates that a rigid foot plate significantly restricts the toe's natural movement, particularly in DF. The toe plays a role in weightbearing during the second half of stance and restricting its movement can affect its ability to exert a push-off force [4]. The forefoot PF/DF ROM increased as the foot plate length increased, and the forefoot was more DF in general. This may indicate that the arch of the foot is compensating for the foot plate. Alternatively, this may indicate that as the foot tries to flex the foot plate resists and squeezes the arch of the foot via the strap. A longer plate generally decreased ABD/ADD of the forefoot, while changes in INV/EV ROM were inconclusive. This disagrees with [2] in which stiffer soles led to less ABD/ADD and INV/EV with little effect to PF/DF. This could be due to the difference in stiffness of a foot plate versus a sandal. Additionally, [2] used a 2-segment foot model compared to the 3-segment model used here. It is possible that the axes defining the rotations are not aligned between these models. The hindfoot PF/DF ROM decreased as foot plate length increased, while changes in ABD/ADD and INV/EV ROM were inconclusive. This agrees with [5] in which running with sandals had no effect on hindfoot INV/EV. The kinematics of the hip and knee are generally unaffected ($p < 0.05$). Using the Oxford foot model, the hindfoot is the closest measure to the typical ankle angle. It is interesting to note that despite significant changes in the kinematics of the foot segments, compensations for the changes do not manifest further up the kinematic chain.

CONCLUSIONS

It is clear that a foot plate has a significant effect on the motion of the foot, with a longer foot plate having a greater effect. The toe kinematics in particular are affected by a foot plate and thus should be considered when designing devices for the feet. An application in which the user has no control over toe flexion may benefit from a longer foot plate while an application trying to assist or strengthen would use a shorter foot plate.

REFERENCES

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Table 1: Range of motion in degrees for each of the foot segments.

Condition	**Toe**			**Forefoot**			**Hindfoot**		
	PF/DF	**ABD/ADD**	**INV/EV**	**PF/DF**	**ABD/ADD**	**INV/EV**	**PF/DF**	**ABD/ADD**	**INV/EV**
Control	21.0	10.5	6.9	10.0	4.2	5.9	15.0	11.2	10.2
Three-quarter	13.6	9.3	4.7	12.9	3.8	4.7	15.2	13.4	11.4
Full	8.9	5.8	2.9	13.8	1.8	4.3	13.9	14.2	11.6