Stiffness properties in the frontal plane of multiaxis prosthetic feet and the influence of shoes

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Introduction: Prosthetic Feet

- Provide essential connection between prosthesis and ground

- Currently divided into traditional foot classifications (Lusardi 2007, Smith 2004)
  - SACH
  - Single axis
  - Multiaxis
  - Flexible Keel
  - Dynamic response
  - Dynamic response/multiaxis

- Multiaxis feet
  - Allow motion in sagittal, frontal and/or transverse planes (Lusardi 2007)
  - Popular among amputees for activities on uneven terrain (Stark 2005)
Variation in designs of multiaxis feet
- Previous research suggests feet in same classification vary functionally
- Current classification system may be inadequate for optimal prescription recommendation
- Stiffness can be used as metric to divide feet into more specific subcategories (Geil 2001)

Influence of shoes on materials testing is unknown
- Vast majority of foot materials testing performed barefoot
- Prosthetic feet are designed to be worn with shoes
- Test environments should strive to meet real world conditions (Hafner 2005)
Objectives/Hypotheses

- Analyze stiffness properties of multiaxis feet in the frontal plane
  - Hypothesis: Stiffness properties of feet will vary and feet will divide themselves into subcategories

- Determine the influence of a shoe on the stiffness properties of multiaxis feet in the frontal plane
  - Hypothesis: Shoe will influence the stiffness properties of the foot
Methods: Foot selection

- Foot selection (n=6)
  - Donations to MSPO program by manufacturers and distributors
  - SACH used for comparison
- Foot specifications
  - Adult, male
  - 175 lbs
  - Size 26
  - Left side amputation
- Shoe
  - Athletic Works, velcro closure
Methods: Test set-up

- Instron 8521: servo-hydraulic testing machine

- Simulate mid-stance of gait
  - Neutral inversion/eversion
  - Parallel to ground (sagittal plane)

- Custom built inclines
  - 5°, 10°, 15°, 20°

- 2 conditions
  - Eversion and inversion
Methods: Test set-up

- Cyclic loading
  - Amplitude: 1350 N (Toh 1993)
  - Frequency: .95 Hz (Perry 1992)
- 6 cycles of data collected
- Tested with and without shoes
- Stiffness = force/deflection slope
  - Calculated at 800N
Results: All Feet Barefoot

* No statistical difference between feet A & B, and feet D & E
Results: All Feet Barefoot

* No statistical difference between feet A & B, and feet D & E
Results: All Feet with Shoe

- Influence of shoe
  - Lower stiffness of feet at all inclines compared to barefoot
  - Magnitude of decrease in stiffness varied by foot

Example: Foot A
Results: All Feet with Shoe

* No statistical difference between feet A, B, C
Results: All Feet with Shoe

* No statistical difference between feet A, B, C
Results: Barefoot vs. Shoe

- Influence of shoe: Shoe changes natural divisions among feet

<table>
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<tr>
<th>Subcategory</th>
<th>Feet</th>
<th>With shoe</th>
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Stiffness properties of multiaxis feet will vary and feet will divide themselves into subcategories
- Hypothesis is supported

Shoe will influence the stiffness properties of the foot
- Hypothesis is supported
Discussion

- Limitations
  - Anonymity of feet
  - Variability of shoes
  - Only simulate part of gait cycle

- Future research
  - Similar studies on other foot classifications
  - Comprehensive study of all multiaxis feet
  - Improve classification system
References

Thank You

- Sean Zeller, MSPO
- Chris Hovorka, MS, CPO/L, FAAOP
- Mark Geil, PhD
- Jon Jowers
- Theresa Snow, PhD
- Yudan Wang
- Southern Prosthetic Supply
- Otto Bock HealthCare
Extra slides
Current State of Research

- Most current research compares feet to SACH; Little research compares feet within/across categories (Hafner 2005)
- Majority of research investigated sagittal plane; Paucity of data on frontal plane motion (SSC (JPO) 2005)
- Stiffness can be used to divide dynamic response feet into subcategories (Geil 2001)
- Prosthesis performance different while wearing shoes than barefoot (Han 2003)
Data collection

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Collect Data
Mean = 442.06
St. Dev = 5.47

Warm-up period
Influence of shoes

Foot A

$\text{Stiffness (N/mm)}$

Incline (°)

Difference

Foot A
Foot B
Foot C
Foot D
Foot E
Foot F

Incline (°)

Difference (N/mm)
Statistical Analysis

- Repeated measure design
- General linear model
  - Within subject factor: stiffness data
  - Between subject factor: prosthetic foot
- Multiple comparison test on feet
  - Post hoc: Bonferroni (p-value < .05)
Multiple Comparisons

Measure: MEASURE_1

Based on observed means.

* The mean difference is significant at the .05 level.

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