

FOOT PLACEMENT SPECIFIES THE RESISTANCE ARM OF THE GROUND REACTION FORCE DURING PUSH-OFF IN GAIT INITIATION

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INTRODUCTION

The foot may be considered to be a simple lever with its fulcrum at the ankle (Carrier *et al.*, 1994). The moment of the Achilles' tendon force about the ankle is resisted by the moment of the ground reaction force (GRF); the nature of this opposition determines how loads are transmitted between the musculoskeletal system and the ground. Gage (1993) suggested that gait deformities that involve abnormal foot rotations reduce the moment arm of the GRF, resulting in "lever arm deficiencies" that are potentially destabilizing.

Anatomical and geometrical analyses performed by Bojsen-Møller (1978) suggested that the GRF lever arm depends on selection of a rotation axis at the metatarsophalangeal joint during push-off. Two such axes were defined: a transverse axis passing through the first and second metatarsal heads, and an oblique axis through the second and fifth metatarsal heads. Bojsen-Møller (1978) theorized that an internally-rotated foot placement results in rotation about the oblique axis, giving the GRF a lower resistance arm, which is useful during high-load, low-speed activities, but this has not yet been demonstrated experimentally.

Viale *et al.* (1997) examined the changes in ankle kinematics and foot loading that occur with natural variation in foot orientation. Foot placement was found not to affect resistance lever arm, but this study lacked a controlled change of foot orientation and only considered running, a high-speed

activity for which only large lever arms would be expected. Carrier *et al.* (1994) measured resistance arms during two activities, steady-state running and acceleration from a standing start. The authors found smaller late push-off resistance arms during the standing start activity. Whether resistance arms can be manipulated by foot placement, however, was not addressed.

The purpose of this study was to investigate whether internal/external rotation of the foot determines the resistance arm of the GRF during push-off. Selection of walking initiation as the activity to be studied permitted foot orientation to be precisely controlled. We hypothesized that an internally-rotated foot placement would result in smaller resistance arms than those found for an externally-rotated placement.

METHODS

Kinematic data, GRF, and center of pressure (COP) location were measured during the walking initiations of ten healthy, barefoot subjects (5 m, 5 f; 23-29 yr) using a six-camera motion analysis system (Vicon 370; Oxford Metrics Ltd.) and a force plate (Kistler Inst. Corp.). Reflective marker clusters were placed on the left foot and shank to record motions of these segments during the push-off period, defined to begin at the onset of plantarflexion and end at toe-off.

The left foot of each subject was placed such that an axis determined by the second toe and the posterior aspect of the heel was

aligned with markings on the force plate (Figure 1). The right foot was placed in neutral position. Subjects began each trial standing in this manner, then walked several steps forward, leading with the right foot. Each subject completed ten trials with each of two foot placements: 20° internally rotated and 30° externally rotated.

The resistance arm of the GRF was determined by calculating the distance from the talocrural joint axis to the line of action of the GRF. The talocrural joint axis was determined using the optimization technique proposed by Bogert *et al.* (1994). A two-way repeated-measures ANOVA followed by pairwise comparisons was used to test the effects of foot placement (internally and externally rotated) and time (25 levels; every 4% of push-off).

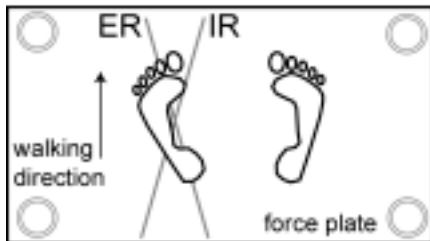


Figure 1: Initial placement of the feet on the force plate.

RESULTS AND DISCUSSION

Externally-rotated foot placement produced larger GRF resistance arms in late push-off (Figure 2). ANOVA revealed an interaction between foot placement and time of push-off; significant resistance arm differences were found between foot placement conditions only from 76%-100% of push-off (p -values ≤ 0.038). Advancement of the talocrural joint axis toward the GRF vector decreased the resistance arm of the GRF when the foot was internally rotated (Figure 3). Resistance arm was maintained in the externally rotated case, however, as the COP

moved anteriorly under the head of the first metatarsal and the large toe.

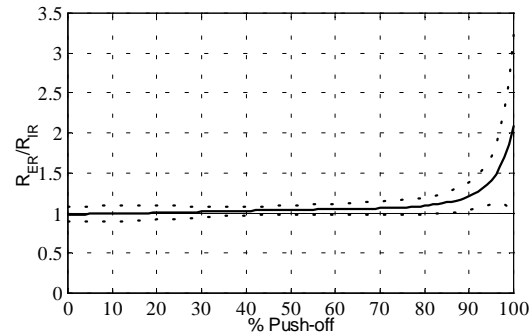


Figure 2: Ratio of resistance arms during push-off, averaged over ten subjects (ER: externally rotated, IR: internally rotated).

This study demonstrates that internal rotation of the foot reduces the resistance arm of the GRF during push-off in gait initiation. Future studies will determine whether foot placement is used to achieve favorable mechanical advantage during activities such as uphill walking, and will quantify changes in lever arm associated with pathological conditions such as internal rotation gait.

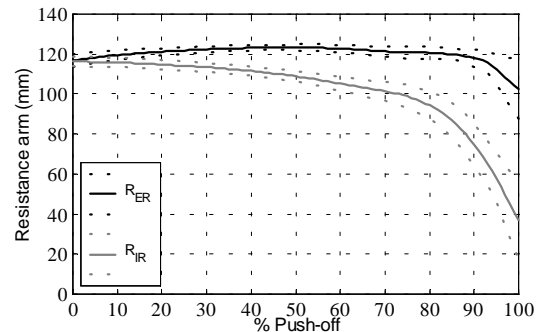


Figure 3: Resistance arms during push-off for a single subject, averaged over 10 trials.

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