Characterizing the performance of human leg force control

Introduction

Our legs act as our primary contact with the surrounding environment, generating external forces that enable motion far more agile than our robot counterparts. The control of the magnitude of this force, and the location where it is applied on the ground, are key determinants of the ability to accelerate and rapidly change direction and may explain why humans are more agile than robots.

Objective

To characterize the performance of the human leg in controlling the magnitude and position of the externally applied force.

Methods

To accomplish this objective, we built an apparatus that vertically constrains subjects (N=10) standing over top of a force plate (Figure). The constraint immobilizes the body but allows for subjects to exert variable but controlled forces on to the ground by selectively pushing more or less with their leg. Custom software provides subjects with real-time feedback on either the leg force-magnitude or force-position (centre-of-pressure). We instruct subjects to best match their real-time force-magnitude or force-position signal to prescribed step functions and characterize the control performance of the nervous system in matching this target.

Results

When transitioning from one steady-state target force magnitude to another, the leg force magnitude control required 0.2±0.04s to approach a new steady-state value (rise time), with a steady-state error of 3.7±1.8% body weight, a steady-state variability of 2.7±0.6% body weight, and a bandwidth of 1.6±0.3 Hz. For leg force position control, we found a rise time of 0.3±0.1s with a steady-state error of 0.6±0.3% foot length, a steady-state variability of 5.2±1.9% foot length, and a bandwidth of 1.4±0.5 Hz.

Conclusions

Compared to some legged robots, our ability to control leg forces is slower and less accurate (Figure). This suggests that our agility is due to knowing what forces to generate rather than our ability to generate them.