Dynamic balance during uphill and downhill walking in unilateral transfemoral prosthesis users

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Summary

Transfemoral prosthesis users (TFPUs) face significant challenges in maintaining dynamic balance during uphill and downhill walking. Effective regulation of whole-body angular momentum (WBAM) around the center of mass (COM) is crucial for balance control. This study evaluated dynamic balance in TFPUs across five surface conditions: level (0%), 5% decline, 5% incline, 12% decline, and 12% incline. Results indicated that uphill walking increased dynamic leg swing movements, while downhill walking reduced arm swing, both contributing to greater WBAM ranges. Steeper slopes further challenged lateral stability in the frontal plane. These findings highlighted the need for interventions to improve dynamic balance of TFPUs across various terrains.

Introduction

Transfemoral prosthesis users (TFPUs) face significant challenges in maintaining dynamic balance during uphill and downhill walking. To achieve the dynamic balance during walking, TFPUs are required to regulate the whole-body angular momentum (WBAM) about body center of mass (COM). In particular, an increase in the range (peak-to-peak) of WBAM reflect a greater magnitude of the body's rotation about body COM throughout the gait cycle. Thus, the range of WBAM is employed to quantify the effect of perturbed conditions on the dynamic balance [1]. In this study, we aimed to evaluate the dynamic balance of TFPUs during uphill and downhill walking by comparing the range of WBAM under different slope conditions.

Methods

Twelve TFPUs participated in this study (age: 40.3 ± 9.6 years, height: 1.75 ± 0.08 m, mass: 75.6 ± 10.5 kg, mean ± SD). Each participant walked on five different surfaces: level (0%), 5% decline, 5% incline, 12% decline, and 12% incline. Three-dimensional kinematic data were collected using reflective markers and an optical motion capture system. For each of the five surface conditions, four successful trials were selected. The sagittal, transverse, and frontal WBAM was calculated using a 15-segment model and normalized by body mass, height, and walking speed. The range of WBAM was calculated as the peak-to-peak value through the gait cycle. One-way repeated measures ANOVA was performed to compare the variable across the five surface conditions. If significant main effects were observed, Bonferroni post-hoc multiple comparisons were performed. Statistical significance was set to $p < 0.05$.

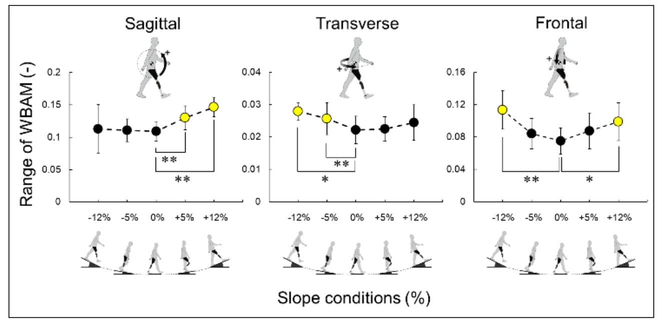

***Figure* 1**: Range of whole-body angular momentum through gait cycle in TFPUs across slope conditions. Asterisks denote significant differences from level ground walking: *$p < 0.05$, **$p < 0.01$.

Results and Discussion

In sagittal, transverse and frontal planes, we found significant main effects of the slope conditions.

Sagittal plane: TFPUs exhibited a significantly greater range of WBAM in uphill conditions (+5%, +12%) compared to the level surface. Uphill walking requires greater propulsion and mechanical work [2], which may result in a more dynamic leg swing movements and lead to an increased WBAM range.

Transverse plane: A significant increase in the WBAM rage was observed under downhill slope conditions (-5%, -12%) than the level surface. Segmental contribution analysis revealed that this increase was primarily due to reduced arm swing during downhill walking compared to level walking [3].

Frontal plane: TFPUs exhibited a greater range of frontal-plane WBAM under steep slope conditions (-12%, +12%) than on the level surface. This suggests that the maintaining lateral stability becomes more challenging under both steep uphill and downhill conditions.

Conclusions

This study highlighted the challenges TFPUs face in maintaining dynamic balance during uphill and downhill walking. Uphill walking increased dynamic leg swing movement, while downhill walking reduced arm swing, both leading to greater WBAM ranges. Steep uphill and downhill slopes further challenge lateral stability in the frontal plane.

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References

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