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Short communication

The effects of sloped surfaces on locomotion: Backward walking as a perturbation

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Abstract

The purpose of this study was to examine lower extremity kinetics and muscle activity during backward slope walking to clarify the relationship between joint moments and powers and muscle activity patterns observed in forward slope walking. Nine healthy volunteers walked backward on an instrumented ramp at three grades (−39% (−21°), 0% (level), +39% (+21°)). EMG activity was recorded from major lower extremity muscles. Joint kinetics were obtained from kinematic and force platform data. The knee joint moment and power generation increased significantly during upslope walking; hip joint moment and power absorption increased significantly during downslope walking. When compared to data from forward slope walking, these backward walking data suggest that power requirements of a task dictate the muscle activity pattern needed to accomplish that movement. During downslope walking tasks, power absorption increased and changes in muscle activity patterns were directly related to the changes in the joint moment patterns. In contrast, during upslope walking tasks, power generation increased and changes in the muscle activity were related to the changes in the joint moments *only* at the ‘primary’ joint; at adjacent joints the changes in muscle activity were unrelated to the joint moment pattern. The ‘paradoxical’ changes in the muscle activity at the adjacent joints are possibly related to the activation of biarticular muscles required by the increased power generation at the primary joint. In total, these data suggest that changing power requirements at a joint impact the control of muscle activity at that and adjacent joints.

Keywords: Neural control; EMG; Kinetics; Backward slope walking; Biomechanics

1. Introduction

Forward slope walking is a locomotor task that has been used to study neural control in humans (Earhart and Bastian, 2000; Lay et al., 2006b) and quadrupeds (Gregor et al., 2001; Smith and Carlson-Kuhta, 1995). Data from humans suggests that up- and downslope walking require different control strategies than level walking (Lay et al., 2006a, b). Understanding such strategies requires exploration of the association between muscle activation patterns and joint moment patterns. From forward slope walking data we hypothesize that the primary influence on muscle activation patterns is joint power requirements. One way to test this hypothesis is to perturb joint power requirements during slope walking and reevaluate the relationship between joint mechanics and muscle activity patterns. Backward slope walking was chosen for this purpose. This task has received only limited attention in the biomechanics literature (Cipriani et al., 1995; Hooper et al., 2004; Minetti and Ardigo, 2001).

The purpose of this study was to compare joint kinetics and muscle activity patterns observed in the hip and knee joints during backward slope walking to those observed during forward slope walking. We expect that forward and backward upslope walking and forward and backward downslope walking will have similar relationships between the mechanics and the muscle activation patterns because the joint power requirements are similar in these pairs of tasks. The findings presented herein will complement

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previous reports (Lay et al., 2006a, b), and provide insight into neural control of challenging locomotor tasks.

2. Methods

Nine healthy young adults (five male, four female) volunteered and gave informed consent before participating in the study, which was approved by the Institutional Review Board at the Georgia Institute of Technology. The experimental protocol and data processing are described here briefly, but have been presented in detail in previous reports (Lay et al., 2005, 2006a, b).

Electrodes were applied unilaterally on each participant's preferred limb (8R, 1L) over the bellies of the rectus femoris (RF), vastus medialis (VM), biceps femoris (BF), and semimembranosus (SM). Retroreflective markers were placed over 15 bony landmarks (Vaughan et al., 1999). Participants were habituated to the ramped walkway and then performed at least eight walking trials at every grade (−39% (−21°), 0% (level), +39% (+21°)). Trials were discarded if foot contact with the force platform was incomplete, or if visible stride alterations were made to target the platform. Walking speed was not controlled during the experimental testing.

This report will focus on stance phase data from level and ±39% grades. Temporal stride parameters, joint moments, and joint powers were calculated from the collected kinematic and force platform data. Points of interest on the joint moment curves were identified for statistical analysis (Table 1). Burst onset, duration, and offset (as %stride) as well as mean activity (as %activity of that burst during level walking) were calculated for all EMG data. All variables were compared across grades using a repeated measures analysis of variance design (ANOVA) ($\alpha = 0.05$, a priori). When a significant main effect for grade was identified for any kinetic variable, Bonferroni confidence interval adjustments were used during follow-up analysis. For the EMG variables, when a significant main effect for grade was identified dependent t-tests with an adjusted p-value ($p = 0.01667$) were used in follow-up analyses. Select results from these analyses are presented here. The complete data set has been reported previously (Lay, 2005).

3. Results

Although walking speed was not controlled during the trials, no grade effect was observed for either the stance or stride durations (Table 2).

During backward upslope walking there were significant increases in the knee extensor moment, but the hip moment was similar to that for backward level walking (Fig. 1, Table 3). These joint moment changes were similar to those observed during forward downslope walking. Power generation increased at the knee with increased slope (Fig. 2). During backward upslope walking the mean BF and SM activity levels were statistically the same as during level walking, but the duration of activity increased (Fig. 3). Durations of the stance RF and VM bursts did not change, but mean activity levels increased significantly from level walking (Fig. 4).

During backward downslope walking, as in forward upslope walking, the knee joint moment was similar to that

Table 1
Description of points of interest from joint moment data used for statistical analysis

Backward walking points of interest used for statistical analysis		
Knee	KM1	Peak value in early mid-stance (~25% stance)
	KM2	Value at 50% stance
	KM3	Maximum extensor moment in late mid-stance
	KM4	Maximum flexor moment in late stance
Hip	HM1	Peak value in early stance (~10% stance)
	HM2	Point of zero crossing in mid-stance
	HM3	Peak extensor moment in late mid-stance

These points are also indicated in Fig. 1 for the 0% grade.

Table 2
Gait cycle parameters (stance and stride duration) averaged across trials and subjects for each grade

Mean (S.D.) backward walking gait cycle parameters			
	−39%	0%	+39%
Stance duration (s)	0.86 (0.09)	0.83 (0.08)	0.84 (0.09)
Stride duration (s)	1.36 (0.13)	1.35 (0.11)	1.30 (0.12)

The ANOVA indicated no significant grade effect for either variable.

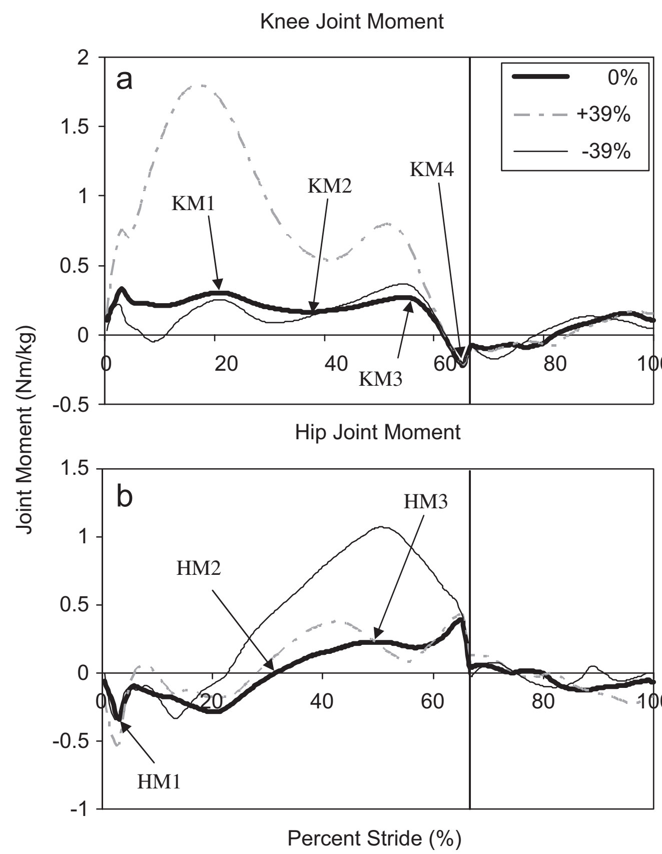

Fig. 1. Group ensemble average joint moment curves, normalized to body mass. Positive moments are extensor. Plots begin and end with toe contact, vertical line marks heel off. Points of interest are indicated on the plot for 0% grade.