Analysis of Dynamic Balance Control in Transtibial Amputees with Use of Powered Prosthetic Foot

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Abstract

The powered prosthetic foot (PPF) is designed to provide transtibial amputees (TTA) with active propulsion and plantar flexion similar to that of the biological limb. Previous studies have demonstrated the PPF's ability to increase TTA walking speeds, while reducing the energetic costs, however, little is known about its effects on dynamic balance control. The purpose of this study was to assess dynamic balance control in a sample of TTA subjects during level ground walking and obstacle-crossing tasks. Control subjects (n=5) and TTA subjects (n=4) were instructed to complete a series of functional walking tasks during each lab visit. The TTA subjects completed the walking protocol twice, first in their traditional passive prosthetic foot and again in the prescribed PPF after two weeks of acclimation. Motion data were collected via a 10-camera system with a 53-marker and 15-segment body model. Center of mass (CoM) motion within the frontal plane were analyzed and used as functional indicators of dynamic balance control. Preliminary findings from the study indicate that TTA subjects wearing the PPF generally experienced a greater mediolateral CoM motion and peak velocity, thus signifying a reduced ability to maintain dynamic balance control. Our findings may be of particular interest to clinicians and PPF designers working to improve the amputee population's quality of life. Further data analysis is needed to support these initial findings.

INTRODUCTION

- Transtibial amputees (TTA) are at a greater risk of falling due to their loss of ability for muscle contraction, joint manipulation, and sensory feedback that normally function together within the amputated limb for balance control.
- The powered prosthetic foot (PPF) is designed to provide TTA with active plantar flexion and propulsion similar to that of the biological limb.
- The PPF has been shown to increase TTA preferred walking velocity, while reducing the metabolic cost of transport [1], however, little is known about its effect on dynamic balance control.

Purpose:

- The purpose of this study was to examine the compensatory mechanisms of TTA gait and balance control during level-ground locomotion and obstacle-crossing while wearing the PPF.

Hypotheses:

- We hypothesized that 1) as walking speed decreased and obstacle height increased, subject CoM motion would increase, 2) the TTA group would experience a great CoM motion in all conditions compared to their able-bodied control group, 3) the TTA group would experience an increased CoM motion when wearing the PPF.

METHODS

Subjects:

- Four TTA subjects (47.5 ± 12.0 years) and five able-bodied control subjects (29.0 ± 12.0 years) were recruited for this study.

Unobstructed Level Ground Walking Task:

- This task included three different self-selected walking speeds of slow (SSS), normal (SSN), and fast (SSF).

Obstacle-Crossing Task:

- This task included two different obstacle heights of 3cm (Low) and 12.7cm (High), representing the height of doorway thresholds and precast parking lot concrete blocks respectively

Protocol:

- First session: the control group and TTA group, while wearing their personal passive prosthetic foot, completed the above mentioned tasks. At the end of the session, a certified prosthetist fitted the TTA with the PPF.
- TTA were given two weeks to acclimate to the PPF.
- Second session: The TTA completed the above tasks in the PPF. Control group did not take part in the second session.

METHODS

Data Collection

- 53-marker set
- 10-camera system (120 Hz)
- Low pass filtered (4th order Butterworth)
- 15-segment full body model
- CoM motion

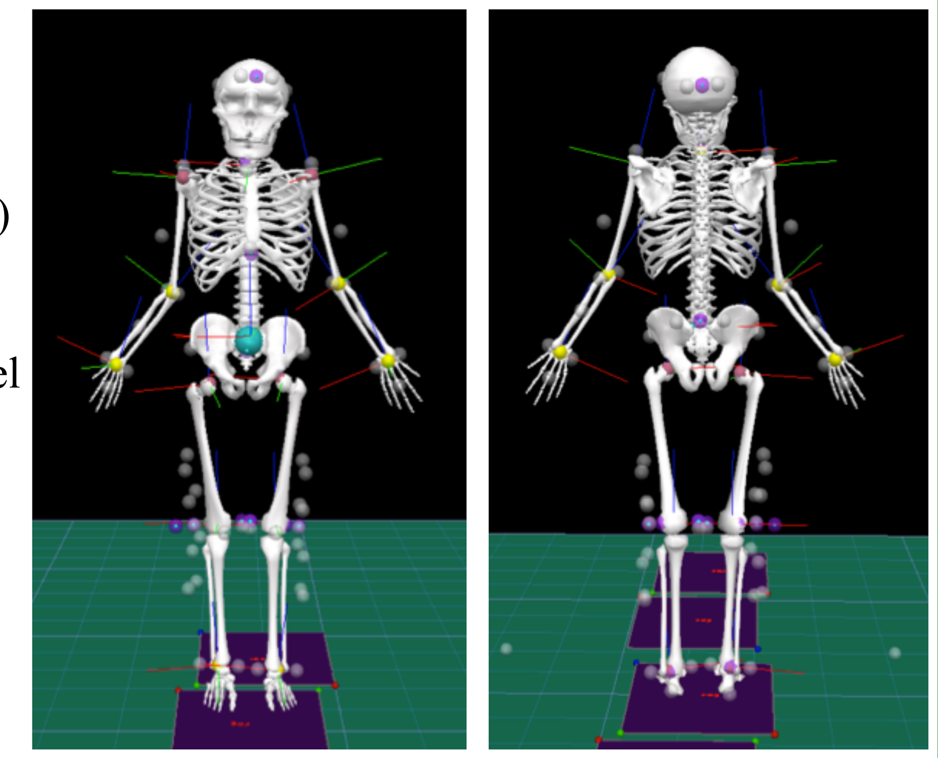

Figure 1: 15-segment full body model used to identify CoM motion.

Results

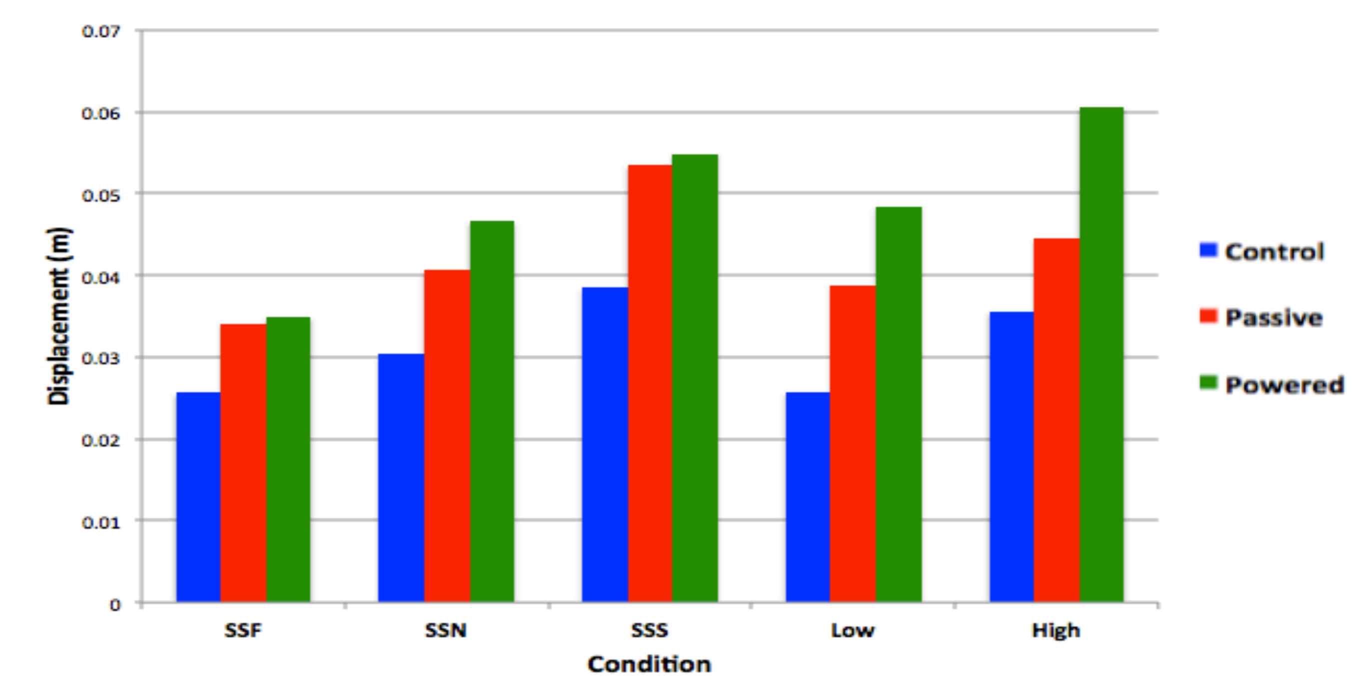

Figure 2: M-L CoM displacement during level ground and obstacle -crossing conditions.

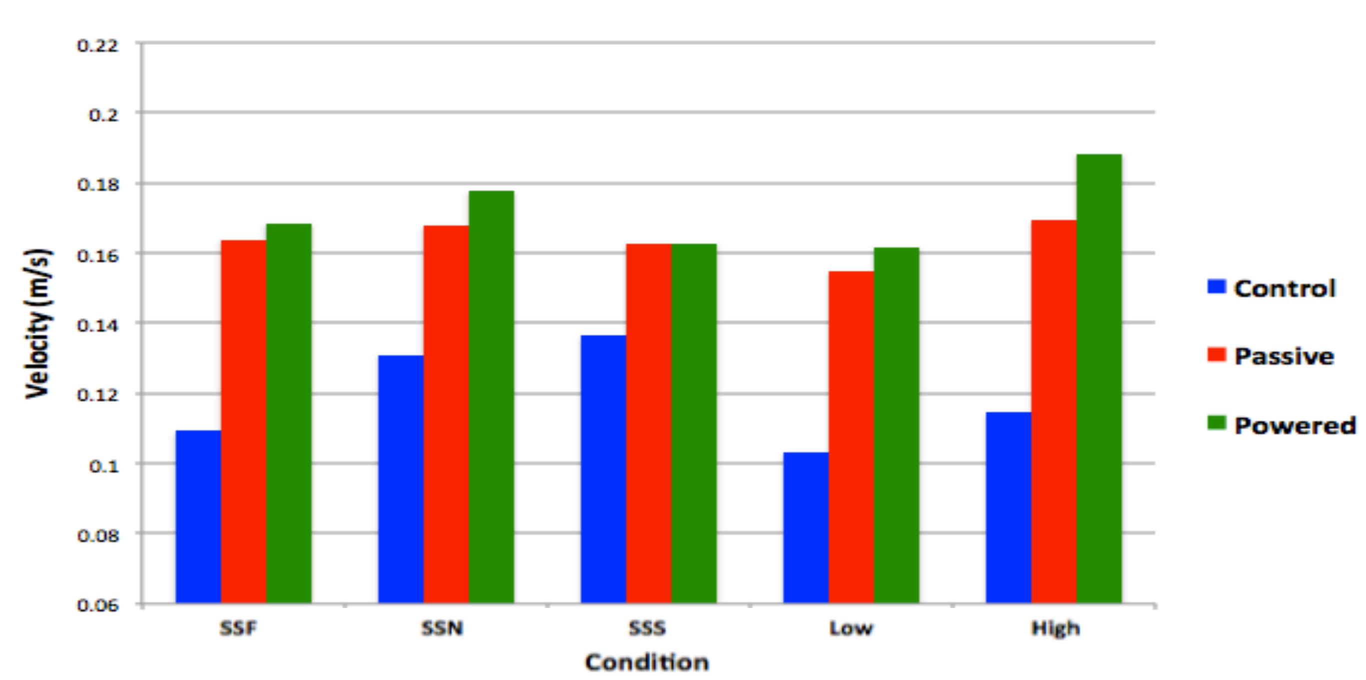

Figure 3: M-L CoM peak velocity during level-ground and obstacle crossing conditions.

	Walking Speed (m/s)				
	SSF	SSN	SSS	Low	High
Control	1.65 ± 0.14	1.36 ± 0.11	1.04 ± 0.14	1.43 ± 0.17	1.30 ± 0.11
TTA w/ passive	1.45 ± 0.21	1.16 ± 0.17	0.90 ± 0.04	1.28 ± 0.10	1.31 ± 0.03
TTA w/ powered	1.52 ± 0.39	1.12 ± 0.24	0.92 ± 0.02	1.34 ± 0.10	1.33 ± 0.05

Table 1: Self-selected walking speeds during level ground and obstacle-crossing conditions; sample mean ± SD.

Results

- As walking speeds decreased, all subject groups experienced an increase in CoM displacement (Figure 2)
- As obstacle height increased, all subject groups experienced an increase in CoM displacement and CoM peak velocity (Figures 2 and 3).
- The TTAs experienced an increase in CoM displacement and CoM peak velocity across all conditions compared to the control group (Figures 2 and 3).
- The TTA experienced an increase in CoM displacement and CoM peak velocity across all conditions when wearing the PPF compared to wearing the passive foot (Figures 2 and 3).

Noteworthy Trends

- The TTA group wearing the PPF walked at a greater speed during the SSF condition compared to when wearing the passive foot (Table 1).
- The TTA group wearing the PPF experienced a relatively large increase in CoM displacement during the High condition compared to when wearing the passive foot (Figure 2).

Discussion

- The TTA demonstrated an increased capacity to walk faster when wearing the PPF (Table 1), which may indicate increased walking confidence.
- Walking confidence could result in a more casual and less calculated approach to the obstacle crossing task, as indicated by the increased CoM displacement in the High condition (Figure 2).
- Mediolateral (side-to-side) motion of CoM within the frontal plane has been chosen for its effectiveness as a functional indicator of dynamic balance control [2].
- The task of obstacle crossing introduces an inherent asymmetry between the lead limb and trail limb, which amplifies any CoM motion.
- Therefore, we expect to find the largest differences in our dependent variable when subject balance control is challenged, which is the High condition in this study.
- Also, the reintroduction of net-positive power may alter their adapted gait patterns completely, resulting in changes to their CoM motion pattern.

Limitations

- Statistical significance of the findings were not identified in the ongoing study due to the limited number of participants.
- Insufficient time for TTA to acclimate to the PPF in terms of balance control.

Future Direction

- Recruit more TTA subjects to increase sample size.
- Recruit age, sex, height, and weight matched able-bodied control subjects for each TTA in order to make more direct comparisons between the two groups.
- Analyze the effects of lead limb preference on center of mass trajectory.

Conclusion

- Our preliminary findings indicate a possible reduction in TTA ability to maintain dynamic balance control when wearing the PPF. If supported by further data, these findings may be of interest to clinicians and PPF designers working to improve the quality of life in lower limb amputees.

REFERENCES

[1] Herr, H.M., &Grabowski, A. M. *Proc. Royal Soc B*, **279**: 457-464, 2012.

[2] Chou, L. S., et al. *Gait & Posture* **18**: 125-133, 2003.