EFFECT OF FOOT PLATE LENGTH ON HEALTHY GAIT

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INTRODUCTION

Assistive ankle devices such as braces often use a stiff foot plate to help constrain the motion of the ankle and restore a more typical gait [1]. Design of the foot plate is critical for powered assistive devices such as exoskeletons because of the greater force transfer. Given that the human foot does not function like a stiff plate during gait [2], it is unclear what affect a stiff plate has on the user's gait, independent of any other mechanical constraints or assistance. It is also unclear how the length of the foot plate affects gait. A longer plate allows the force to be distributed over a larger area but a shorter plate may have less undesirable effects because it constrains the foot less. In one of the few studies investigating foot plate length, [3] found that foot plate length does affect gait slightly for stroke victims wearing an articulated ankle-foot orthosis. However, this study primarily compared each orthotic condition to healthy speed-matched gait, making it difficult to determine what affect the foot plate itself had. The goal of this work is to quantify how different length foot plates, in and of themselves, alter gait.

METHODS

Four healthy young adult subjects (2 male) walked overground at their self-selected speeds while kinematic (Vicon, Oxford, UK) and kinetic (Bertec, Columbus, OH) data were collected. The subjects wore shoes in which the sole was replaced with a foot plate. Three conditions were tested – a foot plate ending just before the metatarsal joints (three quarters condition), a foot plate equal to the length of the foot (full condition), and an unmodified insole from the shoe (control condition). The foot plates were made of 5 mm thick Delrin and a thin 2 mm layer of foam rubber for comfort. For the three quarters condition, a denser 5 mm foam was used under the toes to maintain a constant insole height. Each subject completed 20 trials per condition, with each trial consisting of walking approximately 20 feet. The left

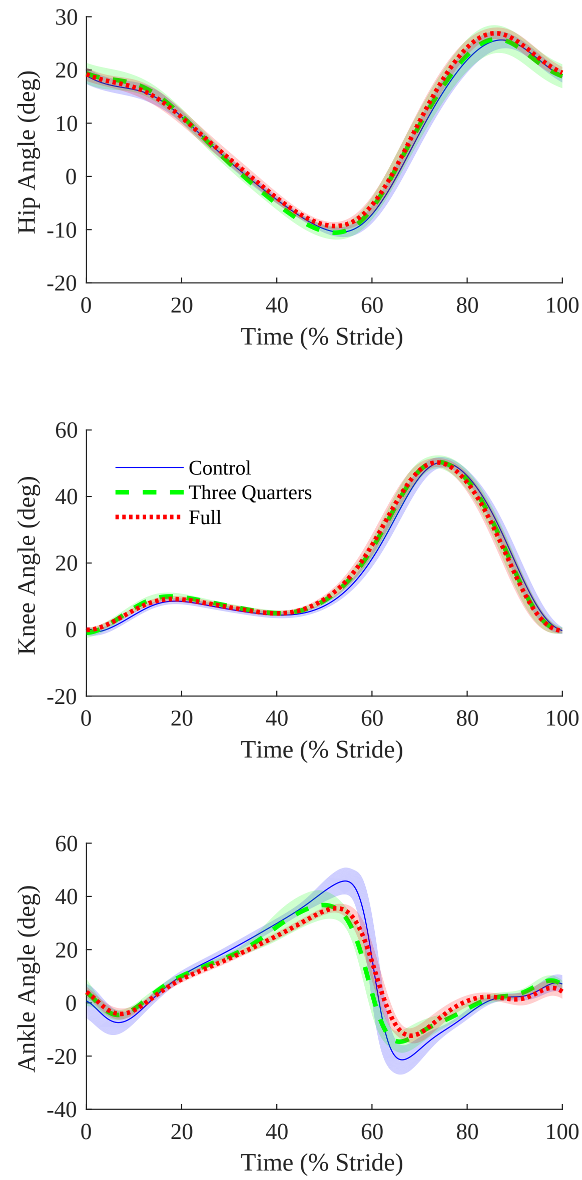

Figure 1: The hip, knee, and ankle joint trajectories for the three conditions for a representative subject. The ankle range of motion tends to decrease as the foot plate gets longer. The hip and knee trajectories are unaffected by a foot plate regardless of length. This suggests that any kinematic variation caused by the foot plate is accounted for at the ankle.

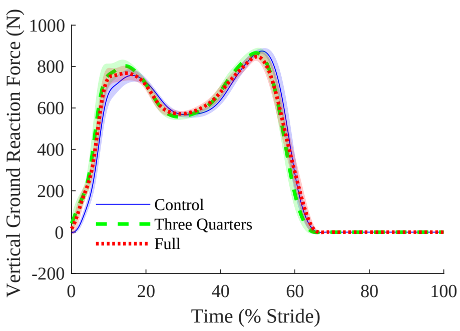

Figure 2: The vertical ground reaction force is unchanged by a foot plate.

and right legs were analyzed separately due to several of the subjects having a somewhat asymmetric gait. Data were tested for statistical differences and equivalence using standard t-tests and the two one-sided tests procedure [4]; $\alpha = 0.05$ and data were considered equivalent if they were within 6% of mean value of the no foot plate condition. A statistical difference indicates that the observed difference between conditions is not due to measurement noise, while statistical equivalence indicates that any changes are not meaningful. All statistical testing compared the control condition to the full plate or the three quarter plate conditions. P-values for statistical differences are indicated with p_d while p-values for statistical equivalence are indicated with p_e.

RESULTS AND DISCUSSION

The subjects walked at an average speed of 1.27 $\pm$ 0.10 m/s for the control condition, 1.32 $\pm$ 0.11 m/s for the three quarters condition, which is a significant change ($p_d < 0.05$), and 1.28 $\pm$ 0.13 m/s for the full condition, which is equivalent to the no plate condition ($p_e < 0.05$). For the three quarters condition, two subjects increased their speed significantly when wearing the three quarter foot plate by an average of 0.10 m/s while the other two subjects maintained their walking speed ($p_e < 0.05$). The faster walking speed may be caused by some energy storage and return in the foot plate. For all four subjects, their step cadence was statistically equivalent to their no foot plate conditions regardless of foot plate length ($p_e < 0.05$). The subjects walked with an average cadence of 0.94 $\pm$ 0.07 Hz for the control condition, 0.95 $\pm$ 0.07 Hz for the three quarters condition, and 0.93 $\pm$ 0.07 Hz for the full condition.

In general, the foot plate decreased ankle range of motion but had little effect on the hip and knee kinematics (Fig. 1). The timing of the trajectories are consistent across all conditions for all joints. Peak stance knee flexion increased ($p_d < 0.05$) in two subjects by an average of 1.9°, altering weight acceptance. For three subjects, the ankle range of motion decreased ($p_d < 0.05$) by an average of 8° for the full length foot plate. The longer foot plate is likely stiffer than the shorter plate, so these results are consistent with [5] in which progressively stiffer prosthetic feet led to a progressive decrease in the ankle range of motion. This suggests that the foot plate does influence gait somewhat but that most compensations are at the ankle, allowing relatively normal hip and knee kinematics. This is supported by previous findings that people adapt their ankle kinematics when walking with ankle exoskeleton assistance but do not alter their hip and knee kinematics [6].

The vertical ground reaction force is not statistically affected by the foot plate ($p_e < 0.05$, Fig. 2). Since a decreased ankle range of motion may reduce the push-off force, this suggests that the foot plate may provide some energy storage and return in the form of elastic bending. It further suggests that the human compensates for any energy storage in the foot plate.

CONCLUSIONS

The similarity in kinematics between the control and both foot plate conditions suggests that introducing a stiff foot plate has very little effect on gait. Some subjects speed up, but overall the effects appear minimal. This bodes well for exoskeleton design because there is little concern that even a long, stiff, mechanically-advantageous foot plate alters gait.

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