Control Strategy Transitions during Slope Walking

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INTRODUCTION

Investigations of slope walking in quadrupeds have revealed motor programs (control strategies) for up and downslope walking different from that for level walking [1]. Similar results would be expected in humans during slope walking based on the changes in biomechanics and muscle activity [2; 3]. One interesting question that then follows is at what grade does the nervous system switch from the level walking strategy to the slope walking strategy? For the first step of upslope walking, a transition grade has been suggested to exist between 6˚ and 9˚ (11% and 16%) [4]. Although the question of transition grades has not been addressed in detail for slope walking, it has been studied for the similar task of stepping on a wedge [5]. Based on kinematic and EMG patterns, the authors identified two distinct control strategies, with a transition grade at 15˚ (27%) [5]. The goal of this study was to investigate kinematic patterns during upslope walking in order to identify common control strategies, and potentially identify a transition grade between control strategies.

METHODS

Five healthy volunteers (4M, 1F, mean age = 28 yrs) gave their informed consent and then were fitted with fifteen retroreflective markers (Helen Hayes system) and walked at five different grades (0%, +10%, +15%, +25%, +39%) on a modified LifeFitness treadmill. Each participant selected a comfortable pace at +39% and maintained this speed for all trials. After participants adjusted to each condition data were collected for two 10 second trials. Kinematic data were captured at 60 Hz using a six camera Peak 3D Optical Capture system and were exported to in-house software to calculate joint angles. Joint angle data from each leg (L and R) were normalized to 300 points for every stride (200 stance, 100 swing) and then ensemble averaged across all strides for each trial. Ankle-knee angle-angle plots of the stance phase were used to classify the control strategies [5]. Each plot was given a shape score (s-shaped = 0, c-shaped = 1) and a knee angle (KA) score for the value of the knee angle during mid to late stance at the same ankle angle as at heel strike (HS) (larger angle than at HS = 0, smaller angle than at HS = 1). The sum of the two scores was used to classify each plot.

RESULTS AND DISCUSSION

Sample ankle-knee angle-angle plots and their scores are presented in Figure 1. Because of the similarity between the three highest grades, only data from +39% is shown (Fig 1B). All 0% plots (n=18) received a cumulative score of 0 (Fig 1A), and all +15%, +25%, and +39% plots (n=20 for each) received a total score of 2. These findings suggest that a different control strategy is being used for the steeper grades than for level [5]. In contrast, the 10% (n=18) plots received

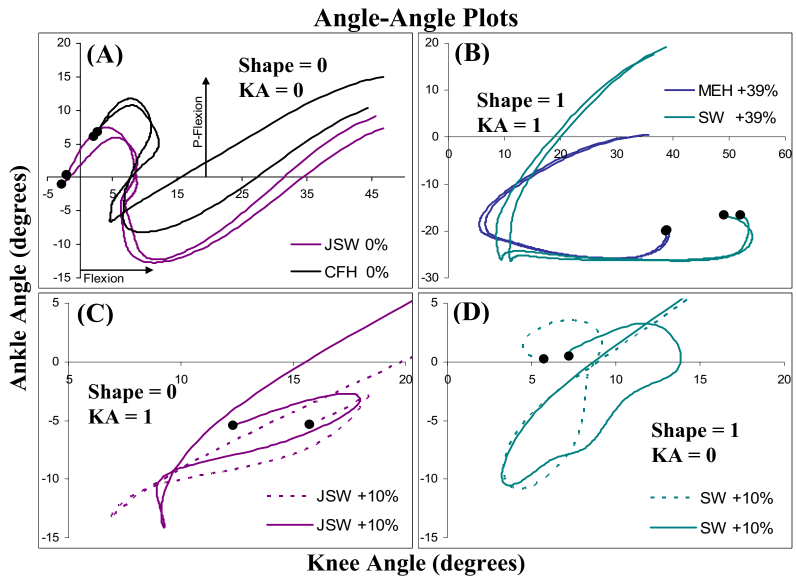

Figure 1: Representative angle-angle plots for stance (● = HS). Knee flexion and ankle p-flexion are indicated in (A). The scales of (C) and (D) are expanded to show the shapes.

mixed scores: 4 received a total score of 0, 9 received a total score of 1 (Fig 1C and 1D), and 5 received a cumulative 2. A cumulative score of 1 indicates a mixed control strategy, and therefore a possible transition grade. The four plots that received a total score of 0 were from one subject (2L and 2R), who used only the level walking form. Another subject used only the mixed strategy shown in Fig 1C, and the remaining three subjects used both pure and mixed strategies. These data suggest the presence of a 10% transition grade for upslope walking. This transition grade is lower than that observed during wedge stepping (27%) [5] and than that predicted for the first step of upslope walking (11-16%) [4]. It is possible that the level walking strategy may be sufficient for a single step on a grade above 10%, but inadequate when sustained walking is required. In light of these findings we expect that for grades of less than 10% the level walking control strategy will prevail. Exploration of this idea, as well as its extension to downslope walking, warrants future research.

REFERENCES

1. Smith JL, et al. *J Neurophysiol* **79**, 1702-16, 1998.
2. Redfern MS, et al. *Gait Posture* **6**, 119-125, 1997.
3. Leroux A, et al. *Exp Brain Res* **126**, 359-68, 1999.
4. Prentice SD, et al. *Gait Posture* **20**, 255-65, 2004.
5. Earhart GM, et al. *J Neurophysiol* **84**, 605-15, 2000.

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