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)

Introduction: Significance

- 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

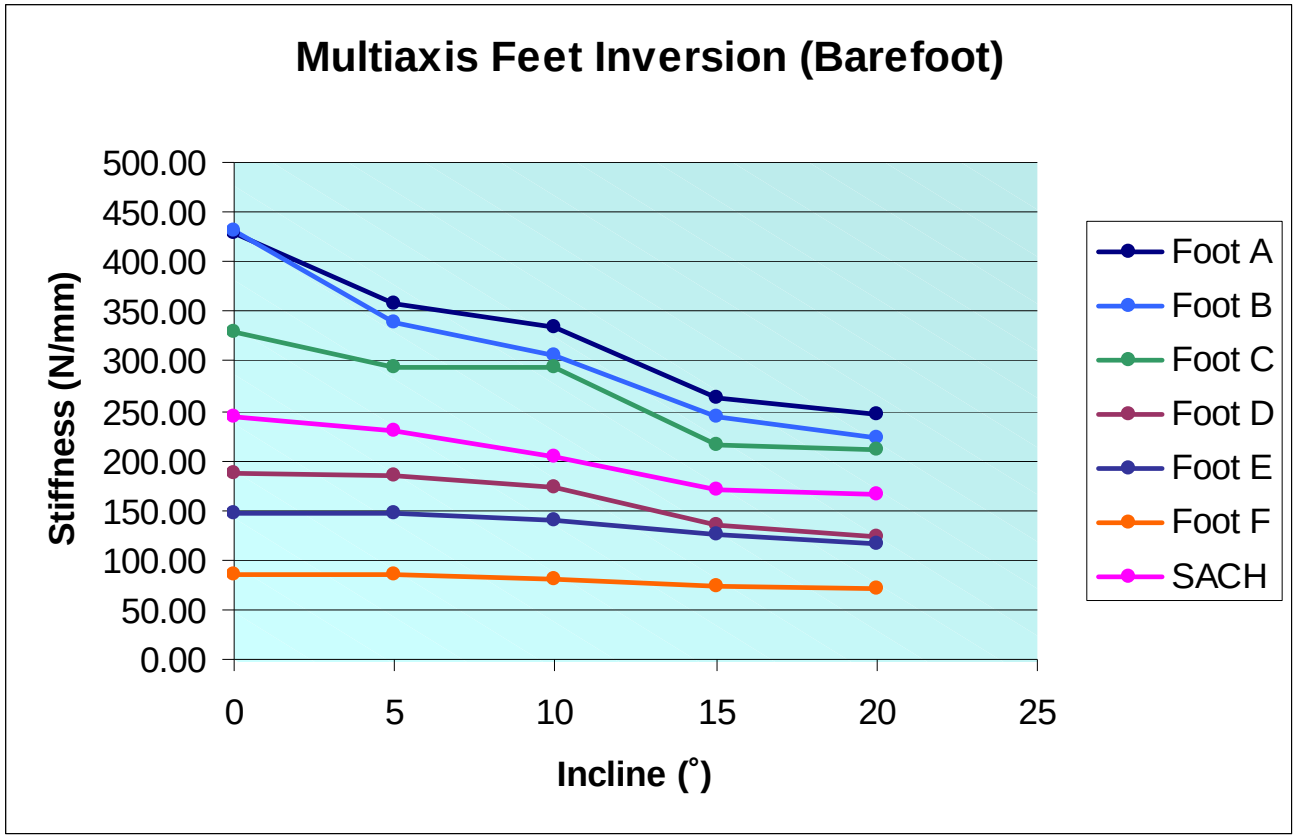
Methods: Test set-up

- 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

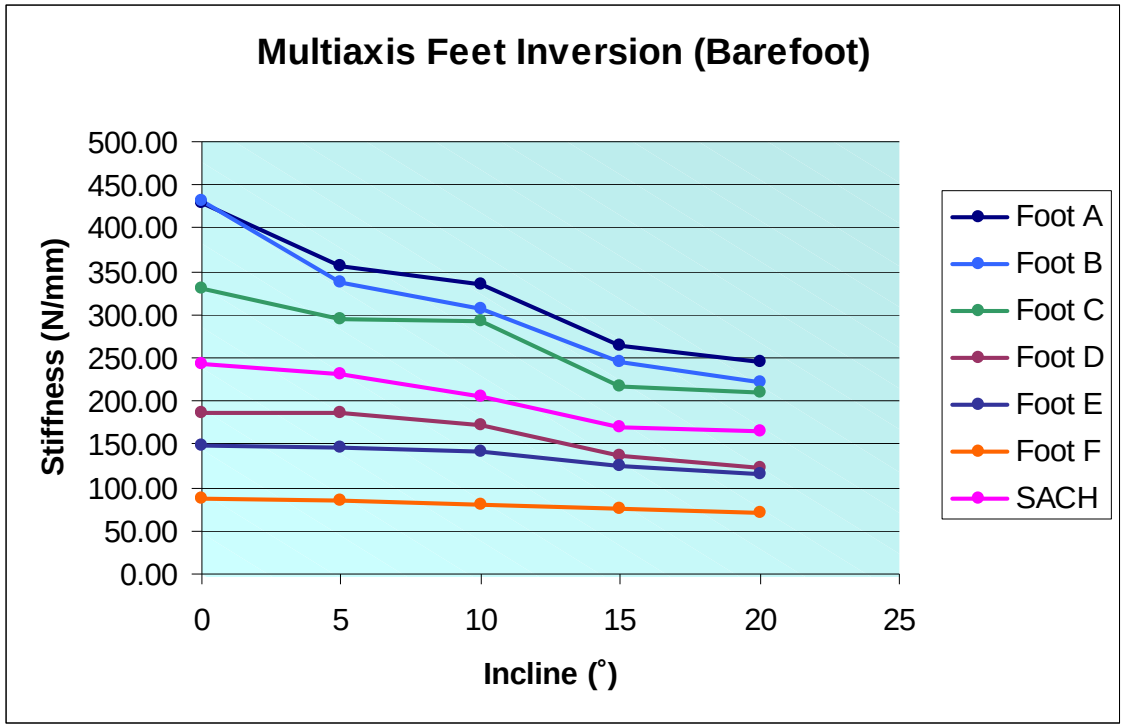
- Cyclic loading
  - Amplitude: 1350 N (Toh 1993)
  - Frequency: .95 Hz (Perry 1992)
- 6 cycles of data collected
- Tested with and without shoes
- Stiffness = force/deflection slope
  - Calculated at 800N

Results: All Feet Barefoot



* No statistical difference between feet A & B, and feet D & E

Results: All Feet Barefoot



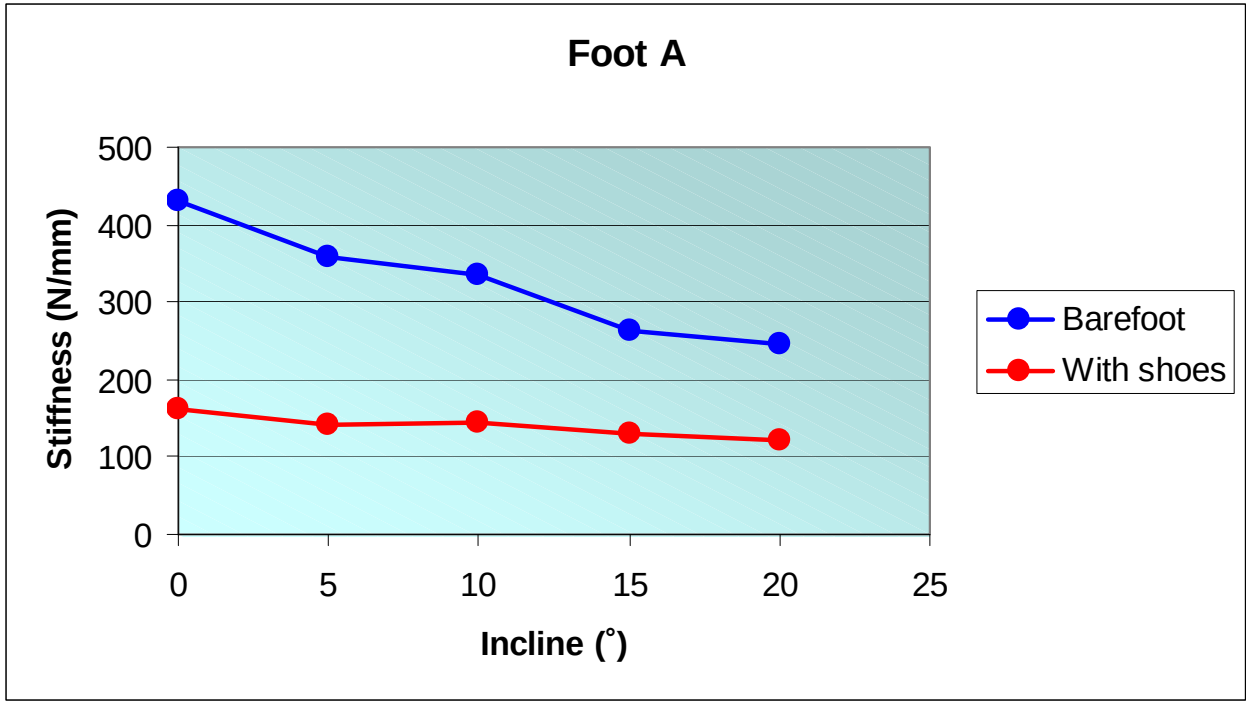
Subcategory	Feet
1	A,B
2	C
3	D,E
4	F

* No statistical difference between feet A & B, and feet D & E

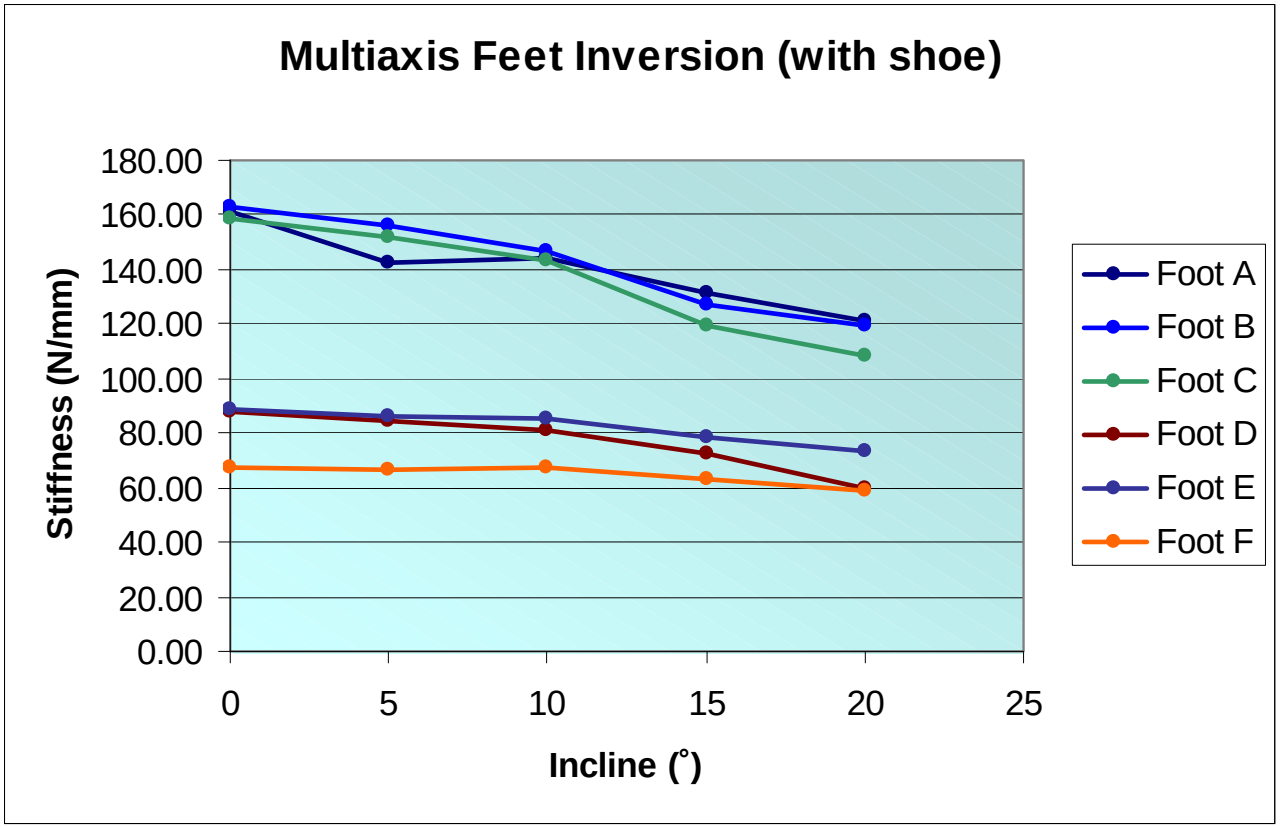
Results: All Feet with Shoe

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

Example:
Foot A

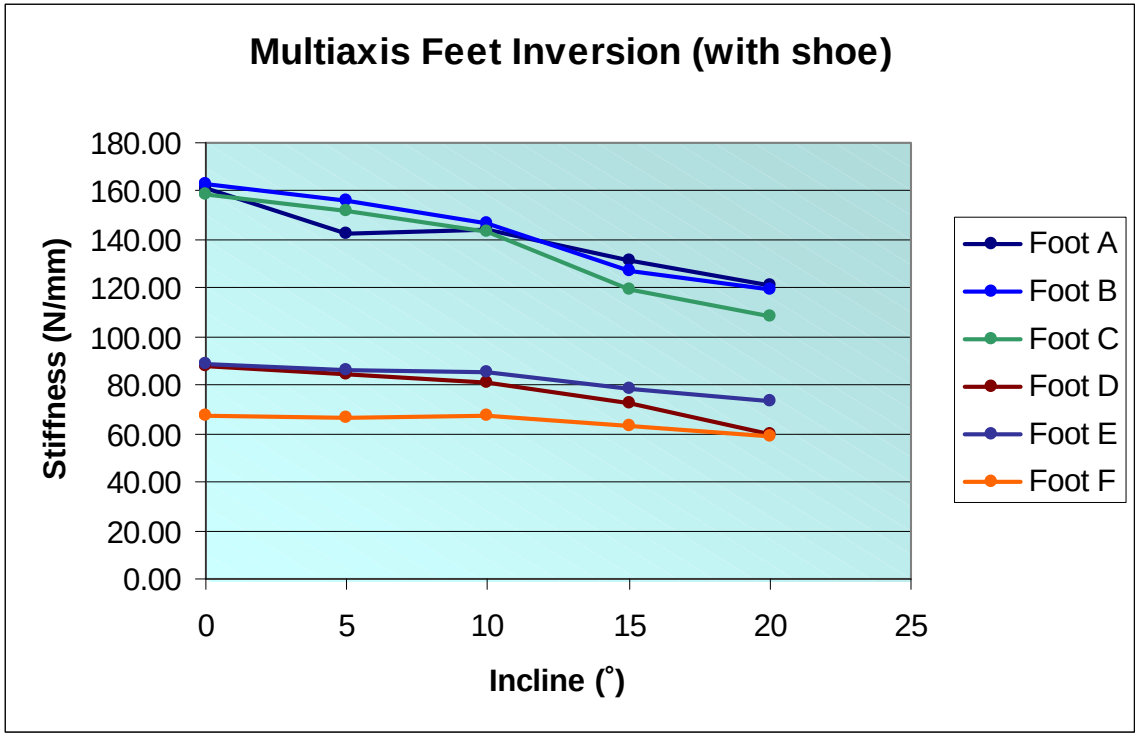


Results: All Feet with Shoe



* No statistical difference between feet A, B, C

Results: All Feet with Shoe



Subcategory	Feet
1	A,B,C
2	D
3	E
4	F

* No statistical difference between feet A, B, C

Results: Barefoot vs. Shoe

Barefoot

Subcategory	Feet
1	A,B
2	C
3	D,E
4	F

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With shoe

Subcategory	Feet
1	A,B,C
2	D
3	E
4	F

- Influence of shoe: Shoe changes natural divisions among feet

Conclusion

- 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

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Thank You

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Extra slides

Current State of Research

- Most current research compares feet to SACH; Little research compare 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

Cycle	Stiffness (N/mm)
1	n/a
2	n/a
3	446.15
4	442.85
5	452.39
6	448.63
7	440.86
8	447.2
9	456.14
10	447.17
11	436.68
12	446.16
13	442.45
14	439.67
15	436.91
16	450.51
•	
•	
•	
29	444.39
30	440.82

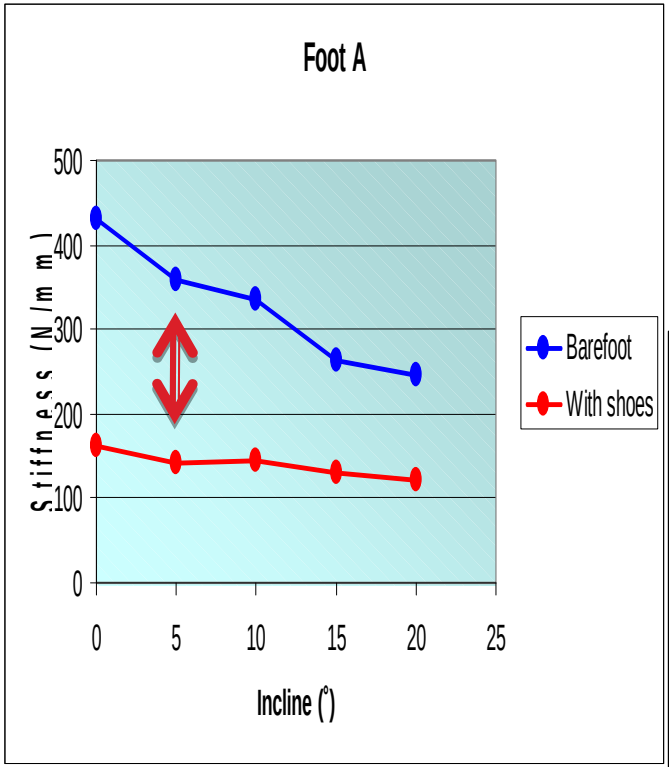
Warm-up period

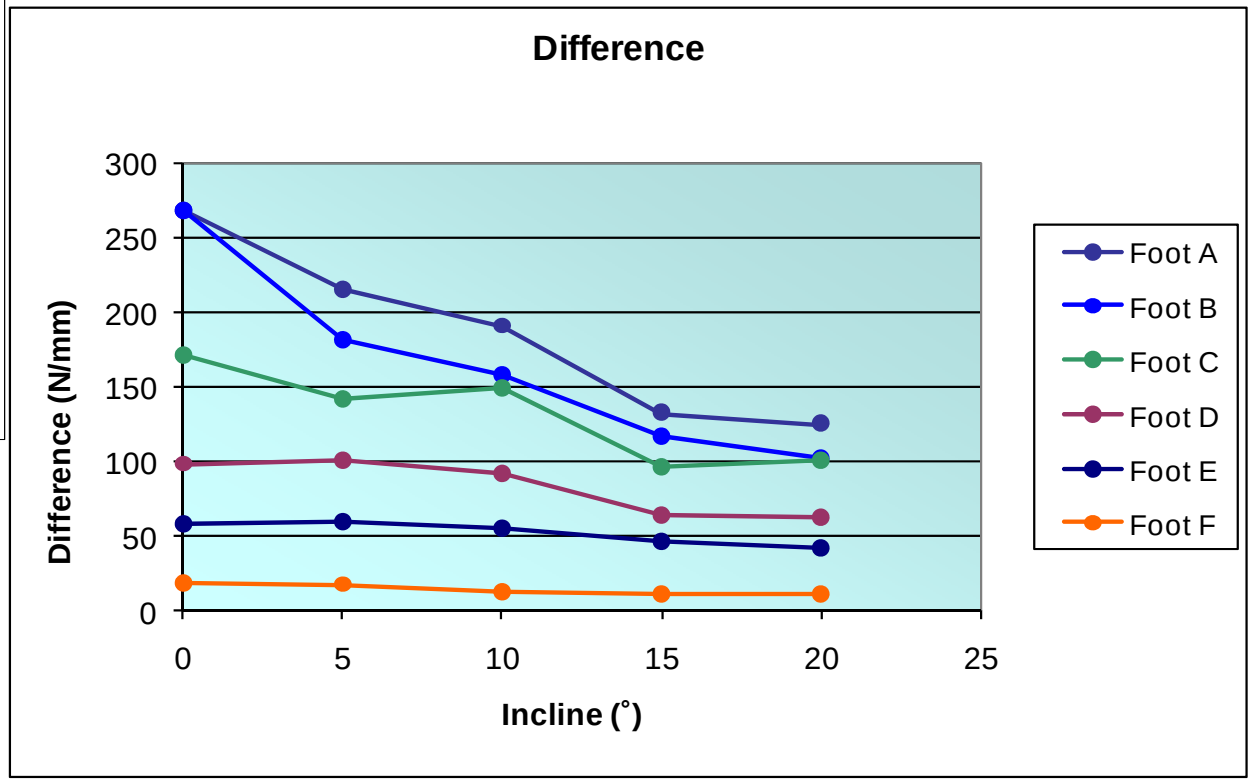
Collect Data

Mean = 442.06

St. Dev = 5.47

Influence of shoes





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

Bonferroni

(I) Foot	(J) Foot	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	18.1303	7.92912	.442	-7.1541	43.4148
	C	57.7213*	7.92912	.000	32.4369	83.0058
	D	165.9417*	7.92912	.000	140.6572	191.2261
	E	191.1357*	7.92912	.000	165.8512	216.4201
	F	246.7530*	7.92912	.000	221.4686	272.0375
B	A	-18.1303	7.92912	.442	-43.4148	7.1541
	C	39.5910*	7.92912	.000	14.3066	64.8754
	D	147.8113*	7.92912	.000	122.5269	173.0958
	E	173.0053*	7.92912	.000	147.7209	198.2898
	F	228.6227*	7.92912	.000	203.3383	253.9071
C	A	-57.7213*	7.92912	.000	-83.0058	-32.4369
	B	-39.5910*	7.92912	.000	-64.8754	-14.3066
	D	108.2203*	7.92912	.000	82.9359	133.5048
	E	133.4143*	7.92912	.000	108.1299	158.6988
	F	189.0317*	7.92912	.000	163.7473	214.3161
D	A	-165.9417*	7.92912	.000	-191.2261	-140.6572
	B	-147.8113*	7.92912	.000	-173.0958	-122.5269
	C	-108.2203*	7.92912	.000	-133.5048	-82.9359
	E	25.1940	7.92912	.051	-.0904	50.4784
	F	80.8114*	7.92912	.000	55.5269	106.0958
E	A	-191.1357*	7.92912	.000	-216.4201	-165.8512
	B	-173.0053*	7.92912	.000	-198.2898	-147.7209
	C	-133.4143*	7.92912	.000	-158.6988	-108.1299
	D	-25.1940	7.92912	.051	-50.4784	.0904
	F	55.6174*	7.92912	.000	30.3329	80.9018
F	A	-246.7530*	7.92912	.000	-272.0375	-221.4686
	B	-228.6227*	7.92912	.000	-253.9071	-203.3383
	C	-189.0317*	7.92912	.000	-214.3161	-163.7473
	D	-80.8114*	7.92912	.000	-106.0958	-55.5269
	E	-55.6174*	7.92912	.000	-80.9018	-30.3329

Based on observed means.

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