The Effect of Prosthetic Foot and Ankle Stiffness Changes on Gait and Standing in People with Unilateral Transtibial Amputations

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Overview: The purpose of this investigation is to determine how systematically varying the prosthetic foot keel stiffness and prosthetic ankle joint stiffness affects standing and walking in persons with unilateral, transtibial amputations. Specifically, we will identify and weigh the different benefits and consequences of combining stiffer prosthetic footplates with more compliant ankle dorsiflexion bumpers, and vice versa, to determine how to best serve the needs of the prosthesis user.

Introduction

Background

- Incidence of Transtibial amputation (approx. 346,520 unilateral transtibial amputees in the US).
- Conducted in parallel with the mechanical characterization of the prosthetic feet.
- Provide prescription guidelines for prosthetists to consider.
- Rotation of Ankle joint is critical for progression and joint absorption
- Able-bodied persons vary their ankle joint stiffness with walking speed (Hansen et al., 2004).
- Previous studies have shown that modular prosthetic ankle components improve walking (Su et al., 2010).
- A previous pilot study suggested that decreased prosthetic ankle stiffness reduces stability during standing.

Specific Aims:

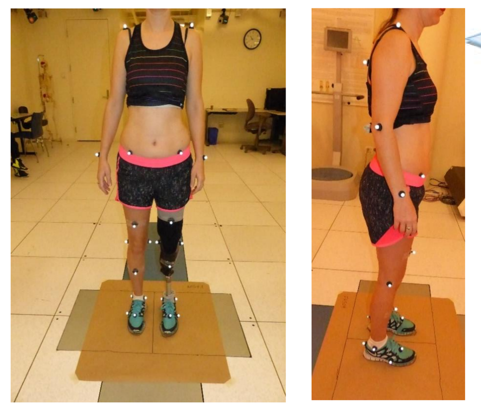
1. To determine the effects of different prosthetic foot and ankle stiffness combinations on gait biomechanics of unilateral, transtibial prosthesis users.
2. To determine the effects of different combinations of prosthetic foot and ankle stiffness on standing stability of unilateral, transtibial prosthesis users.

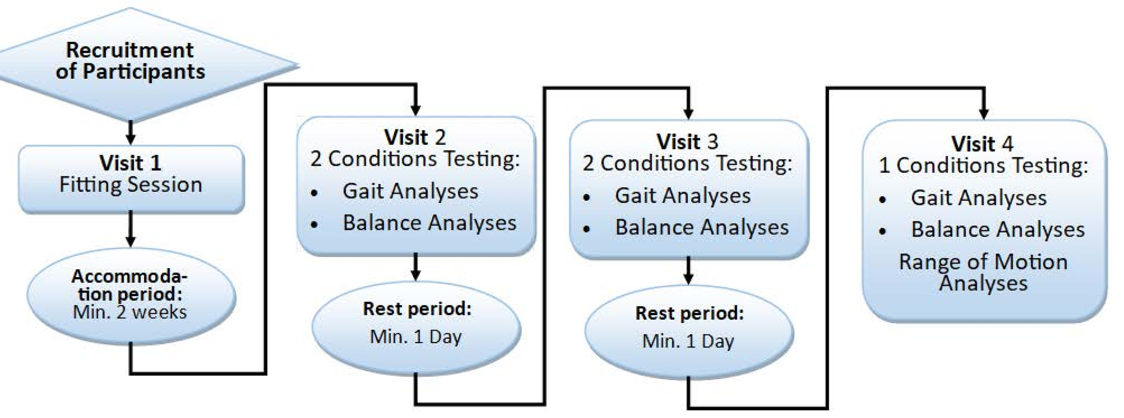
Methods

College Park Venture Foot: The Venture foot was selected because its design enables relatively easy substitution of different footplates and ankle bumpers that the manufacturer provides with different stiffness.

Footplate Stiffness		Ankle Bumper Stiffness: Soft	Ankle Bumper Stiffness: Medium	Ankle Bumper Stiffness: Hard
	Hard	**Combination HS** Footplate: Hard Ankle: Soft	**Combination Not Used** Footplate: Hard Ankle: Medium	**Combination Not Used** Footplate: Hard Ankle: Hard
	Medium	**Combination MS** Footplate: Medium Ankle: Soft	**Combination MM** Footplate: Medium Ankle: Medium	**Combination MH** Footplate: Medium Ankle: Hard
	Soft	**Combination Not Used** Footplate: Soft Ankle: Soft	**Combination Not Used** Footplate: Soft Ankle: Medium	**Combination SH** Footplate: Soft Ankle: Hard

Procedure:





Gait Analyses: Data collection was performed in the JBVAMC Motion Analysis Research Laboratory, using a Helen Hayes full-body marker set, at 3 self-selected speeds (normal, slow and fast). The same procedure was used for all the conditions.

Balance Analyses: Static assessment of quiet standing while the subject stood on two force platforms. The trials last 30 seconds, were repeated three times and performed for eyes open and eyes closed conditions.

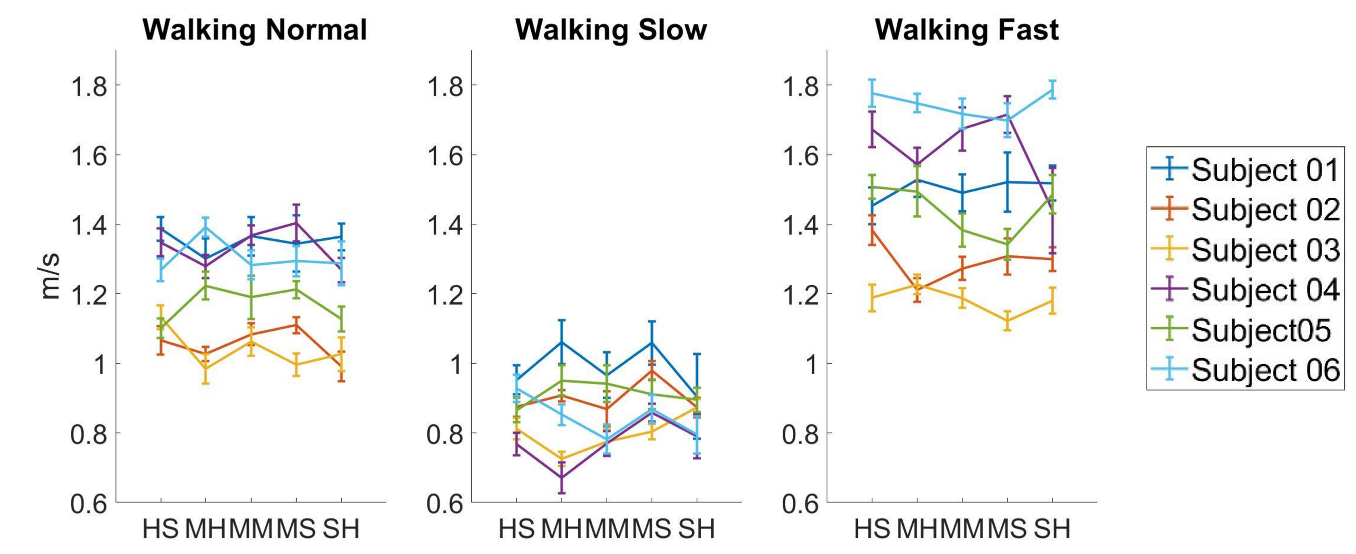
Results

A mechanical characterization were performed on a previous study to determine the combined Ankle-Foot Stiffness providing the order from low stiffness to high stiffness:

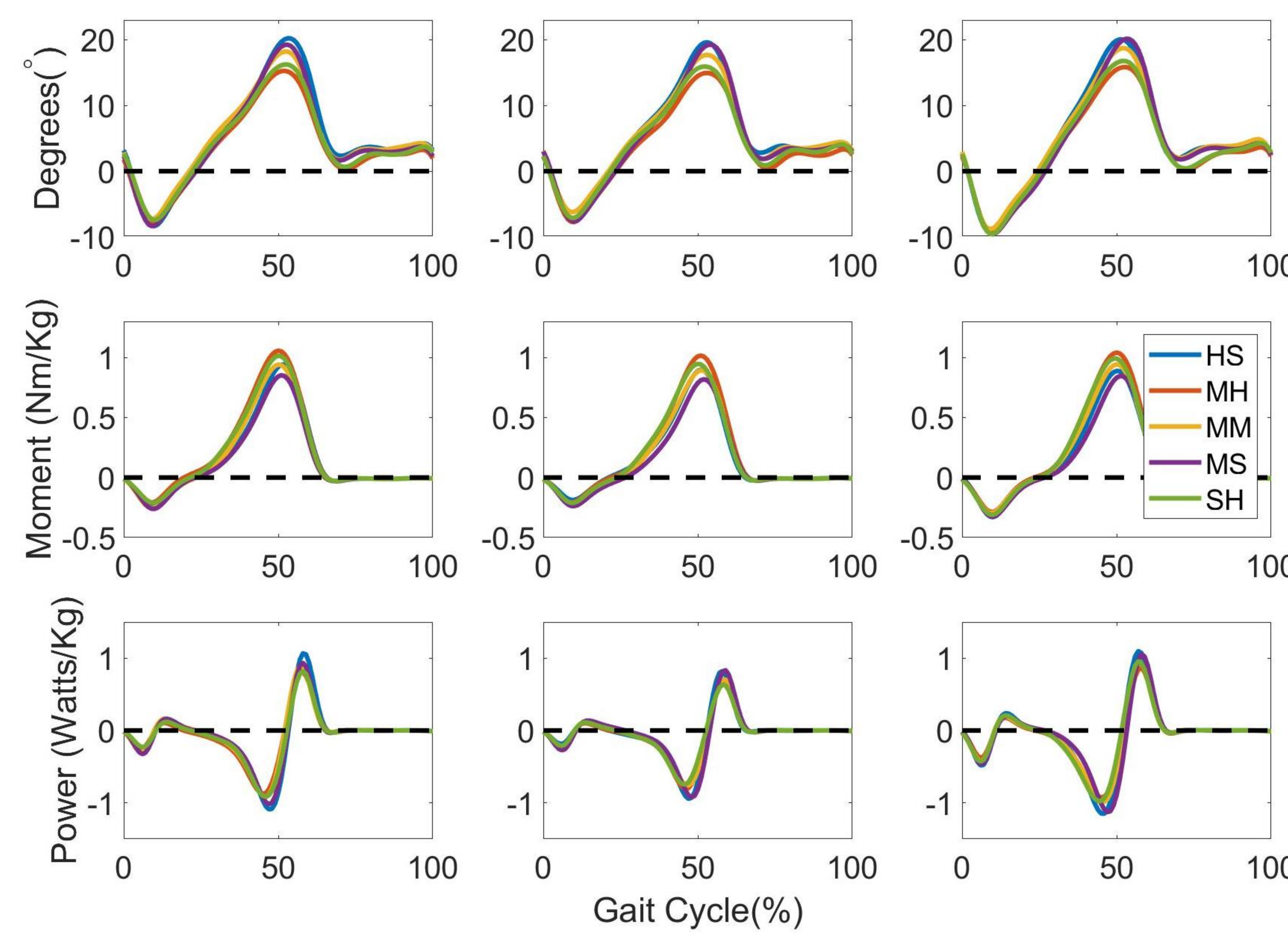
MS < HS < SH < MM < MH

Gait Analyses:

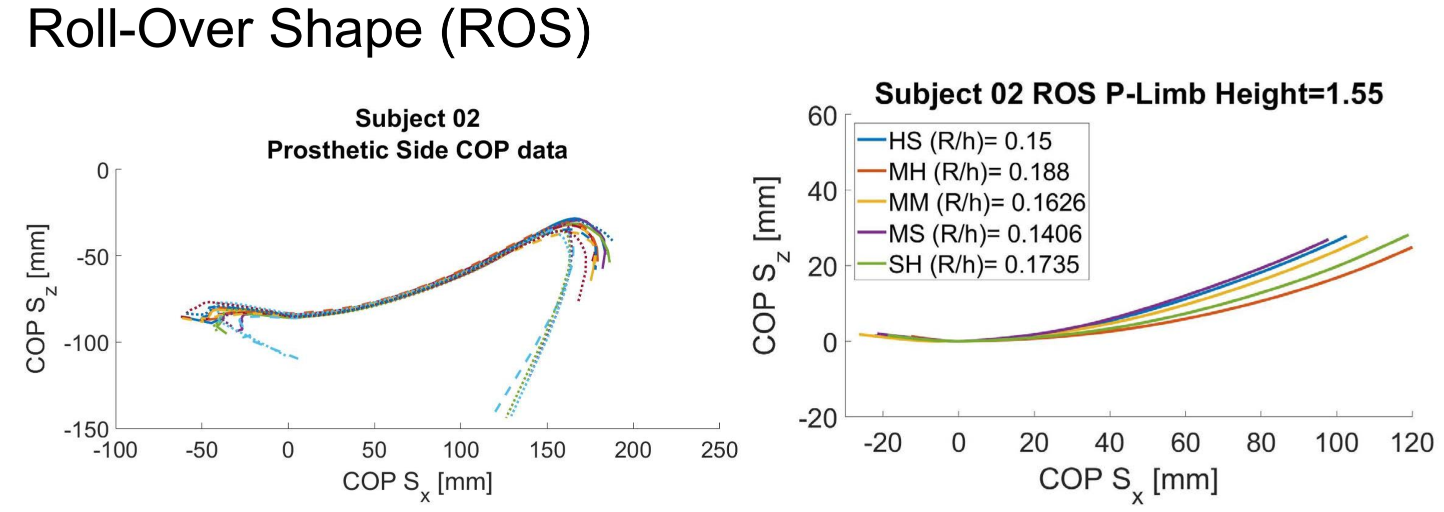
1. Temporal Spatial Parameters



2. Kinetic and Kinematic Data of the Ankle

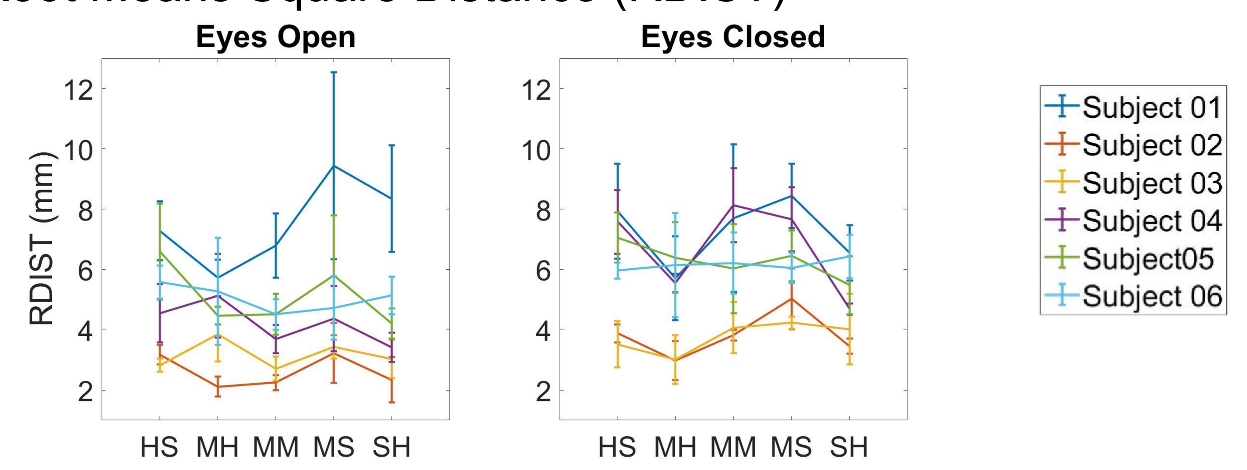


3. Roll-Over Shape (ROS)



Balance Analyses:

1. Root Means Square Distance (RDIST)



Discussion

- Despite the small sample size, there is a trend that suggests that conditions with higher foot-ankle stiffness influence gait patterns of transtibial amputees.
- Data suggests that ankle angle is inversely proportional to ankle-foot stiffness and ankle moment is directly proportional to ankle-foot stiffness.
- During the standing balance experiment for eyes close the RDIST of COP is smaller for the MH condition and larger for the MS condition in support of our hypothesis.
- The youngest participant show a distinct behavior during both standing and walking analyses, suggesting a consistent adaptation to all five conditions.
- High variability was observed across subjects' data for the intermediate conditions.

Conclusions:

- The results demonstrate that prosthetic foot–ankle stiffness affects both gait and standing performance.
- An aspect that should be considered is the ambulatory capability of the subjects. For example, a younger, athletic user readily adapted to the different conditions.
- The systematic variation of the ankle-foot stiffness increases understanding about how prosthetists could potentially fine-tune user performance.
- Each subject demonstrated specific gait strategies for the different stiffness combinations, which is an important point to consider for the fitting process.

References & Acknowledgements

Adams, P.F., Hendershot, G.E. and M.A. Marano (1999). Current estimates from the National Health Interview Survey, 1996. National Center for Health Statistics. Vital Health Stat, 10(200).

Hansen, A., Gard, S., & Childress, D. (2000). The determination of foot/ankle roll-over shape: clinical and research applications. *Pediatric Gait: A New Millennium in Clinical Care and Motion Analysis Technology*, 159–165. https://doi.org/10.1109/PG.2000.858888

Su, P., Gard, S.A., Lipschutz, R.D. and Kuiken, T.A. (2010). The Effects of Increased Prosthetic Ankle Motions on the Gait of Persons with Bilateral Transtibial Amputations. American Journal of Physical Medicine and Rehabilitation, 89(1), 34–47. PMCID: PMC2805409.