

Modeling the Relative Compensatory Ability of Lower Extremity Muscle Groups during Normal Walking

Introduction

During gait, people with the loss of function in one or more muscle groups will often use adaptive strategies based on the ability of other muscle groups to accelerate the joints they do not cross. This study uses a biomechanical model to examine the relative capacity of the different lower extremity muscle groups for producing these adaptive compensations.

Methodology

Five normal subjects were examined while walking at a self selected pace. A six camera Vicon data collection system was used to measure the joint moments and positions. The joint moments and positions were then input into a biomechanical model in order to estimate the sensitivity of the joint accelerations to each lower extremity joint moment.

The biomechanical model consisted of seven segments: two feet, two legs, two thighs, and a single head-arms-trunk segment. The ankles and hips were treated as spherical joints and the knees were treated as pin joints. The model was connected to the floor using a fixed constraint during foot flat and a spherical joint constraint when the heel was off the ground. (Bilateral force data were not available during initial double limb support, thus the results were analyzed from the onset of foot-flat, approximately 13% of stance phase, to toe-off.)

The joint acceleration sensitivities were determined by a two step process. First, the joint accelerations arising from each of the lower extremity joint moments were computed using ADAMS software and the method described by Kepple et al. (1997). Next, the joint moments were separately perturbed by 1 N.m and the method was reapplied. The ensuing changes in the accelerations (sensitivities) indicate the potential that a muscle group has for controlling lower extremity motion and thus providing compensation during normal walking.

Results

For all subjects, the joint acceleration sensitivities were found to be non-linear during the rapid transition from foot-flat to heel-off. (The sensitivities for a single representative subject are presented in Figure 1.) The rapid change divides stance into two distinct phases, foot-flat and heel-off. During foot-flat the ankle, knee and hip joint accelerations were found to be almost twice as sensitive to moments generated at the knee than to the moments at any other joint including their own. During the heel-off phase, the acceleration sensitivities at both the ankle and hip joints increased in response to moments at their own joint. It was also found, as indicated by a change in the sign of the sensitivity data, that the role a muscle group plays in controlling motion at a joint may change during the later part of stance. For example the role of the plantar flexors were found to switch from generating knee extension and hip extension to generating knee flexion and hip flexion just prior to toe-off.

Discussion

From the data, it is clear that there is significant redundancy in controlling the motion of the stance limb and that each muscle group has some ability to control motion at all other joints. These data explain, in part, the ability of persons with muscle weakness to compensate via the use of alternative control strategies. These data give the first clues regarding the relative ability of the different muscle groups to be used in compensatory strategies and it is hoped that these results can aid in the design of treatment intervention and planning.

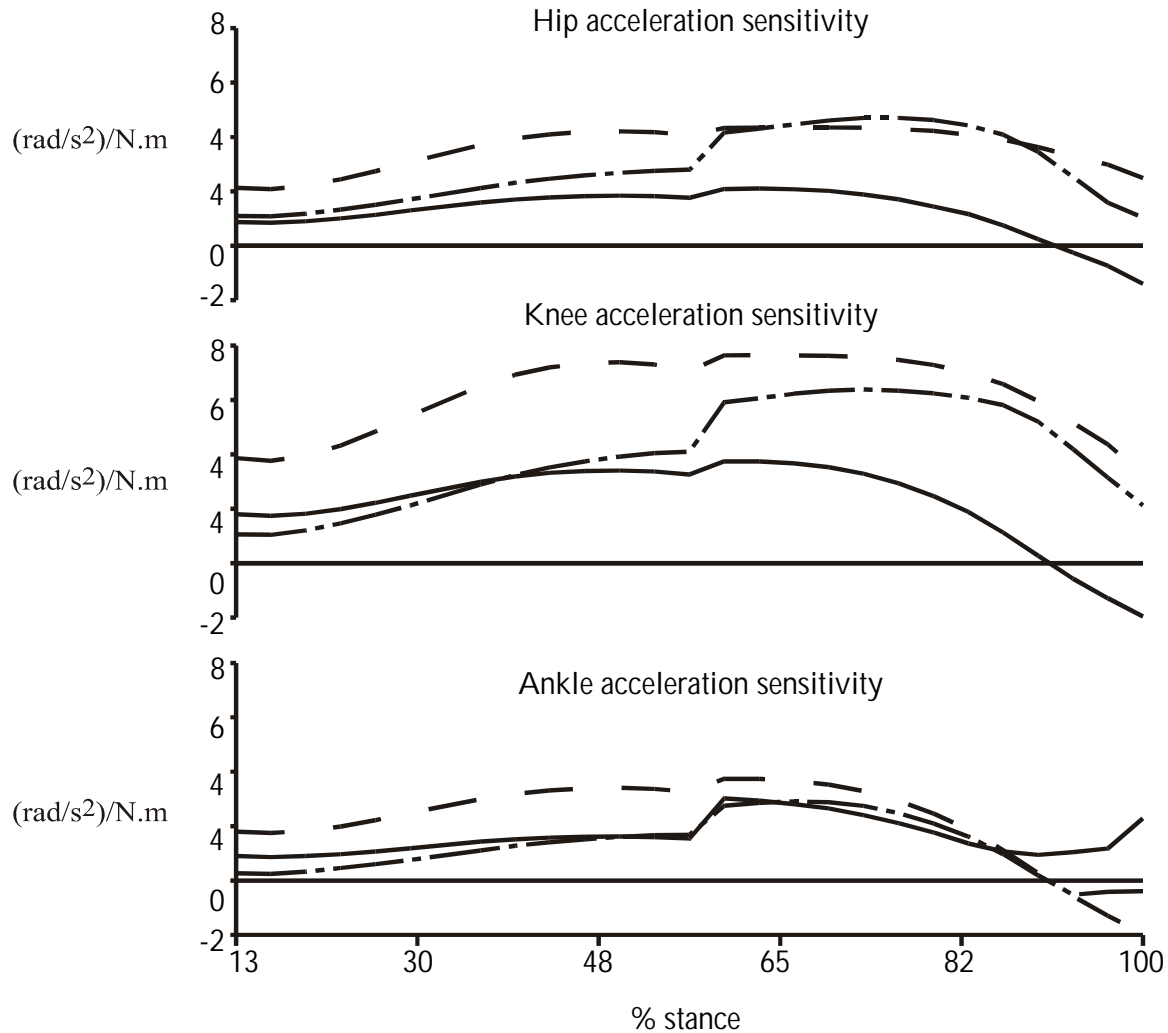


Figure 1. The sensitivity of the ankle, knee and hip accelerations to the joint moments during stance. (Positive sensitivities indicate extension accelerations.) Key: solid = sensitivity due to ankle moments, dash = sensitivity due to knee moments, dot-dash = sensitivity due to hip moments.

Reference

Kepple et al. *Gait and Posture*, 6, 1-8, 1997.