Transtibial Amputees Stepping on Frontally Unexpected Uneven Surface: Insight into Energy Expenditure

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Summary

Most transtibial amputees (TTAs) rely on their passive prosthetic feet and thus experience challenges maintaining balance on uneven terrain. This study sought to provide insight into changes in energy expenditure of TTAs using their prescribed prostheses during a single step on unexpected flat, inverted, and everted surfaces. Compared to non-amputee controls, TTAs exhibited higher negative ankle joint work and lower positive ankle joint work on uneven surfaces, indicating limited energy generation for propulsion. TTAs had lower positive knee joint work during eversion and lower negative frontal hip joint work during inversion, suggesting compensatory strategies that may lead to increased energy expenditure. These findings highlight the limitations of current clinically prescribed prosthetic feet in adapting to uneven terrain and emphasize the need for designs that improve positive ankle joint work. Additionally, rehabilitation efforts focusing on hip strength may enhance balance and affect overall energy for TTAs navigating uneven surfaces.

Introduction

TTAs face challenges maintaining balance on uneven surfaces, increasing fall risk. Non-amputees adapt through biomechanical strategies such as increased joint flexion [1] and power [2]. However, most TTAs walk with passive prosthetic feet that lack active ankle–foot actuation, underperforming on cross-slopes and thus leading to altered gait mechanics including energy. Limited research exists on biomechanical responses to a transient, single step on frontally uneven surfaces, simulating unexpected variations in free-living terrains. This study compared joint work of TTAs and non-amputees during a single step on a frontally unexpected uneven surface. Lower limb joint work was quantified to give insight into energy expenditure.

Methods

Eight TTAs and eight age- and gender-matched controls provided informed consent and completed the protocol. Using a custom instrumented raised walkway with five embedded force plates [3], participants stepped on a middle disturbance plate with their prosthetic or dominant limb. Three surface conditions - unblinded flush (flat), 15º blinded inversion, and 15º blinded eversion - were tested in randomized order after the flat condition. A single step was chosen to capture biomechanical responses without influencing subsequent recovery steps, and the 15º frontal angle produced an observable effect from the disturbance without causing injury to participants [3]. Linear mixed-effects regression tested for associations between outcomes, group, and surface condition.

Results and Discussion

TTAs showed higher negative ankle joint work during eversion ($p = 0.038$) but lower positive ankle joint work during both eversion ($p = 0.038$) and inversion ($p = 0.01$) (Figure 1), indicating sufficient energy storage but lack of propulsion from prosthetic feet. They also exhibited lower positive sagittal knee joint work during eversion ($p = 0.038$) and lower negative frontal hip joint work during inversion ($p = 0.01$) (Figure 1), potentially increasing energy expenditure. Therefore, the need for prosthetic feet that produce additional positive ankle joint work and rehabilitation therapies focused on hip muscle strengthening is warranted.

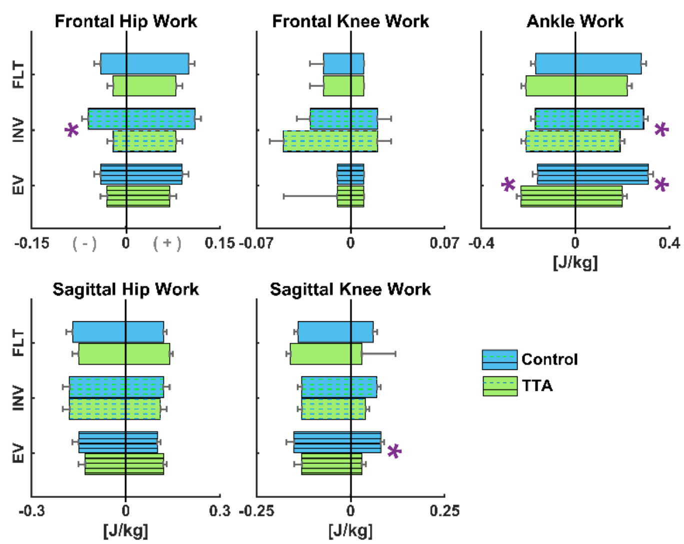

Figure 1: Mean (SE) joint work of TTAs vs. controls. Asterisk (*) indicates a statistically significant difference between groups.

Conclusions

TTAs exhibited altered joint work patterns on uneven surfaces, with lower positive ankle and lower negative frontal hip joint work, indicating insufficient prosthetic propulsion and potentially elevated energy expenditure.

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References

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