The Effect of Inclination and Walking Speed on Foot Placement for Slope Walking

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Summary

We are hypothesizing that when humans walk on the sloped surfaces, the foot placement is dependent on the slope angle and walking speed. In this paper, to have a better understanding of the relationship between the step length to the slope angle and walking speed, we performed a statistical analysis based on the human walking data with different slope angles and walking speeds. We discuss that the step length variation with respect to the slope angle and walking speed.

Introduction

Human kinematics on inclined surfaces have been studied to see the change of human walking traits depending on slope angle and walking speed [1,2]. Different studies related the human kinematics to the slope angles and waking speeds in different ways. For example, Sun et al. observed the step lengths on the slopes from the outdoor environment and performed a regression analysis on walking speed, cadence, and step length, as functions of slope angle [3]. However, we hypothesize that both walking speed and slope angle should be independent variables, which actively affect the foot placement for slope walking. In this study, by looking into a biomechanical data, we plan to investigate the effect of the slope angle and walking speed on the foot placement for slope walking, which could be beneficial for the control of the lower limb assistive device to determine the optimal foot placement for better adaption to sloped surfaces.

Methods

To conduct a biomechanical analysis for human locomotion on the inclined surfaces, we used the human incline walking data captured by the researchers at the University of Texas at Dallas (UTD) using a 10-camera Vicon motion capture system [4]. The experimental protocol was approved by the Institutional Review Board at UTD. During the experiment, 10 healthy subjects (5 female) walked on the treadmill for a minute in 3 different walking speed (0.8, 1.0, 1.2 m/s) while the slope varies from -10° to 10° at 2.5° increments. From the data set, the step length was estimated using the average step time and walking speeds. We performed a two-way repeated measures ANOVA and the series of t-tests to analyze the correlation between the slope, walking speed and step length.

Results and Discussion

In (Figure 1), the step length is shown according to 9 different slopes (-10° to 10° with 2.5° increments) and 3 different walking speeds (0.8, 1.0, and 1.2 m/s). As it is shown in the figure, on the flat-ground and upslope, the step length has no significant trend for all walking speeds. On the contrary, the step length decreases when the slope becomes steeper on the downslope ($p < 0.005$) for all walking speeds, which is also supported by [3]. This is because when the downslope angle, θ, is steep, the equivalent friction coefficient ($f_c = \mu \cos\theta$) decreases, suggesting that the surface becomes more slippery. In this case, people tend to be more cautious and try to increase the cadence rather than longer step length to avoid the excessive ground reaction force and the potential slippage on the surfaces. In other words, people try to use the Cautious Walking (CW) when the slope gets steeper.

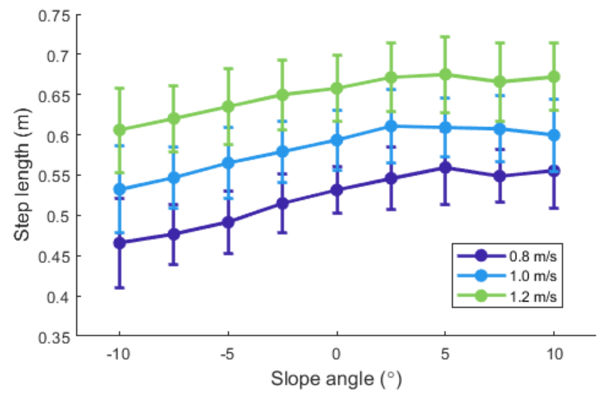

Figure 1: Markers (●) indicate the mean values of step lengths and the error bars indicate their ±1 standard deviation according to 3 different walking speeds.

For the walking speeds, it is clearly shown that the walking speed is significantly correlated with the step length ($p < 1e\text{-}4$) for both the upslope and downslope walking. This also implies that humans tend to change the step length to adjust the walking speed rather than the cadence.

Conclusions

In our analysis, it is shown that how the slope angle and walking speed affect human walking in terms of step length on the sloped surfaces. Humans tend to walk more cautiously on the downslopes by limiting the step length and tend to change the step length to adjust their walking speed. Future work can be conducted to find a numerical relationship between the step length, and slope angle and walking speed, and use this relation to implement the foot placement control for the lower limb assistive devices.

References

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