Senior Design Final Presentation

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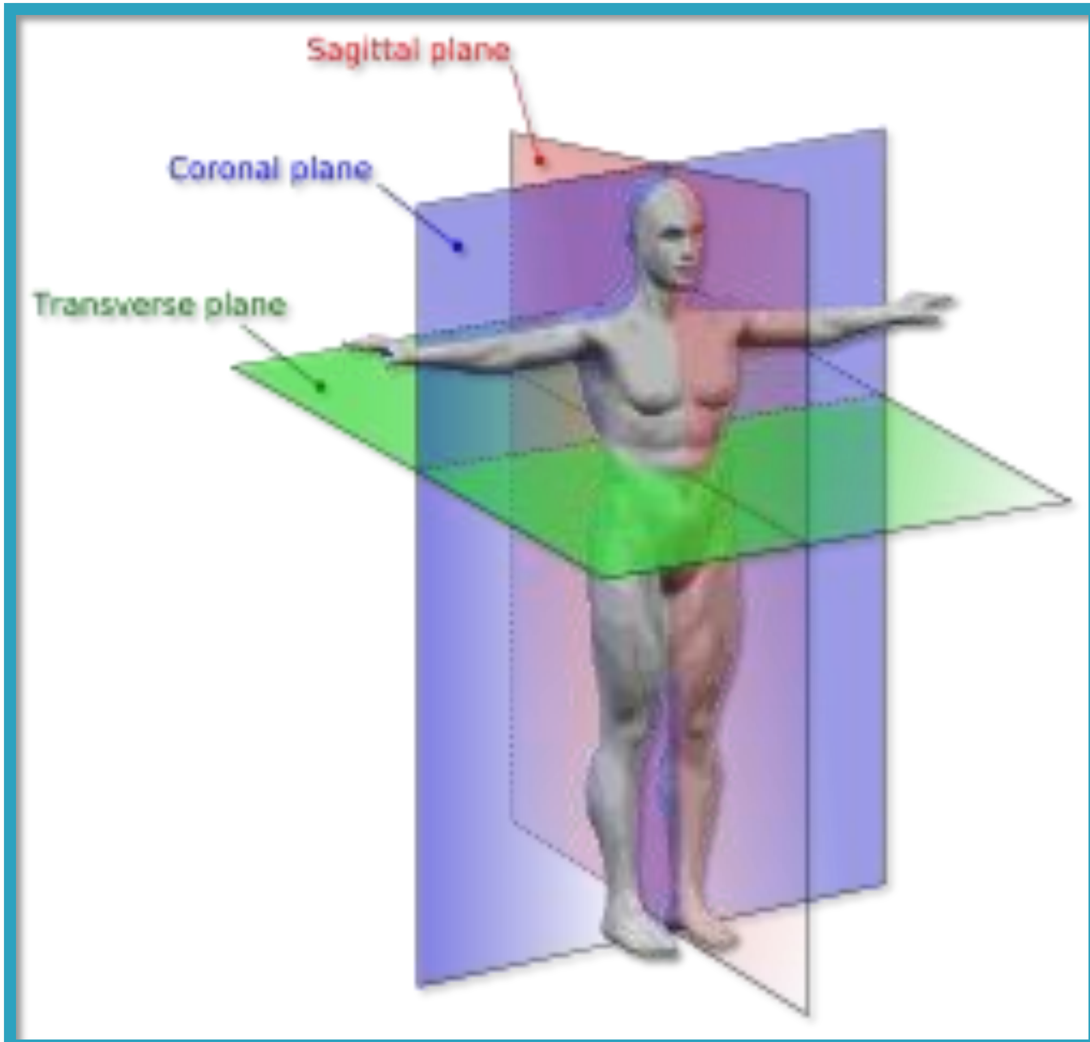
Problem Description

- Design and develop a new technique to obtain quantitative measurements of forces for prosthetic gait analysis
- Use the developed technique to indicate alignment changes that may improve the gait of a unilateral transtibial (below the knee) amputee
- Provide prosthetists with a more scientific and cost effective procedure for fitting the prosthesis in order to obtain proper gait for a patient

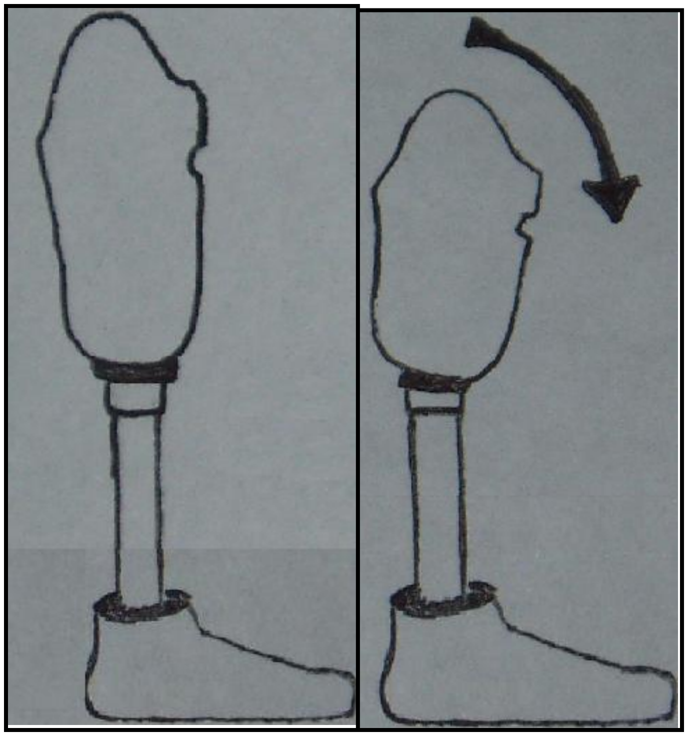
Constraints

- **Economic**
  - Provide a cost effective alternative to computerized gait analysis (CGA)
- **Health and Safety**
  - Must not compromise the integrity of the original prosthetic limb or the safety of the patient
  - The device must also be compatible with the materials and strength of the prosthesis

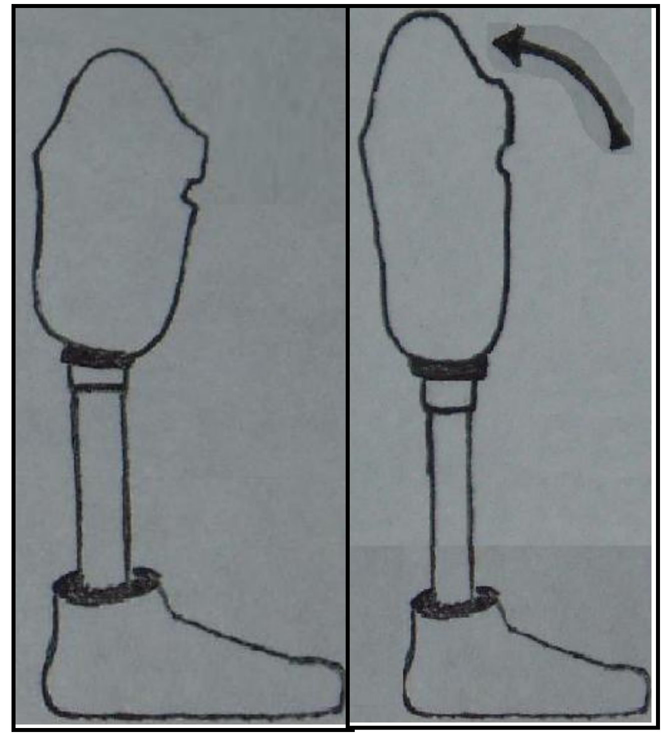


Planes used to describe the body and alignment (Mrabet 2008).

Sagittal Plane



Socket Flexion



Socket Extension

(T.Forest 2009).

Coronal Plane

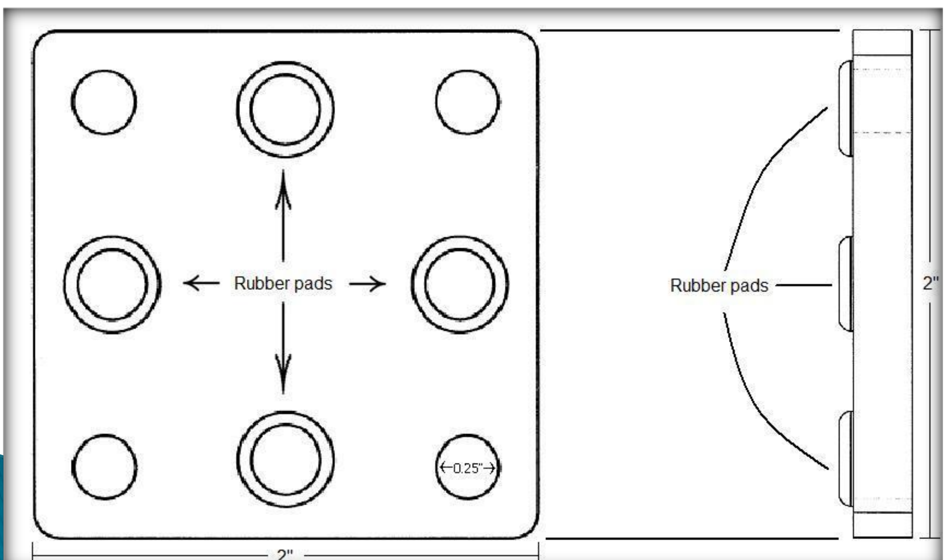
Abduction of the Socket

Adduction of the Socket

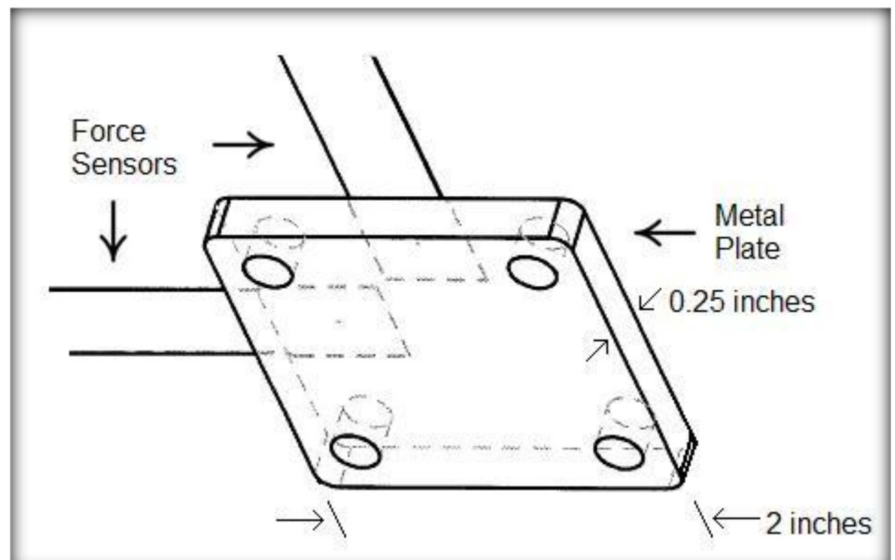
(T. Forest 2009).

Force Sensor System Design

- Sensor Module
  - Bottom and top stainless steel plates
  - 4 Thin-film, piezoresistive sensor with extended leads
  - 4 rubber pads to concentrate force on respective sensors
  - Measure resistance of sensors with DMM

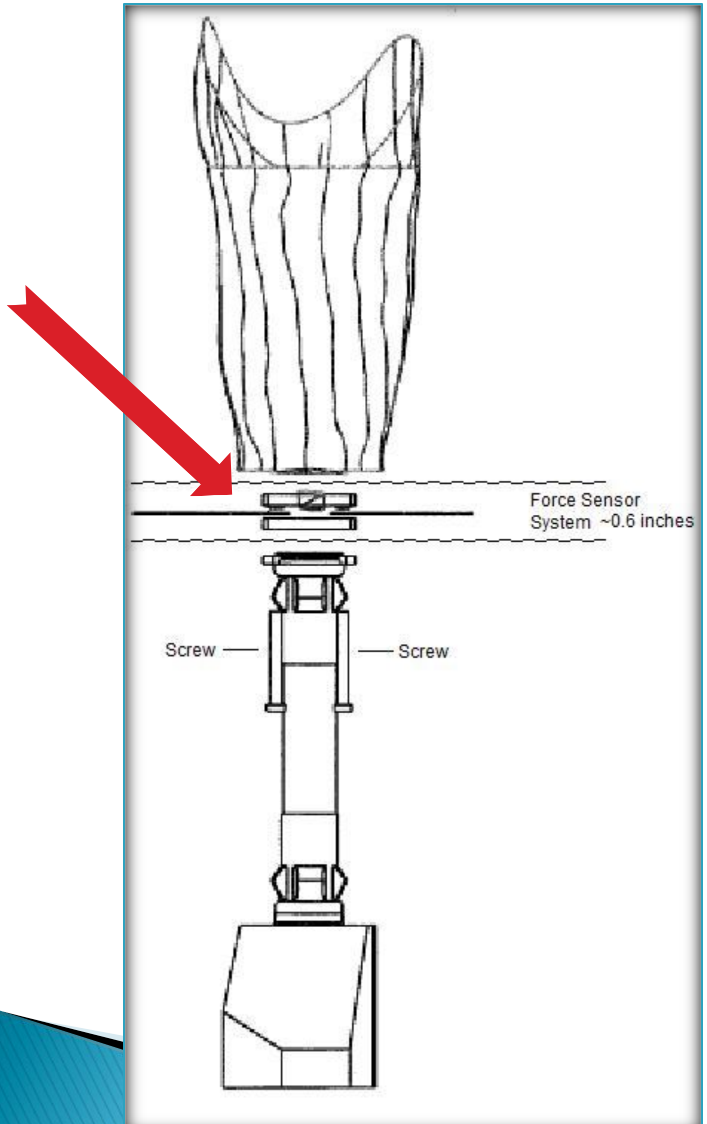


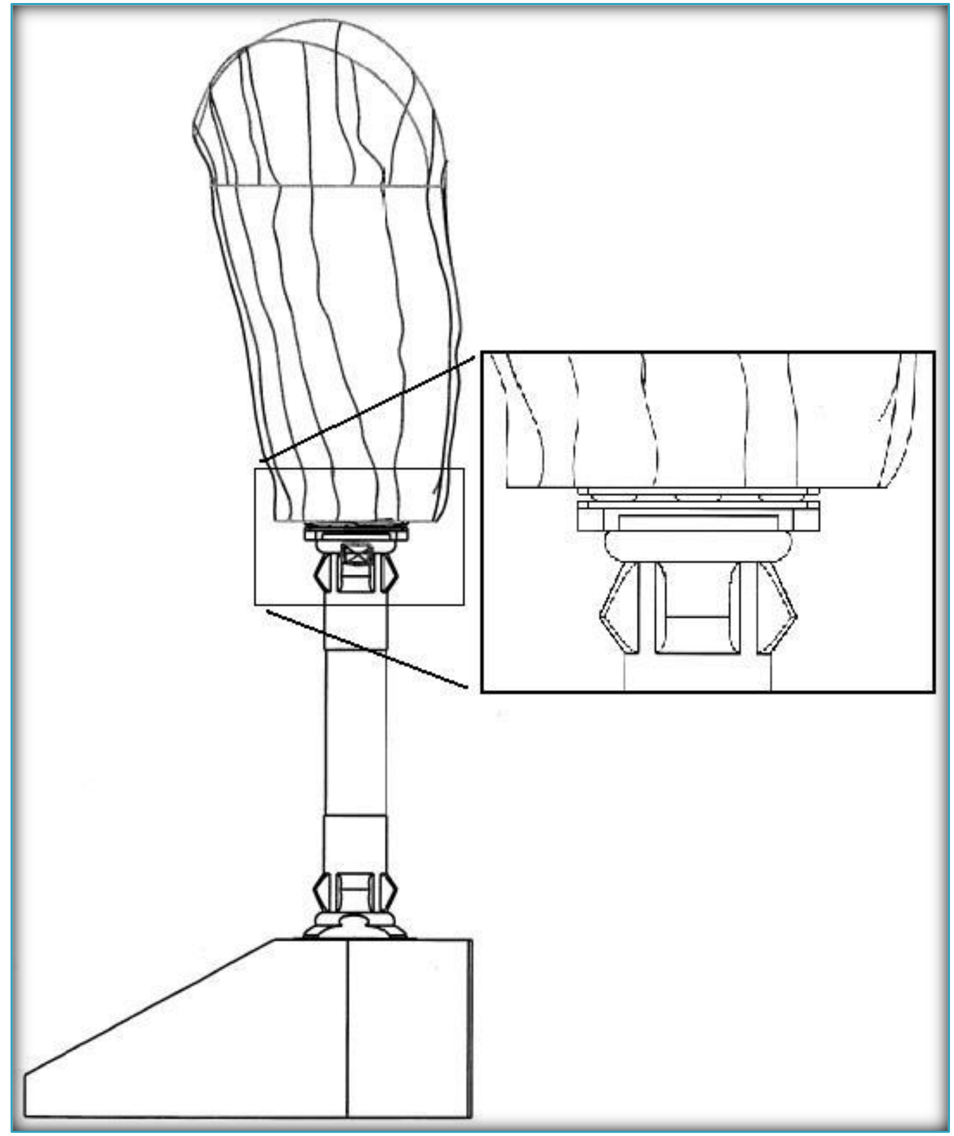
Top portion of force sensor system



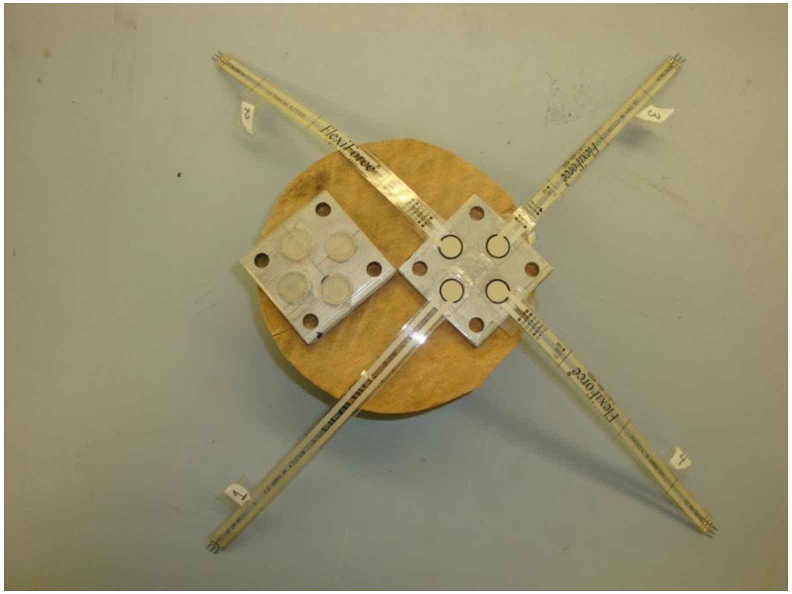
Bottom portion of force sensor system

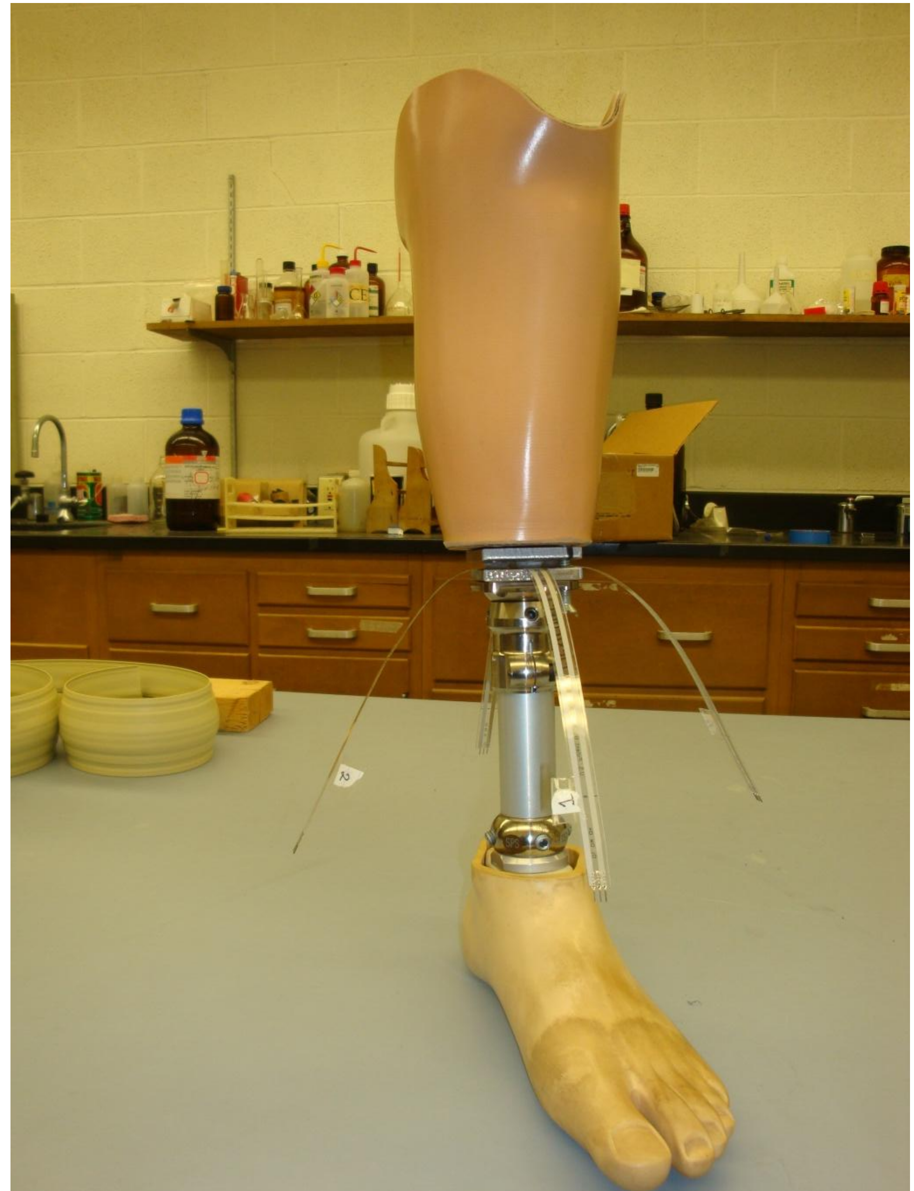
Placement of force sensor system





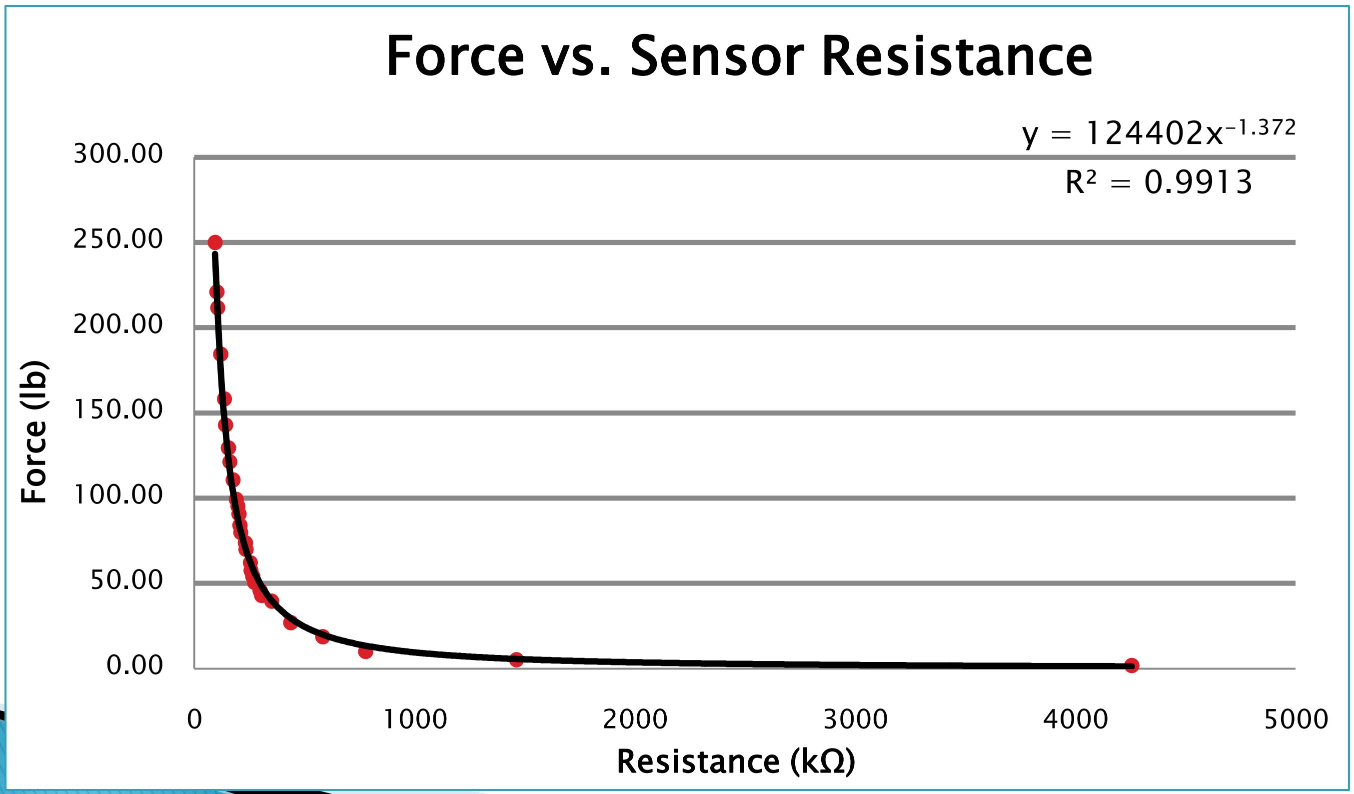
Force Sensor System Prototype





Calibration

- Calibrating Tekscan sensors for use
  - Use Instron to apply known force
  - Record resistance measurement
  - Use excel to find correlation curve equation



Data Output System

- **Inputs:** Resistance measurements of sensors
  - Unloaded (no weight)
  - Loaded (patient standing)

- **Outputs:** Forces & suggestions
  - Forces in each sensor
  - Force distribution (% of total on each sensor)
  - Suggested alignment changes for the prosthetist

Data Output System

Data Output System

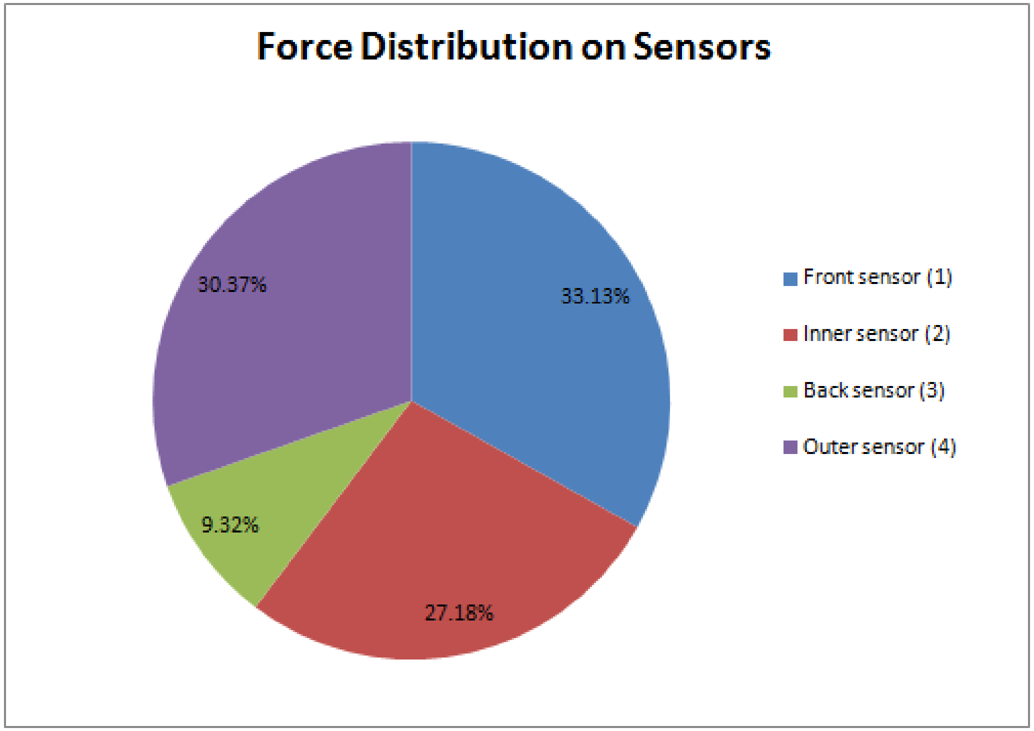
For use during Static Alignment and utlizing the GAIT designed Force Sensing Module to find the Force Distribution

USER INPUTS REQUIRED IN HIGHLIGHTED CELLS

Resistance measurement:	Unloaded (Input Required)	Loaded (Input Required)
Front sensor (1):	500000 kΩ	235 kΩ
Inner sensor (2):	15000 kΩ	204 kΩ
Back sensor (3):	8000 kΩ	228 kΩ
Outer sensor (4):	9800 kΩ	174 kΩ

MEASURED FORCES ON SENSORS AND OVERALL DISTRIBUTION

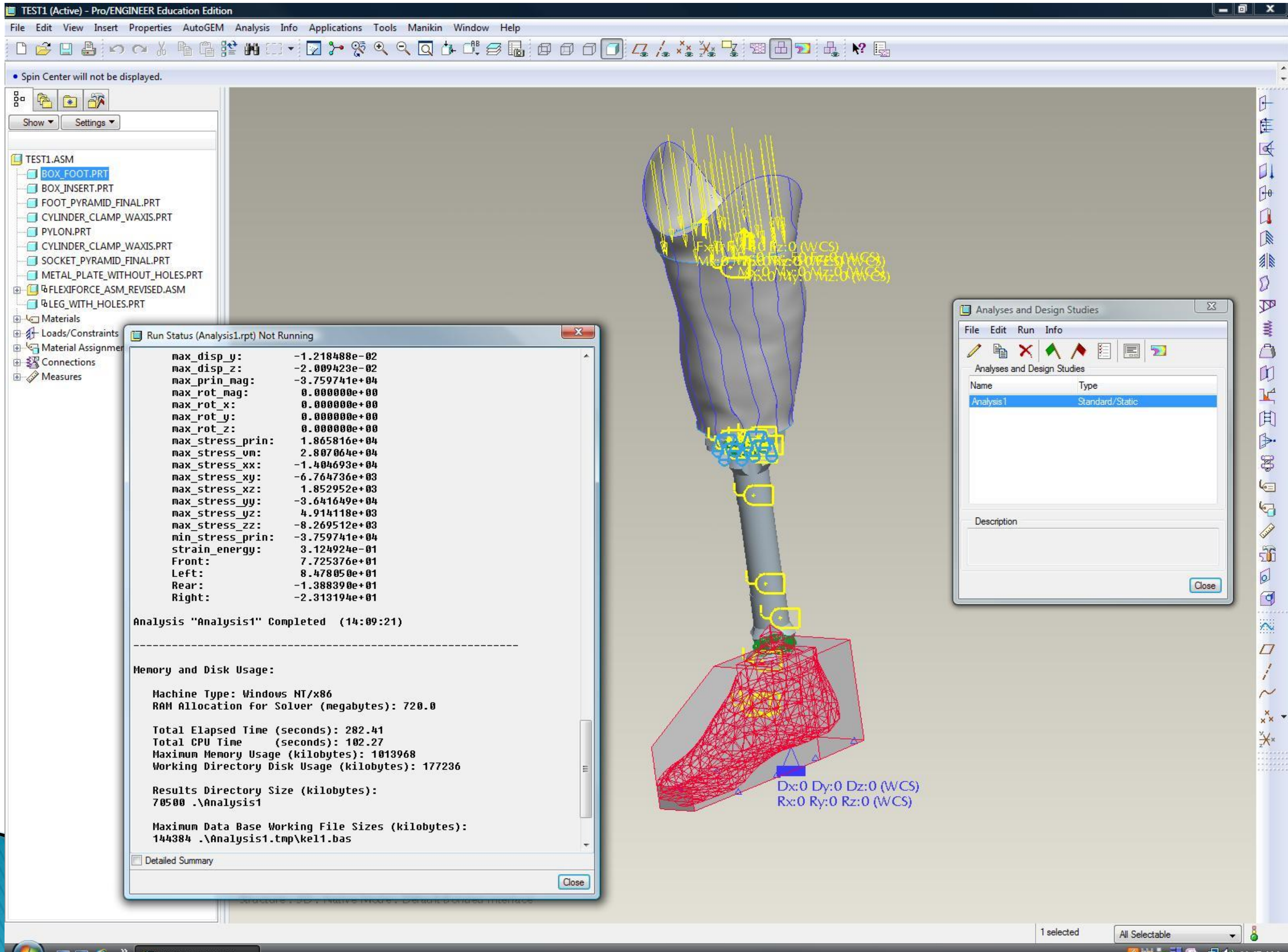
Calculated force on:	Measured Force	% of Total Weight
Front sensor (1)	37.587 lbs	33.13%
Inner sensor (2)	30.831 lbs	27.18%
Back sensor (3)	10.579 lbs	9.32%
Outer sensor (4)	34.455 lbs	30.37%
TOTAL FORCE MEASURED	113.451 lbs	100.00%



SUGGESTIONS FOR ALIGNMENT CHANGES TO IMPROVE FORCE DISTRIBUTION

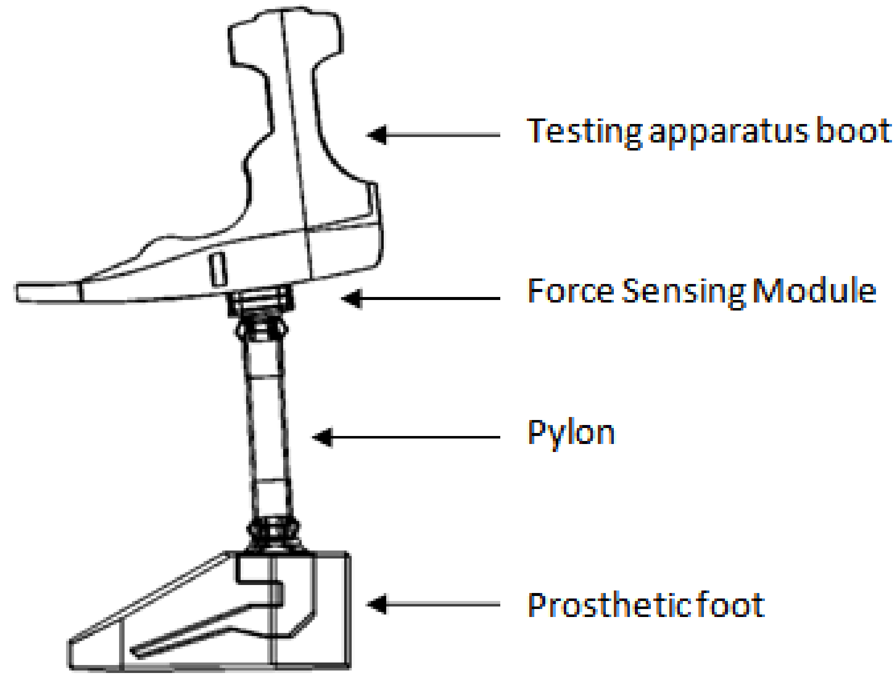
IF Desired Force Distribution Change is:	THEN Change Alignment by:
Increase force on Front sensor	Flex the socket
Increase force on Back sensor	Extend the socket
Increase force on Outer sensor	Adduct the socket
Increase force on Inner sensor	Abduct the socket

Computer Simulation



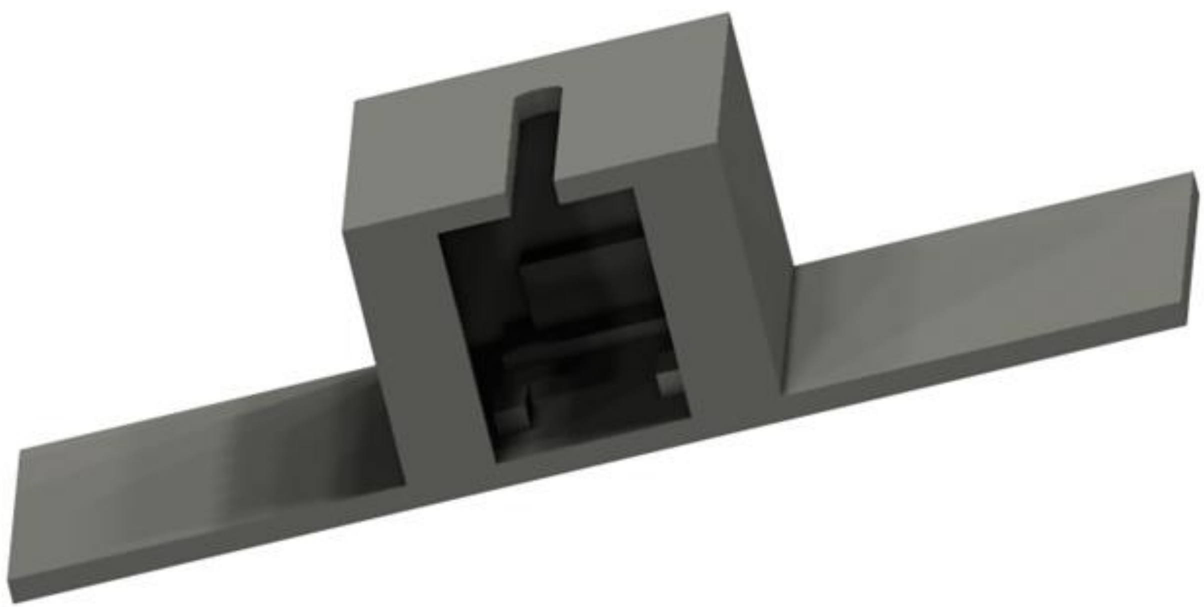
Sensitivity Tests

- Sensitivity tests ensured our sensors were measuring consistent values over a given period of time
- The boot apparatus allows for the movement of the patient when testing

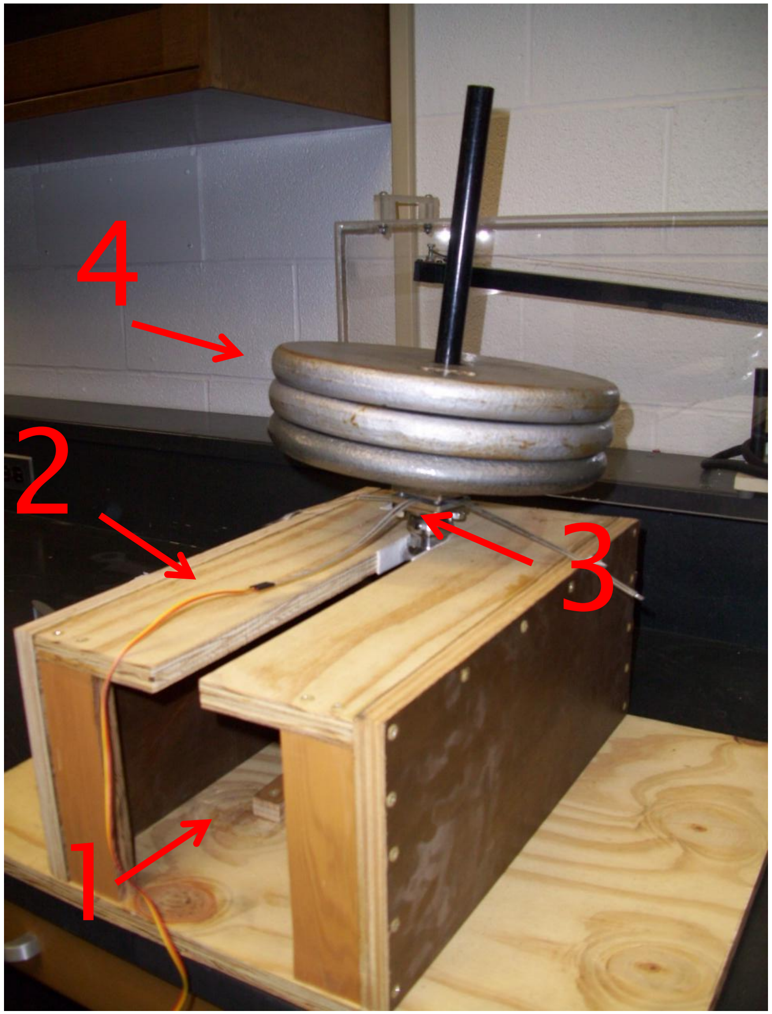


Test Apparatus

- Boot testing apparatus not used for actual testing
- Actual testing apparatus minimizes extraneous variables



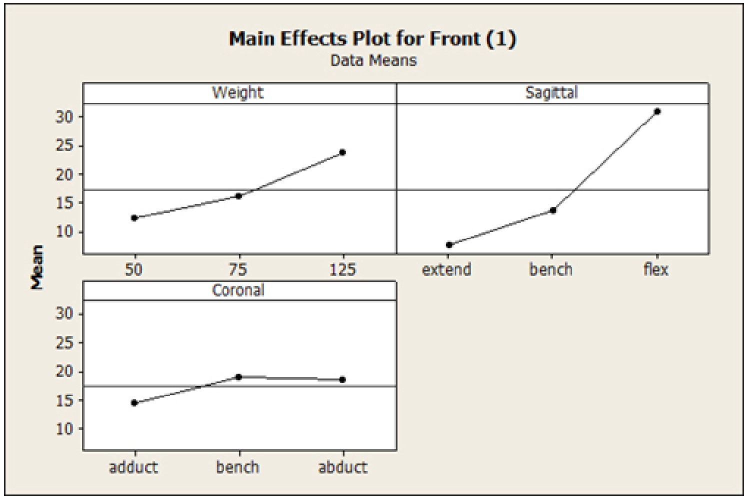
Physical Testing



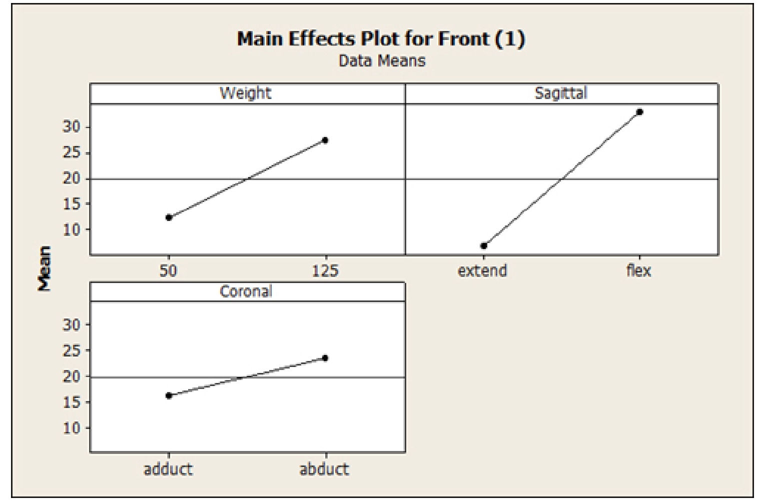
Factorial Design of Experiments: Test Matrix

Test Number	Patient Weight (Load in lb)	Sagittal Plane (front to back) Socket alignment	Coronal Plane (side to side) Socket alignment
1	50	extend (one turn)	adduct (one turn)
2	50	extend (one turn)	bench
3	50	extend (one turn)	abduct (one turn)
4	50	bench	adduct (one turn)
5	50	bench	bench
6	50	bench	abduct (one turn)
7	50	flex (one turn)	adduct (one turn)
8	50	flex (one turn)	bench
9	50	flex (one turn)	abduct (one turn)
10	75	extend (one turn)	adduct (one turn)
11	75	extend (one turn)	bench
12	75	extend (one turn)	abduct (one turn)
13	75	bench	adduct (one turn)
14	75	bench	bench
15	75	bench	abduct (one turn)
16	75	flex (one turn)	adduct (one turn)
17	75	flex (one turn)	bench
18	75	flex (one turn)	abduct (one turn)
19	125	extend (one turn)	adduct (one turn)
20	125	extend (one turn)	bench
21	125	extend (one turn)	abduct (one turn)
22	125	bench	adduct (one turn)
23	125	bench	bench
24	125	bench	abduct (one turn)
25	125	flex (one turn)	adduct (one turn)
26	125	flex (one turn)	bench
27	125	flex (one turn)	abduct (one turn)

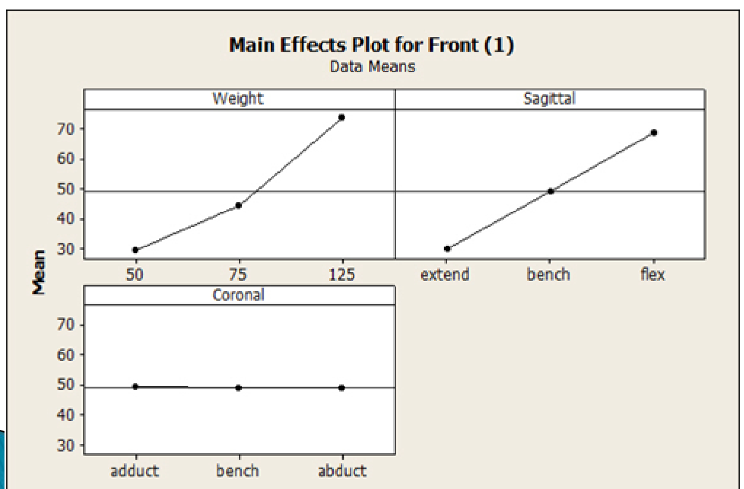
Results: Front Sensor (1)



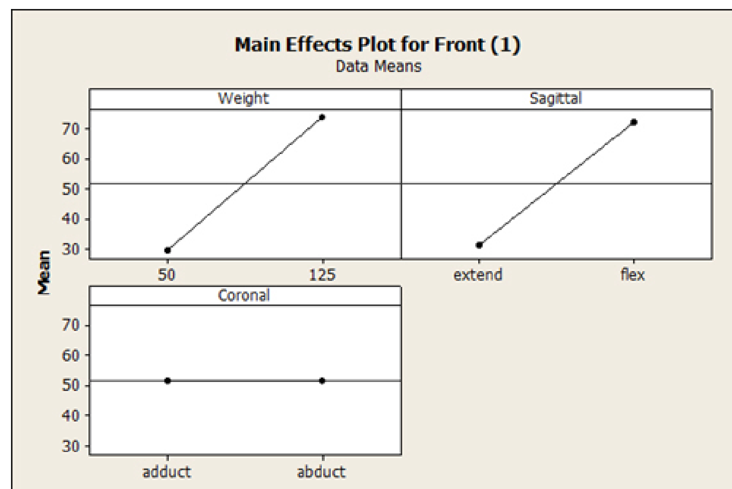
Physical Test with Bench



Physical Test without Bench



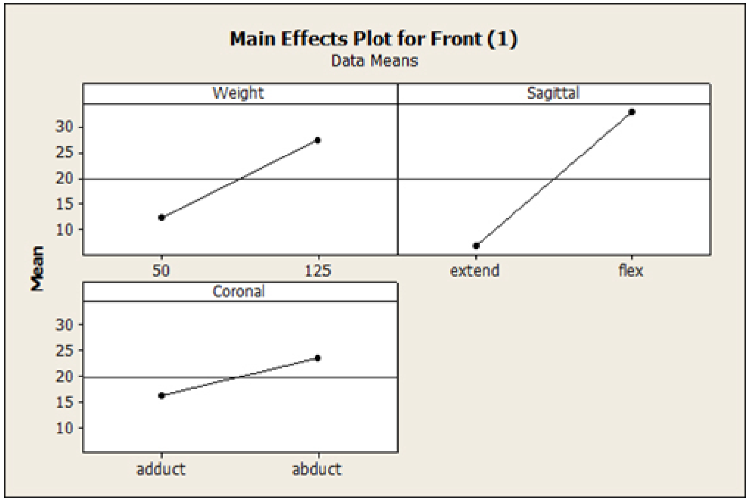
ProMechanica Test Data with Bench



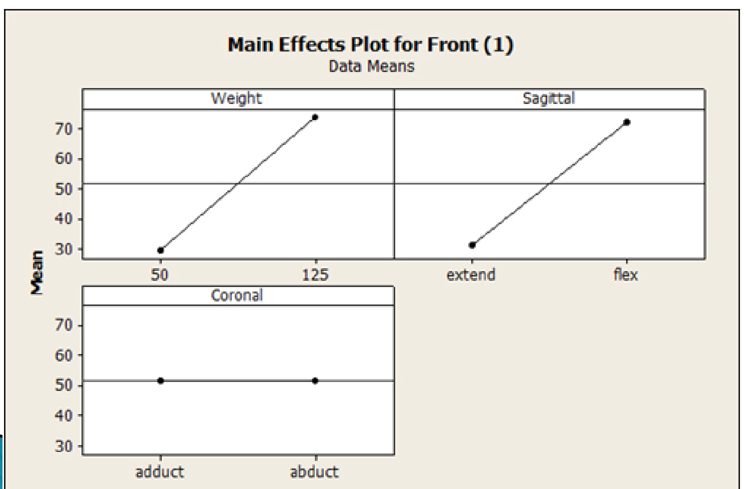
ProMechanica Test Data without Bench

Results: Front vs. Back

Front Sensor

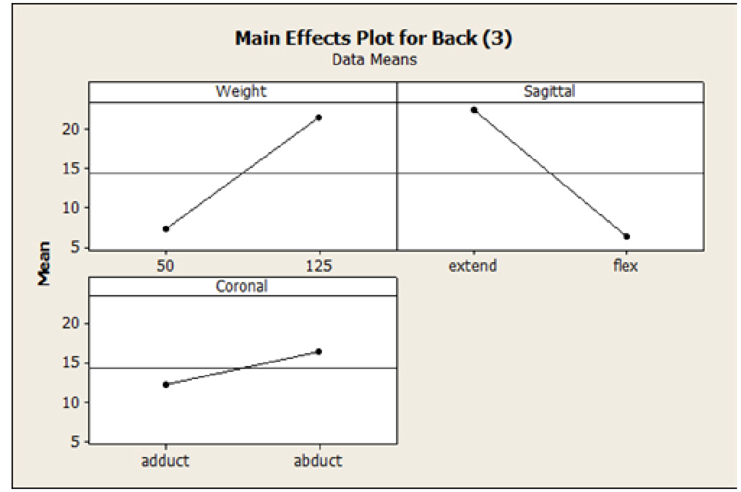


Physical Test

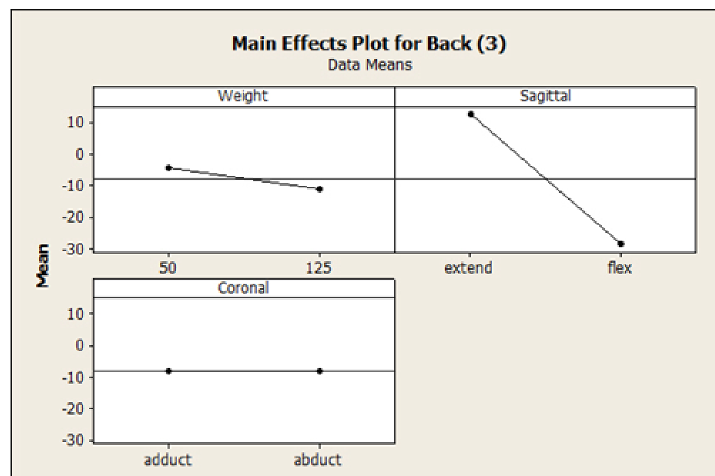


ProMechanica Test

Back Sensor



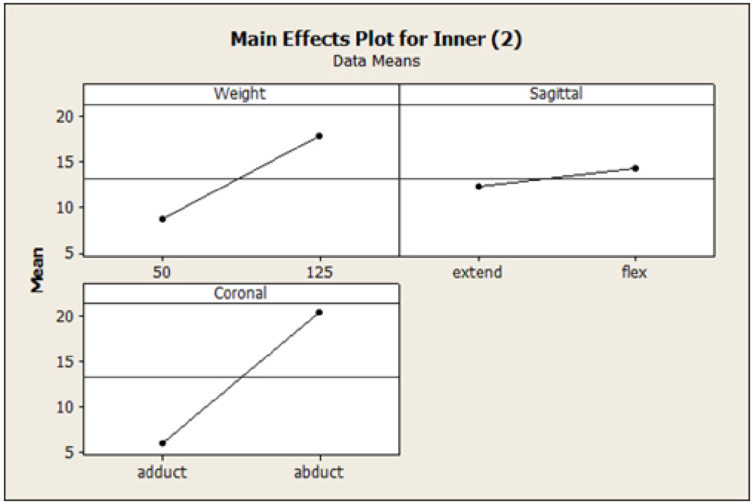
Physical Test



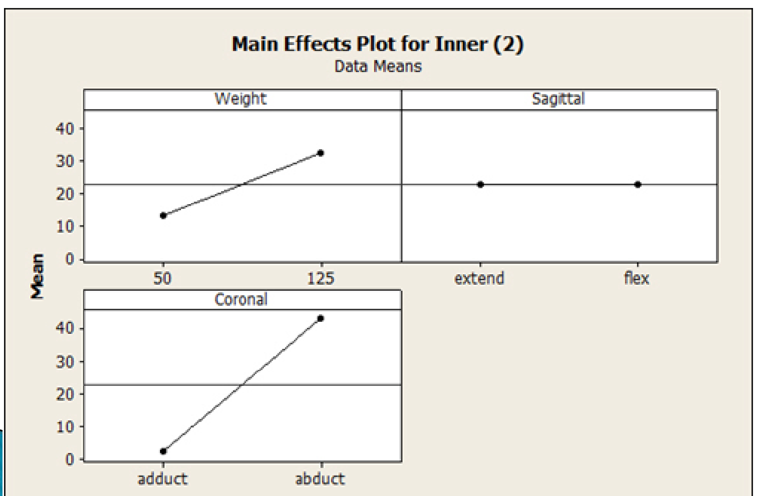
ProMechanica Test

Results: Inner vs. Outer

Inner Sensor

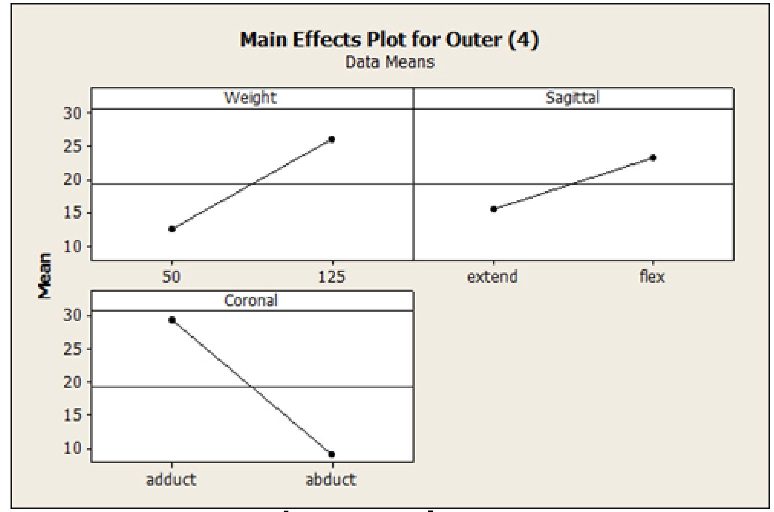


Physical Test

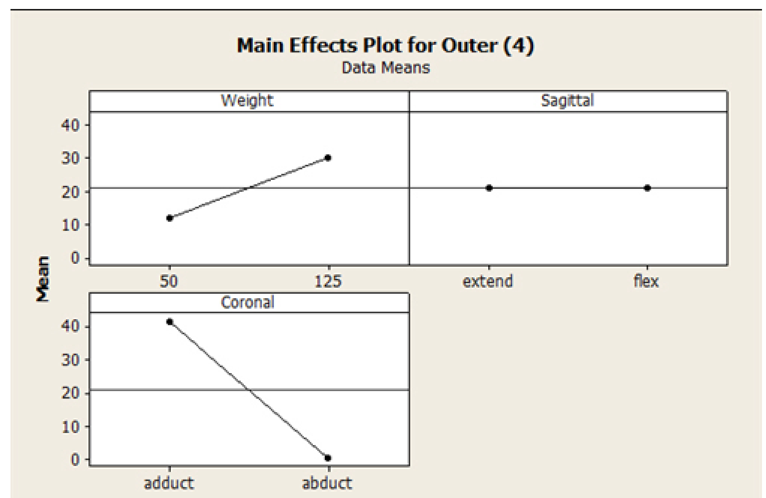


ProMechanica Test

Outer Sensor



Physical Test



ProMechanica Test

Minitab Results

- General Prediction Equation

$$Force = c_0 + c_1 * Weight + c_2 * Sagittal + c_3 * Coronal + c_4 * Weight * Sagittal + c_5 * Weight * Coronal + c_6 * Sagittal * Coronal + c_7 * Weight * Sagittal * Coronal$$

- Prediction Equations in Reduced Form

$$F_{sagittal\,sensor} = c_0 + c_1 * Weight + c_2 * Sagittal + c_3 * Weight * Sagittal$$

$$F_{coronal\,sensor} = c_0 + c_1 * Weight + c_2 * Coronal + c_3 * Weight * Coronal$$

Example of Minitab Analysis

Estimated Effects and Coefficients for Inner (2) (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		13.2407	0.5181	25.56	0.000
Weight	9.0744	4.5372	0.5181	8.76	0.000
Sagittal	2.0659	1.0329	0.5181	1.99	0.081
Coronal	14.4654	7.2327	0.5181	13.96	0.000
Weight*Sagittal	0.6409	0.3204	0.5181	0.62	0.553
Weight*Coronal	10.6734	5.3367	0.5181	10.30	0.000
Sagittal*Coronal	1.7174	0.8587	0.5181	1.66	0.136
Weight*Sagittal*Coronal	1.0804	0.5402	0.5181	1.04	0.328

S = 2.07244 PRESS = 137.441
R-Sq = 97.97% R-Sq(pred) = 91.88% R-Sq(adj) = 96.19%

Analysis of Variance for Inner (2) (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	1183.44	1183.44	394.479	91.85	0.000
2-Way Interactions	3	469.12	469.12	156.375	36.41	0.000
3-Way Interactions	1	4.67	4.67	4.669	1.09	0.328
Residual Error	8	34.36	34.36	4.295		
Pure Error	8	34.36	34.36	4.295		
Total	15	1691.59				

Estimated Coefficients for Inner (2) using data in uncoded units

Term	Coef
Constant	2.65392
Weight	0.120992
Sagittal	0.28525
Coronal	-5.21958
Weight*Sagittal	0.0085450
Weight*Coronal	0.142312
Sagittal*Coronal	-0.40175
Weight*Sagittal*Coronal	0.0144050

Evaluation – Meeting Constraints

- Economic Constraints
  - Departmental budget of $1200
    - $834 remaining
  - Cost effective alternative to computerized gait analysis
    - Below suggested maximum of $150 for the limited use components (force sensing module is ~$72
    - Well below suggested maximum of $500 for long term use (complete system is ~$200 including multimeter)
- Health and Safety Constraints
  - Did not have any safety issues arise during testing, including testing with the boot in place of the socket

Evaluation – Meeting Objectives

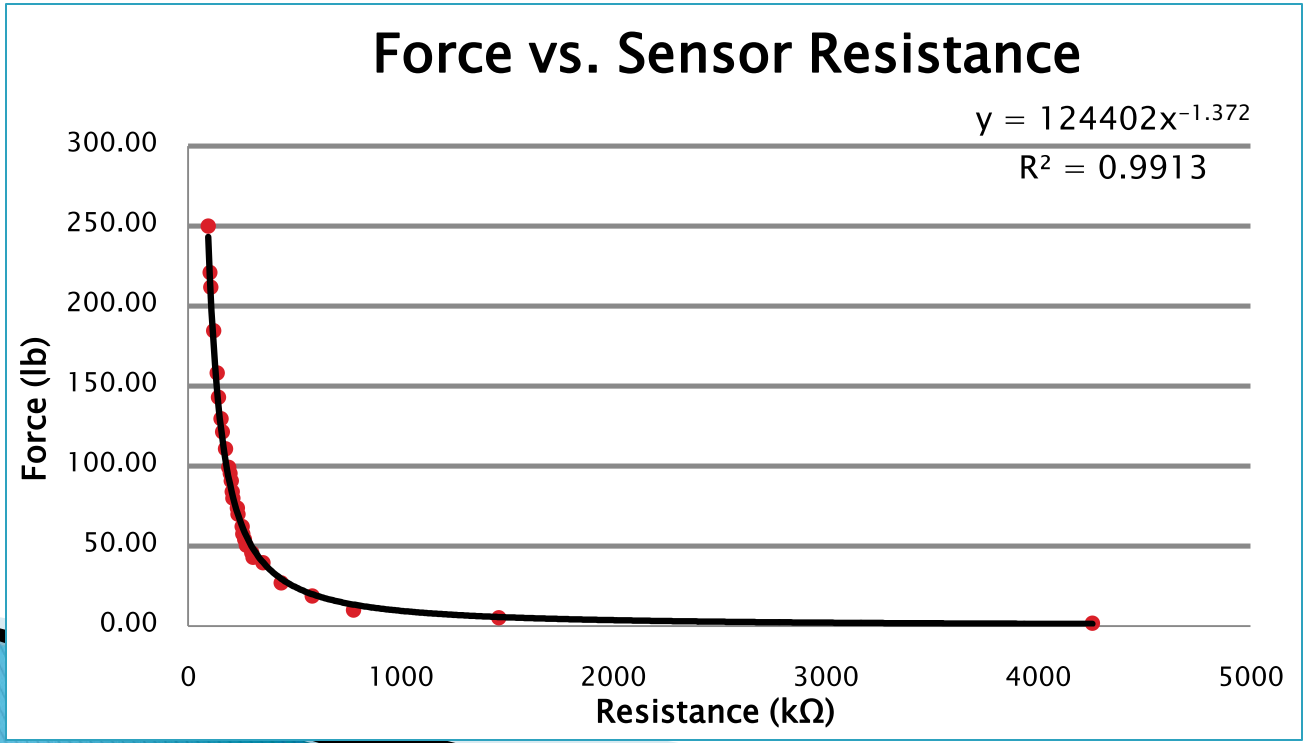
1. Design and develop a prototype device to provide quantitative measurements of the force distribution during a static alignment procedure
2. Make clinically relevant recommendations for alignment changes to improve the force distribution for the amputee
3. Use a computer simulation to model the physical system
4. Our procedure should be more scientific than observational gait analysis and more cost effective than computerized gait analysis

Evaluation – Issues

- Sensor quality was inadequate
- Initial testing procedures included too many extraneous variables
- Time constraint on conducting tests reduced accuracy of the prediction equations generated in Minitab

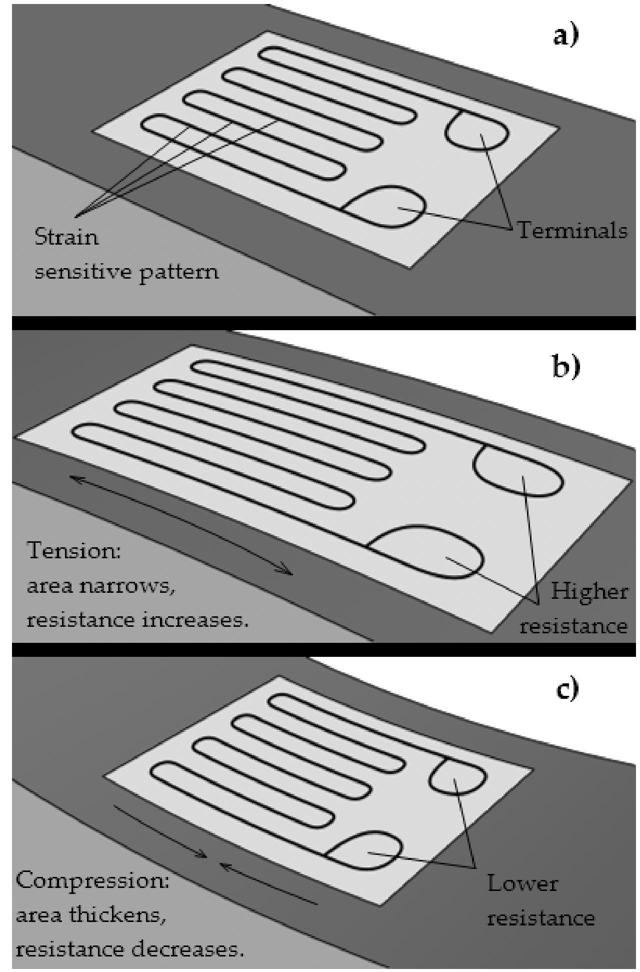
Conclusions & Recommendations

- Room for improvement
  1. FlexiForce sensors did not provide optimal performance
  2. Ability to predict specific quantitative trends
  3. Employment of computer model



Conclusions & Recommendations

- More accurate sensors
- More test replications
- Cross validate data with computer model



http://www.calex.com/images/cis551.jpg
http://en.wikipedia.org/wiki/File:StrainGaugeVisualization.png

A BIG Thank You to…

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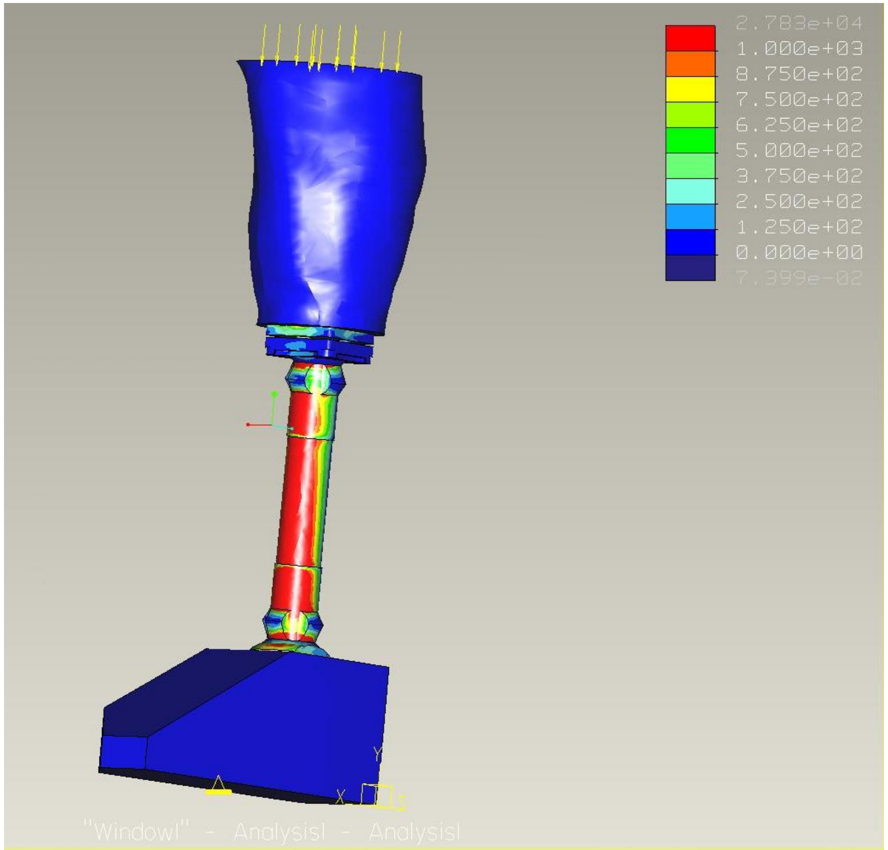

Any Questions?

Boot Testing