ORIENTATION OF LINEAR FOOT FORCE PATH DEPENDS ON LIMB AXIS DURING HUMAN LOWER LIMB PUSHING EFFORTS

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INTRODUCTION

This research investigates how humans push with their foot during lower limb exercise. Specifically, this study evaluates the effect of changes in limb axis on force path linearity and orientation during pushes against a stationary bicycle pedal. Limb axis is defined as the line intersecting the hip joint and pedal pivot.

During cycling, foot force patterns have been shown to be reproducible and consistent across subjects and different levels of experience (Sanderson). Despite this and considerable research efforts no model has yet been developed that can predict foot forces during cycling. Recently, Gruben and López-Ortiz found that humans increase force in a specific manner when pushing against both stationary and moving pedals (Gruben 1999, Gruben & López-Ortiz 2000). They report that increases in foot force are produced through addition of force vectors with directional invariance. This is observed as linearity of the path traced by the head of the foot force vector. This requires the coordinated control of several muscles and suggests a motor control strategy in which foot force path is a key variable. In addition, they found that the orientation (θ_L) of this linear force path is repeatable and varies systematically with changes in pedal axis position. Their data suggest that changes in limb posture for a given pedal axis position have limited affect on force path orientation. We hypothesize that limb axis may be important in determining this orientation.

METHODS

While seated, one healthy human subject performed pushing efforts against a translationally fixed pedal. The pedal was free to rotate about the transverse (horizontal) axis. The subject's right foot was securely fastened to a sole plate that was mounted on a custom pedal. The pedal was instrumented with a multi-axis force transducer. The pedal was constructed to allow adjustment of the pedal pivot location parallel to the sole plate without alteration in limb configuration (joint angles).

With the pedal pivot located under the 1st metatarsal head (1stMTH), subjects were instructed to push to 400N in "the most comfortable manner." This foot/pedal relationship was considered the subject's neutral position. Pedal angle was recorded and for subsequent pushing trials the subject was asked to maintain this same pedal angle. Repeated pushes were then performed for various pedal pivot positions ranging from 12 cm posterior, to 6 cm anterior to the 1stMTH.

Foot force and pedal angle were recorded for each pedal axis position. Sagittal-plane components of force were calculated to yield foot force path. These force paths were evaluated for linearity by propagation of measurement error and for orientation using principal components analysis (Gruben and López-Ortiz, 2000).

RESULTS AND DISCUSSION

Linear force paths were observed for all push efforts. Since force direction was not specified, the foot force direction could have a range of possible values as magnitude increased to the 400N goal. Despite this freedom of direction, foot force increased in a highly specific manner resulting in a linear force path. This suggests that a "preferred" motor strategy for lower limb pushing efforts increases foot force through the addition of directionally invariant forces independent of pedal axis position.

Orientation of the linear force path changed systematically with changes in limb axis (Figure 1). As the pedal pivot moved forward of the first metatarsal head, θ_L decreased. As the pedal pivot moves backward in relation to the first metatarsal head, θ_L increases. Since pedal axis location determines limb axis orientation, these results show that the orientation of the linear force path rotates in the same direction as the limb axis. As suggested by studies in cats, limb axis may play an important role in the control of foot force direction (Bosco & Poppele 1996)

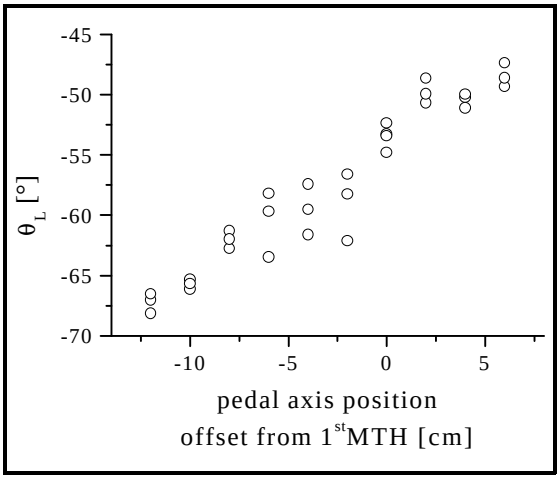

Figure 1 Orientation of foot force path relative to the horizontal plotted vs. pedal axis position. Pedal axis position of zero indicates the pedal axis is under the 1stMTH, while positive positions indicate the pedal axis is anterior of the 1stMTH.

SUMMARY

These results suggest that the motor control system employs a preferred pattern of force generation when pushing against a pedal in a "most comfortable manner." The orientation of this linear force path is dependent on limb axis.

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AKNOWLEDGEMENTS

This work was supported in part by the Virginia Horne Henry Fund for Women's Physical Education Issues.