Pressure Insole for Gait and Balance Estimation

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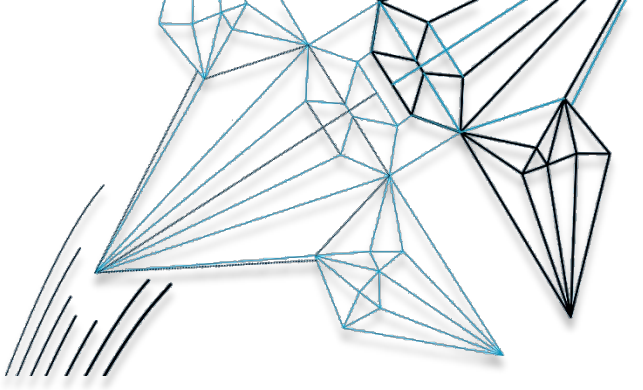


NeuroCIMT project #7

- Stroke subjects
- develop and evaluate an **on-body sensing** system
- Remote monitoring of motor function - lower extremities
- Activities of daily life

Contents

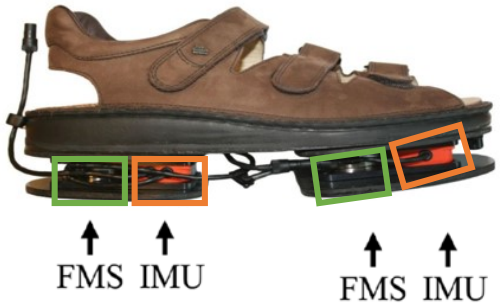
- Existing Technology on ambulatory estimation of Gait and Balance
- An Alternative - Pressure Insoles
- Experimental Study
- Results
- Reflection
- Further Steps

Existing Technology

Weenk et al, 2014

van Meulen et al, 2016

Veltink et al, 2005



Foot Positions

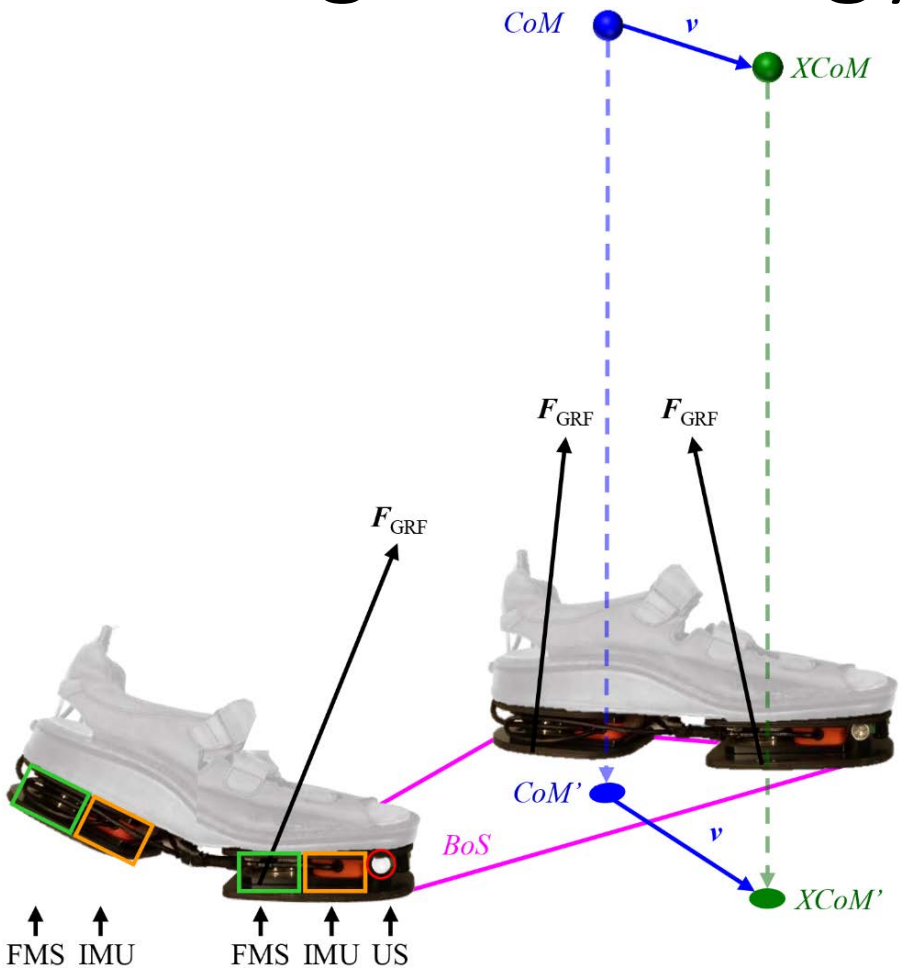
CoP/CoM

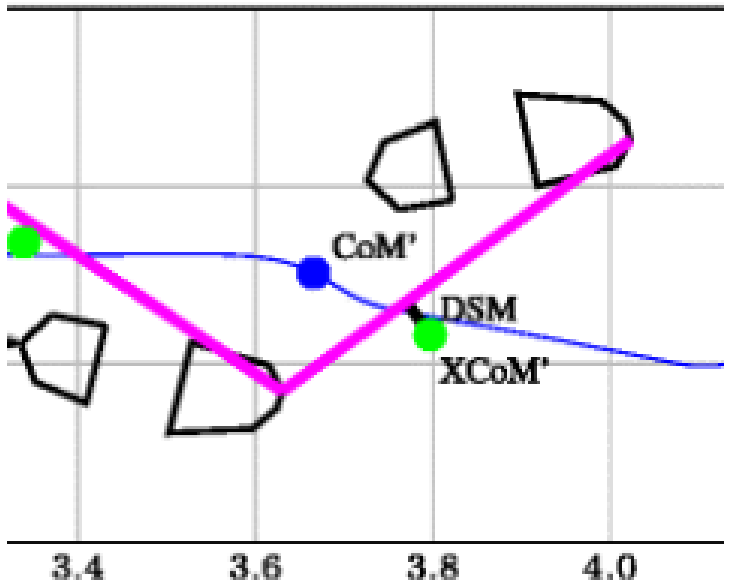
XCoM

Dynamic Stability Margin

Schepers et al, 2009

Existing Technology





- Stability during walking
- Healthy – Positive DSM
- Lower BBS - Negative DSM
- Information about compensatory mechanisms

van Meulen et al, 2016

Disadvantages of ForceShoes

- Heavy
- Conspicuous
- Possible Discomfort

Alternative - Pressure Insoles

- Lightweight, Inconspicuous
- 1D Plantar pressure

Gaps?

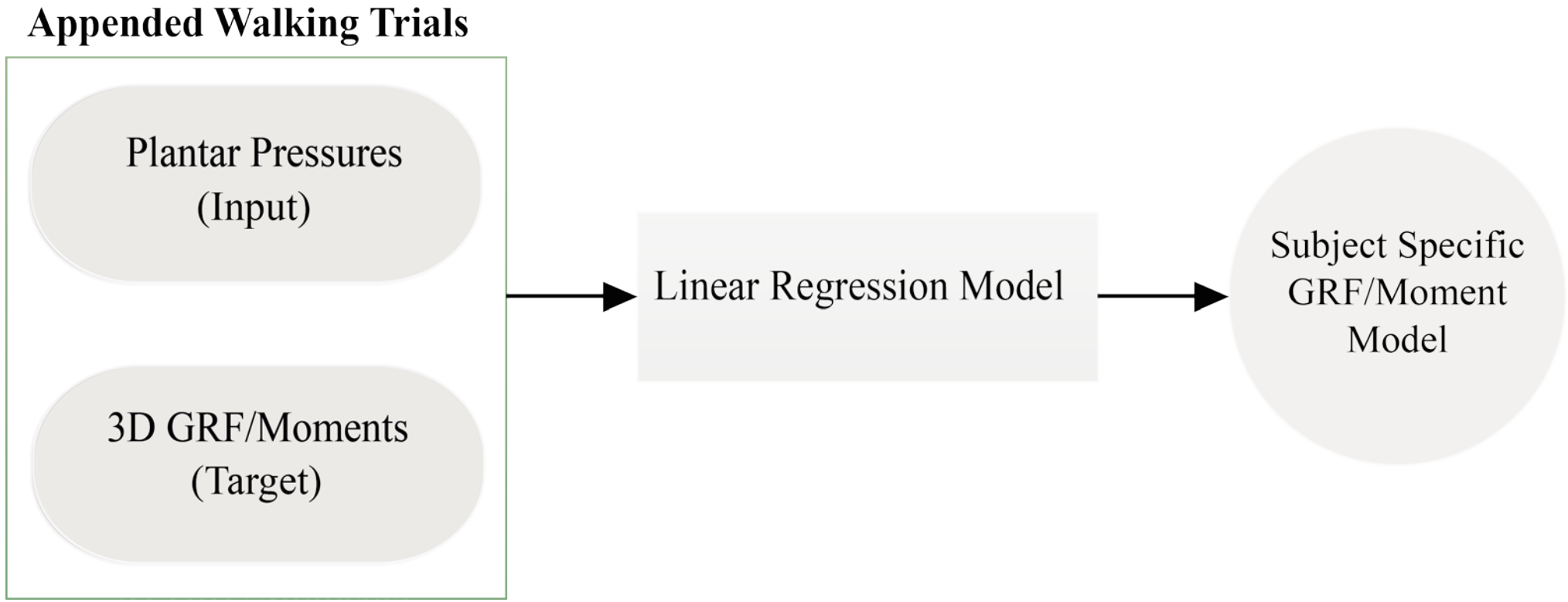
- Require 3D Forces/Moments
  - XCoM and DSM
- 1D Pressure information from Pressure Insole

Regression Modelling?

Experimental Study

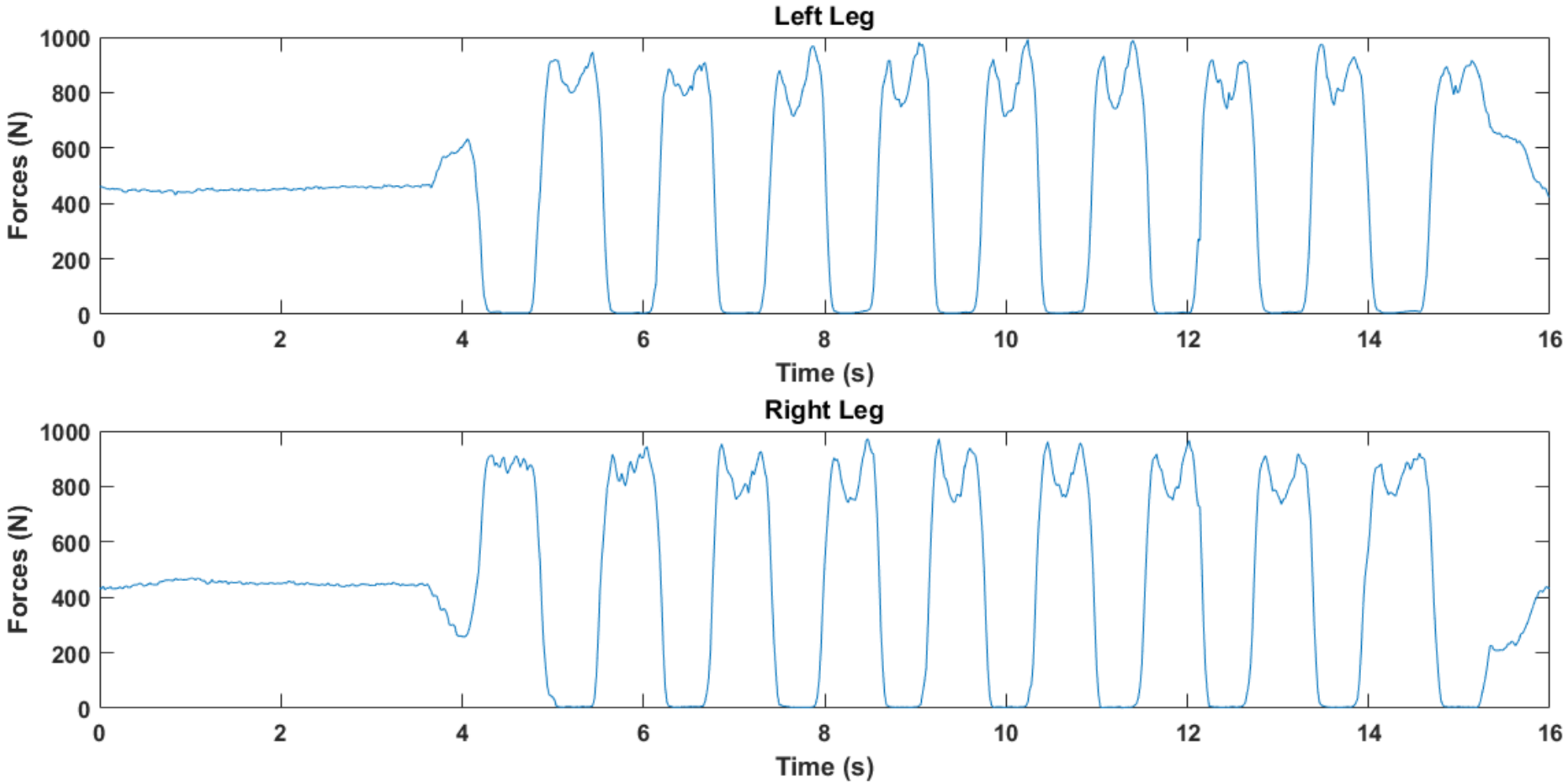
- 10 Subjects wore ForceShoes™ along with Pressure Insole
- 10 m Straight line walking
- Preferred Walking speed

Modeling 3D forces and moments from plantar pressure

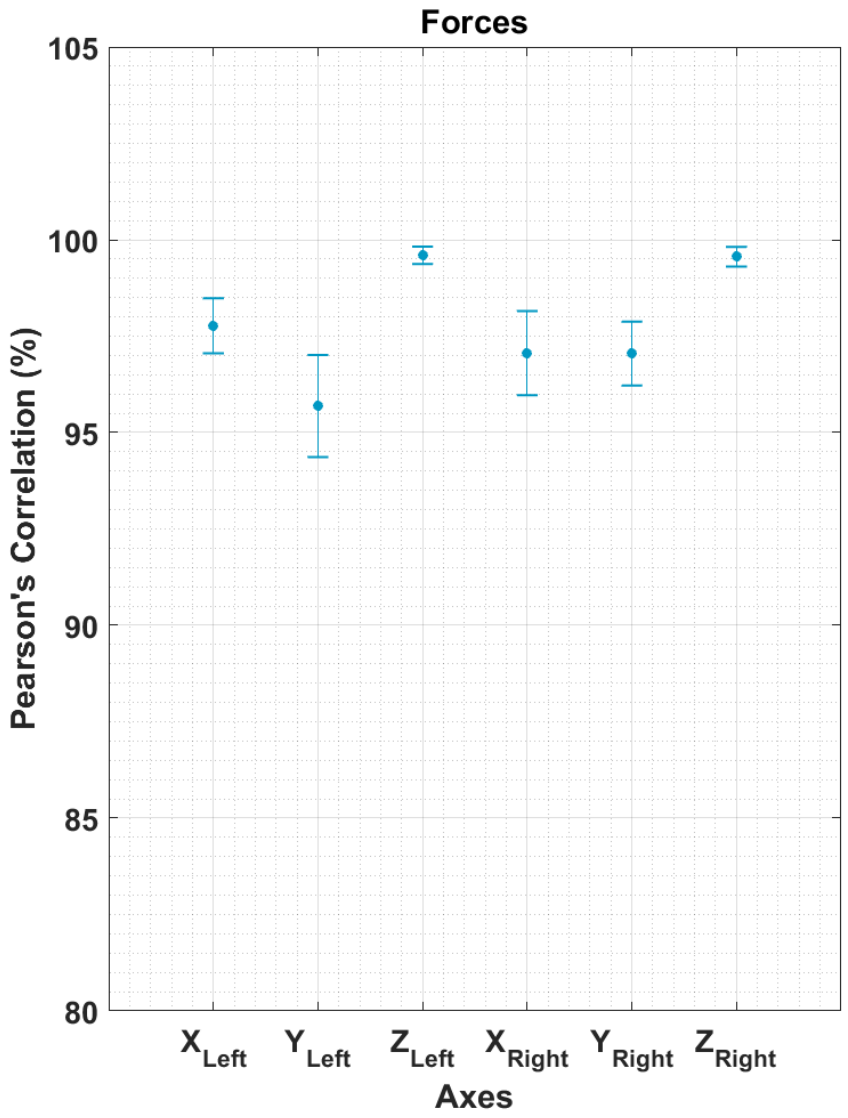


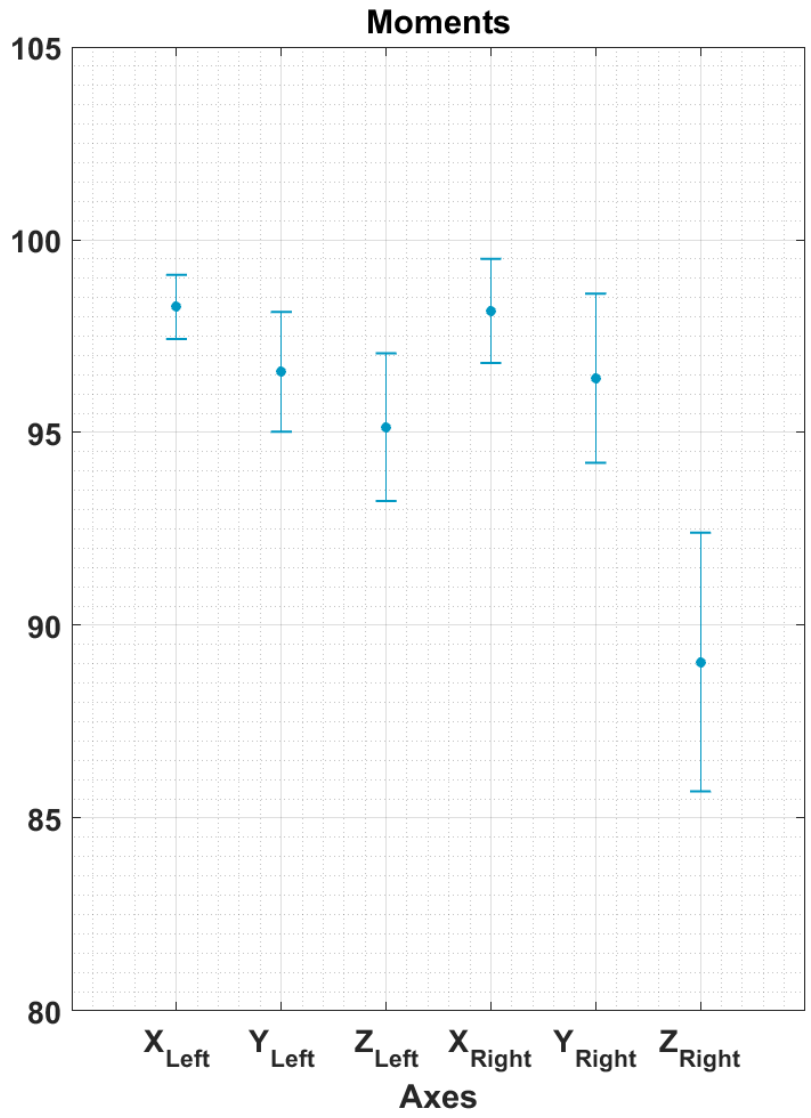
Rouhani et al, 2010

Modeling 3D forces and moments from plantar pressure

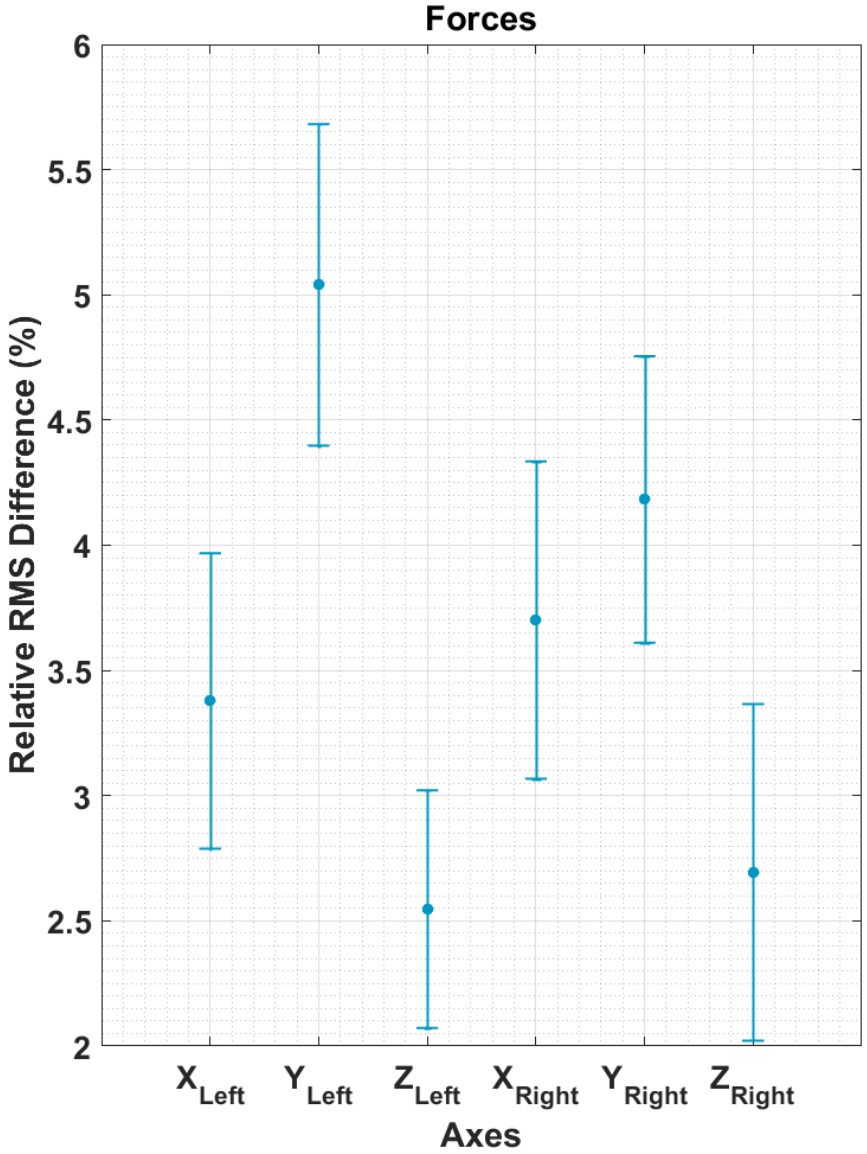


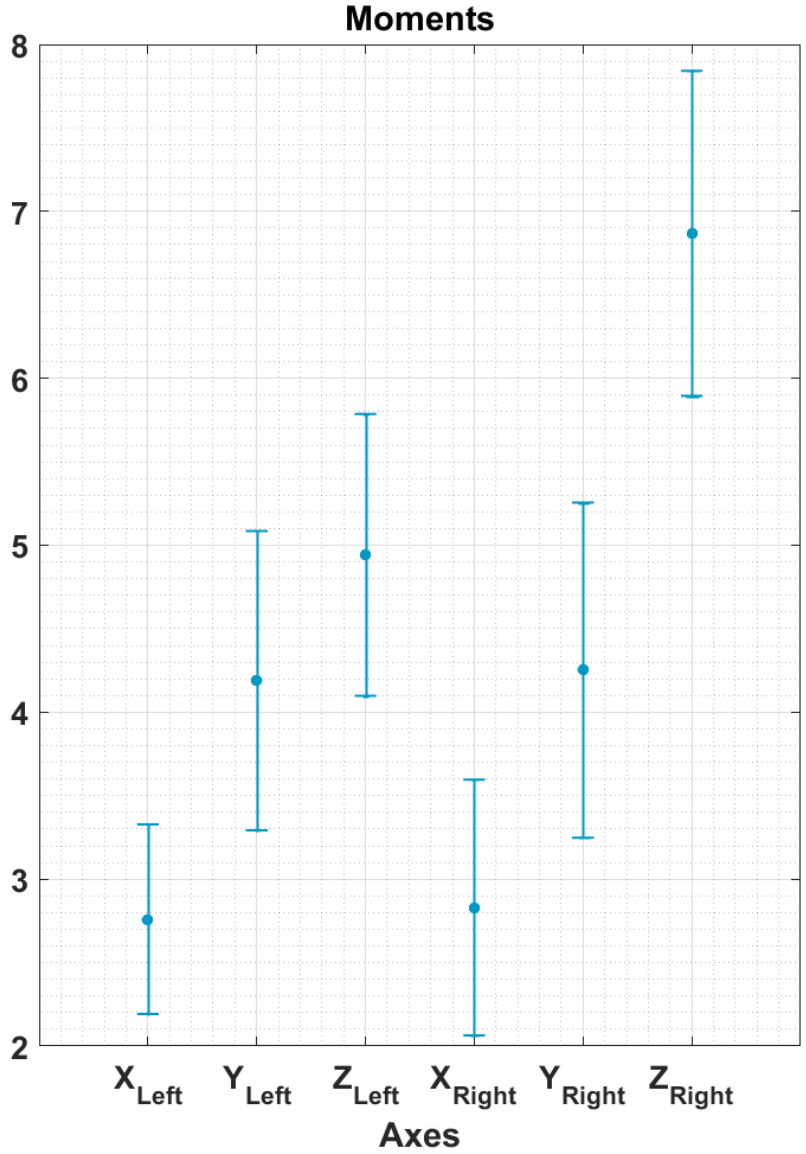
3D Forces and Moments



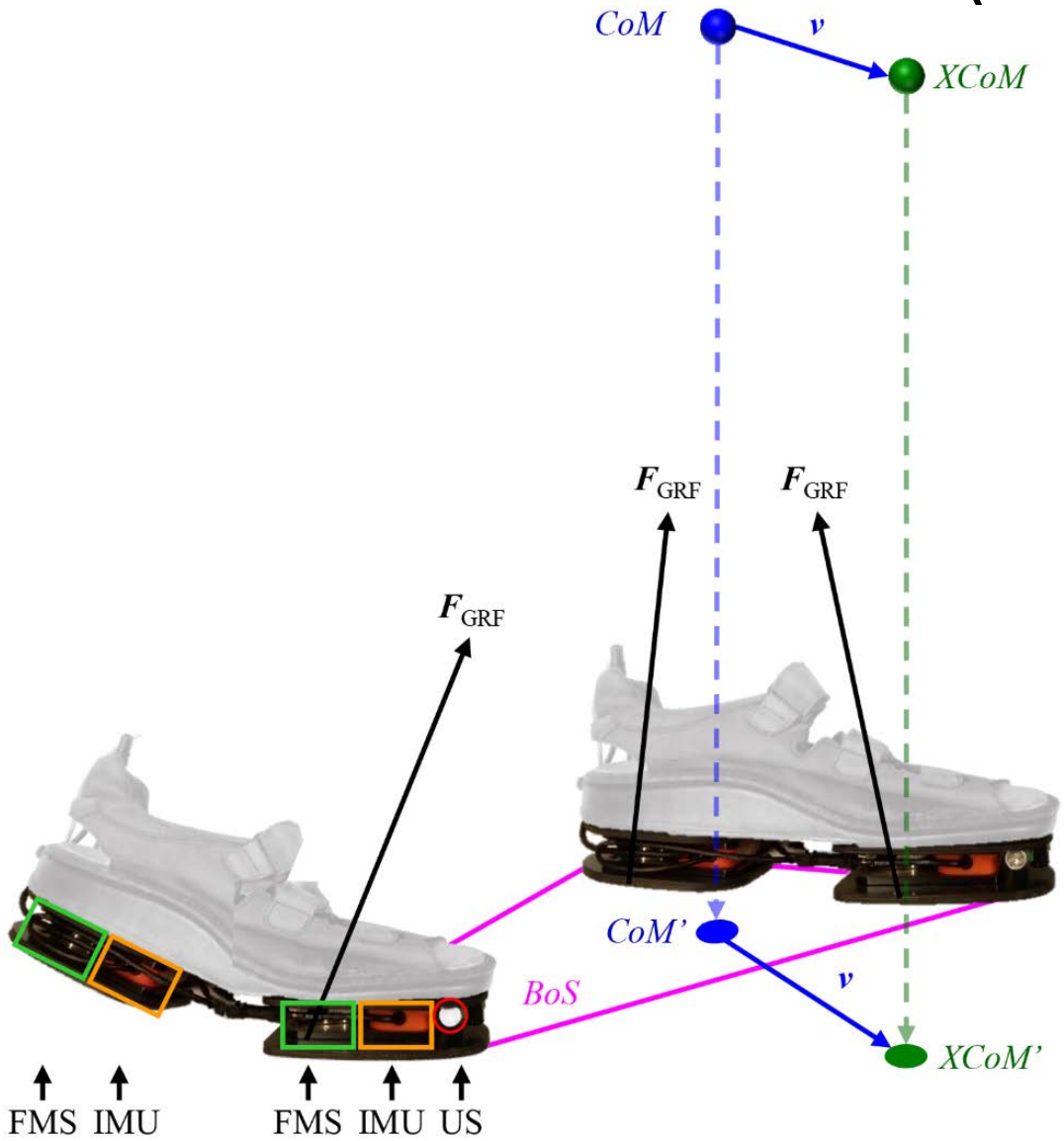


3D Forces and Moments





Extrapolated Center of Mass (XCoM)



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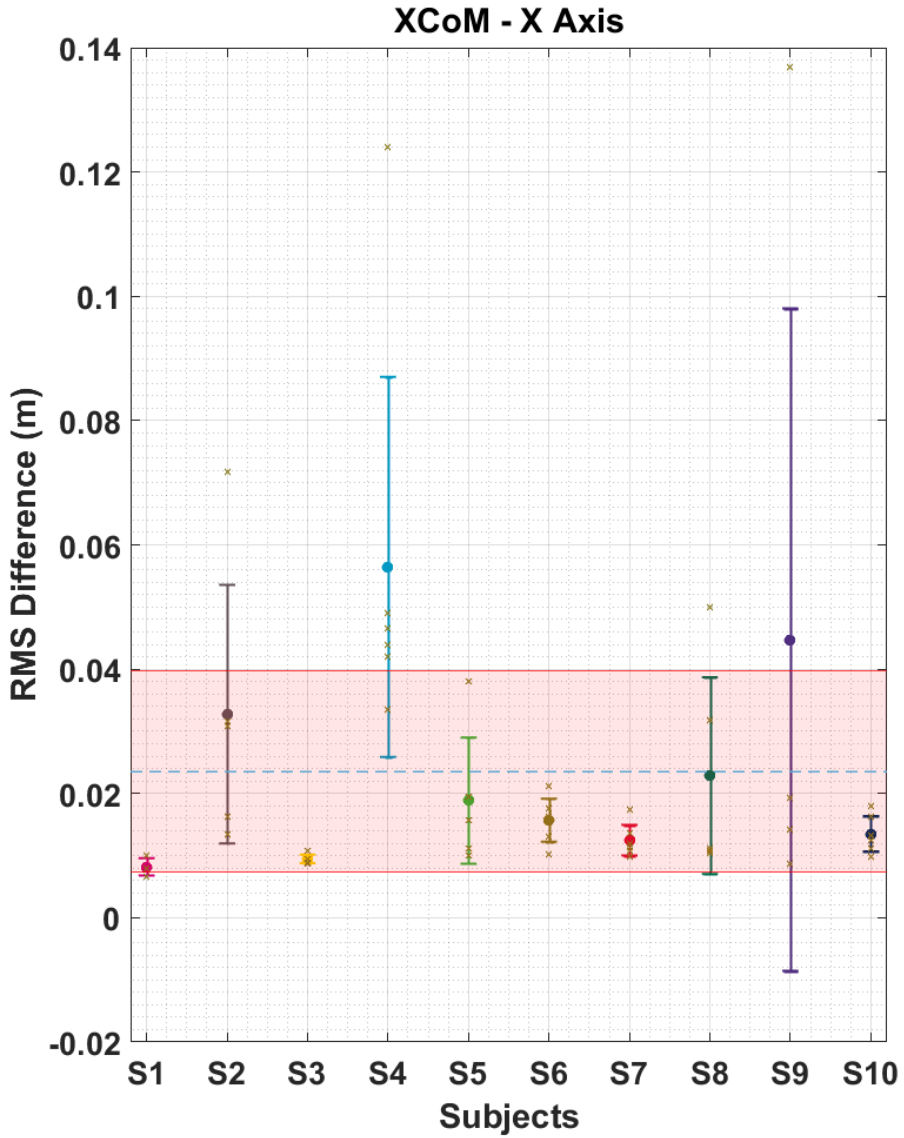

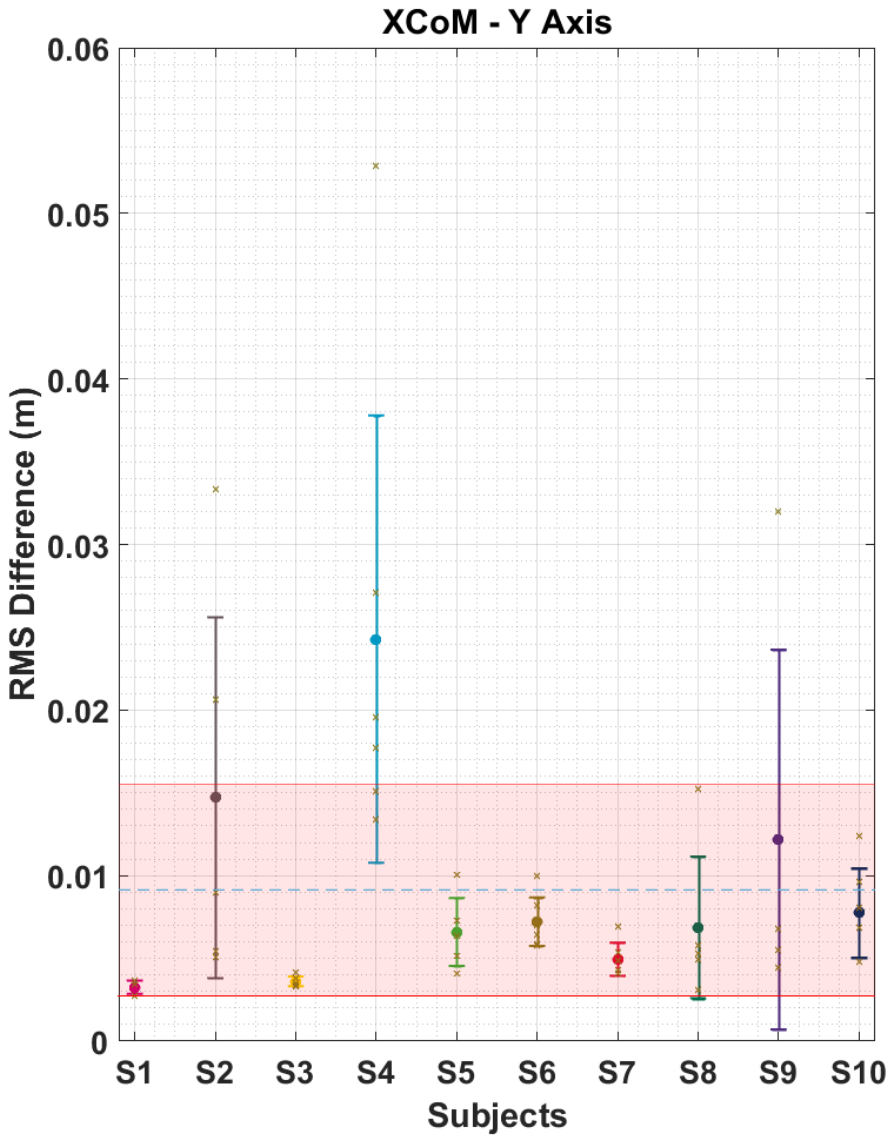

Subject	Walking Speed (m/s)
Subject 1	1.79 ± 0.02
Subject 2	1.51 ± 0.05
Subject 3	1.99 ± 0.05
Subject 4	1.51 ± 0.12
Subject 5	2.33 ± 0.07
Subject 6	1.65 ± 0.08
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Subject 9	2.22 ± 0.15
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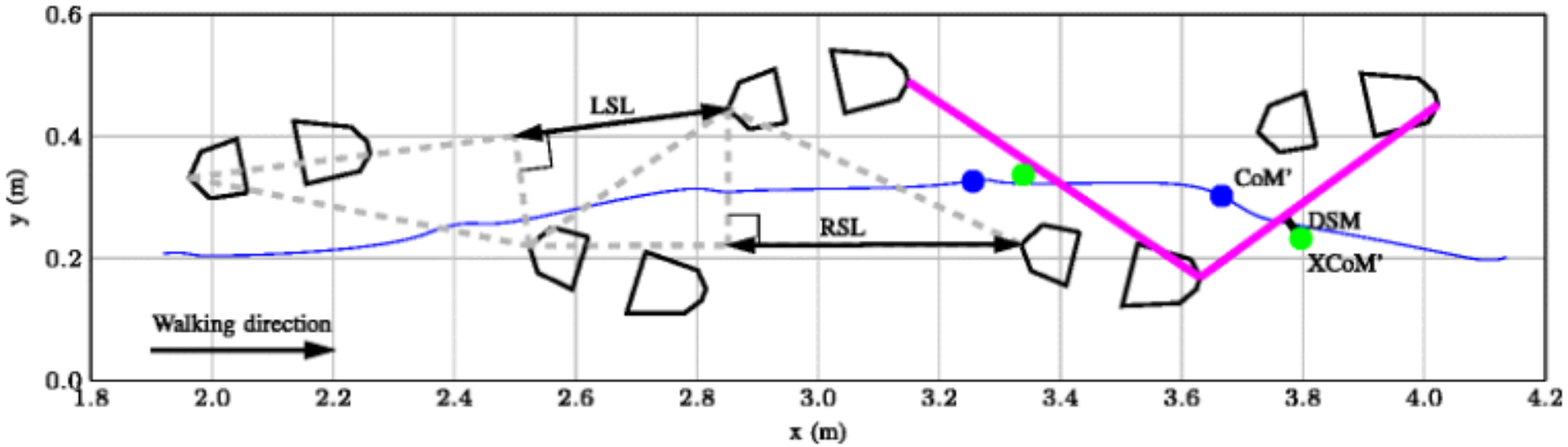
Dynamic Stability Margin



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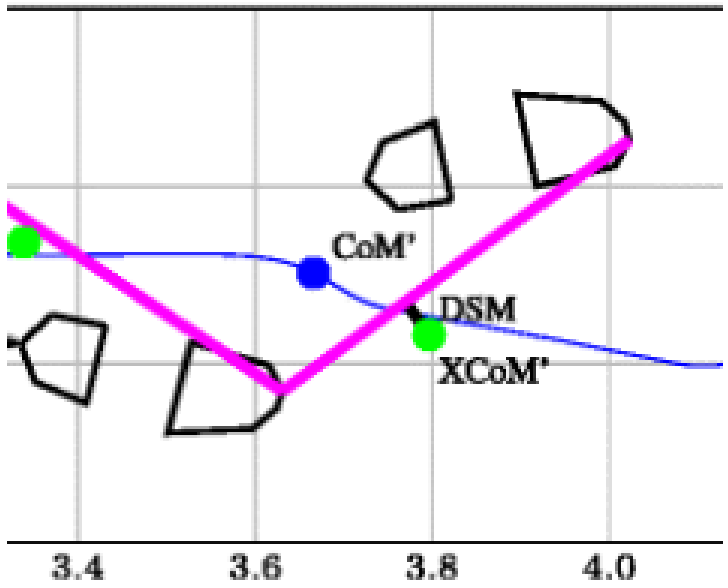

Derivative	Value
Sensitivity (Unstable)	0.95
Specificity (Stable)	0.99
Accuracy	0.98

		Predicted Stability		Total Samples
		Stable	Unstable	
Actual Stability	Stable	14797	140	14937
	Unstable	139	2831	2970

Reflection

- Possible method to replace ForceShoes™
- Lightweight alternative
- High degree of correlation, Low RMS of differences
- High accuracy
- Speed dependent
- Machine Learning?

Further Steps

- Generic Model
- Sensor Reduction
- Standalone Pressure Sensing System
  - Pressure Sensors, IMU, Ultrasound

References

- Veltink, P. H., Liedtke, C., Droog, E., & Van Der Kooij, H. (2005). Ambulatory measurement of ground reaction forces. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *13*(3), 423–427. http://doi.org/10.1109/TNSRE.2005.847359
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- D. Weenk, D. Roetenberg, B.-J. F. van Beijnum, H. Hermens, and P. H. Veltink, "Ambulatory Estimation of Relative Foot Positions by Fusing Ultrasound and Inertial Sensor Data.," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 4320, no. c, pp. 1–10, 2014.
- F. B. van Meulen, D. Weenk, J. H. Buurke, B.-J. F. van Beijnum, and P. H. Veltink, "Ambulatory assessment of walking balance after stroke using instrumented shoes," *J. Neuroeng. Rehabil.*, vol. 13, no. 1, p. 48, 2016.
- Rouhani, H., Favre, J., Crevoisier, X., & Aminian, K. (2010). Gait & Posture Ambulatory assessment of 3D ground reaction force using plantar pressure distribution. *Gait & Posture*, *32*(3), 311–316. http://doi.org/10.1016/j.gaitpost.2010.05.014

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Questions?

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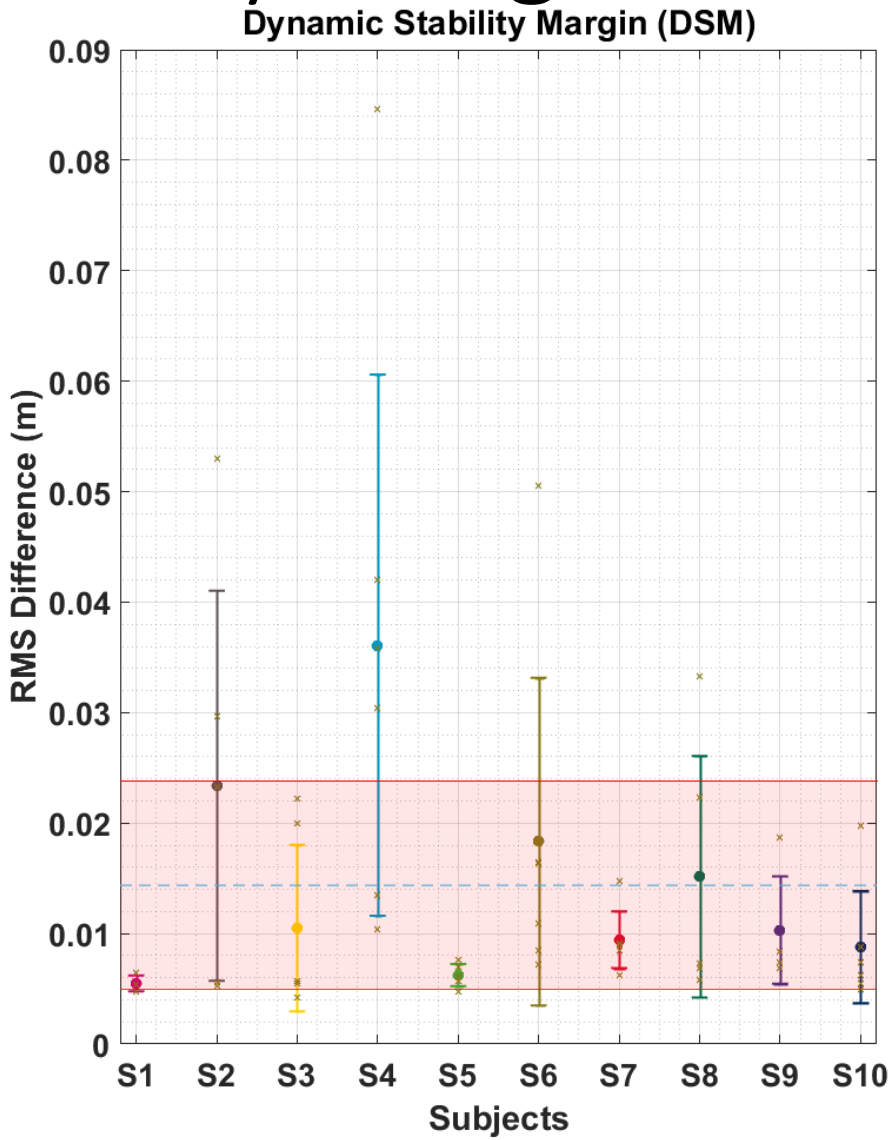
Dynamic Stability Margin



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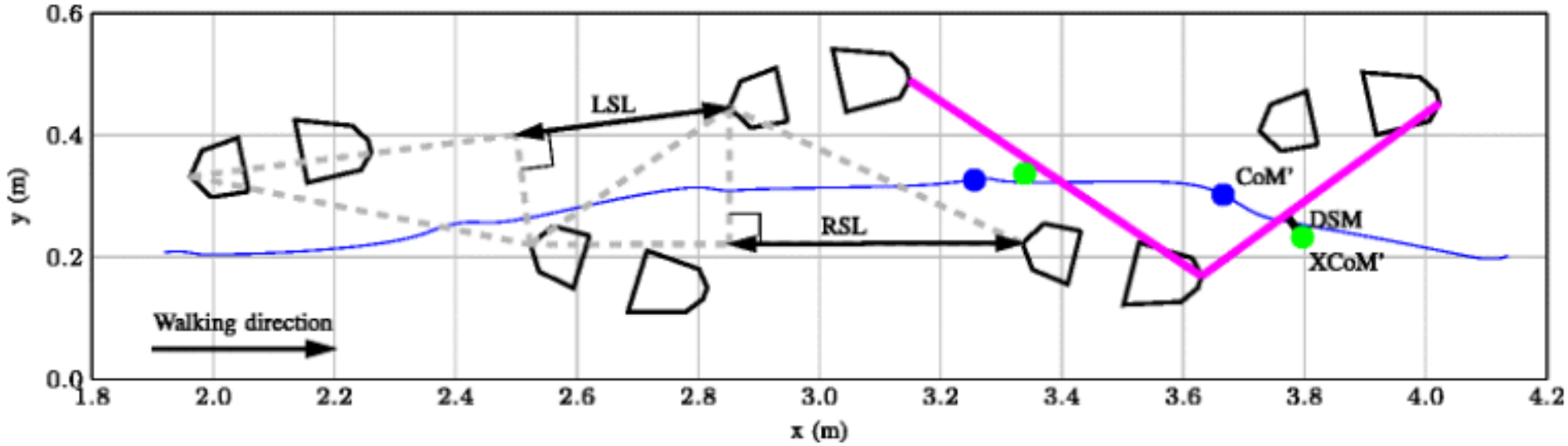
Stable/Unstable?



		Predicted Stability		Total Samples
		Stable	Unstable	
Actual Stability	Stable	14797	140	14937
	Unstable	139	2831	2970

Derivatives of Confusion Matrix

Derivative	Definition	Value
True Positive (TP)	True Instability	2831
True Negative (TN)	True Stability	14797
False Positive (FP)	False Instability	140
False Negative (FN)	False Stability	139
All Positives (P)	Total Instabilities	2970
All Negative (N)	Total Stabilities	14937
Sensitivity	TP/P	0.95
Specificity	TN/N	0.99
Precision	TP/(TP+FP)	0.95
Negative Predictive Value	TN/(TN + FN)	0.99
Fall Out	FP/N	0.01
False Discovery Rate	FP/(TP + FP)	0.05
Accuracy	(TP + TN)/(TP + FP + FN + TN)	0.98
F1	2TP/(2TP + FP + FN)	0.95

Derivative	Value
Sensitivity (Unstable)	0.95
Specificity (Stable)	0.99
Accuracy	0.98

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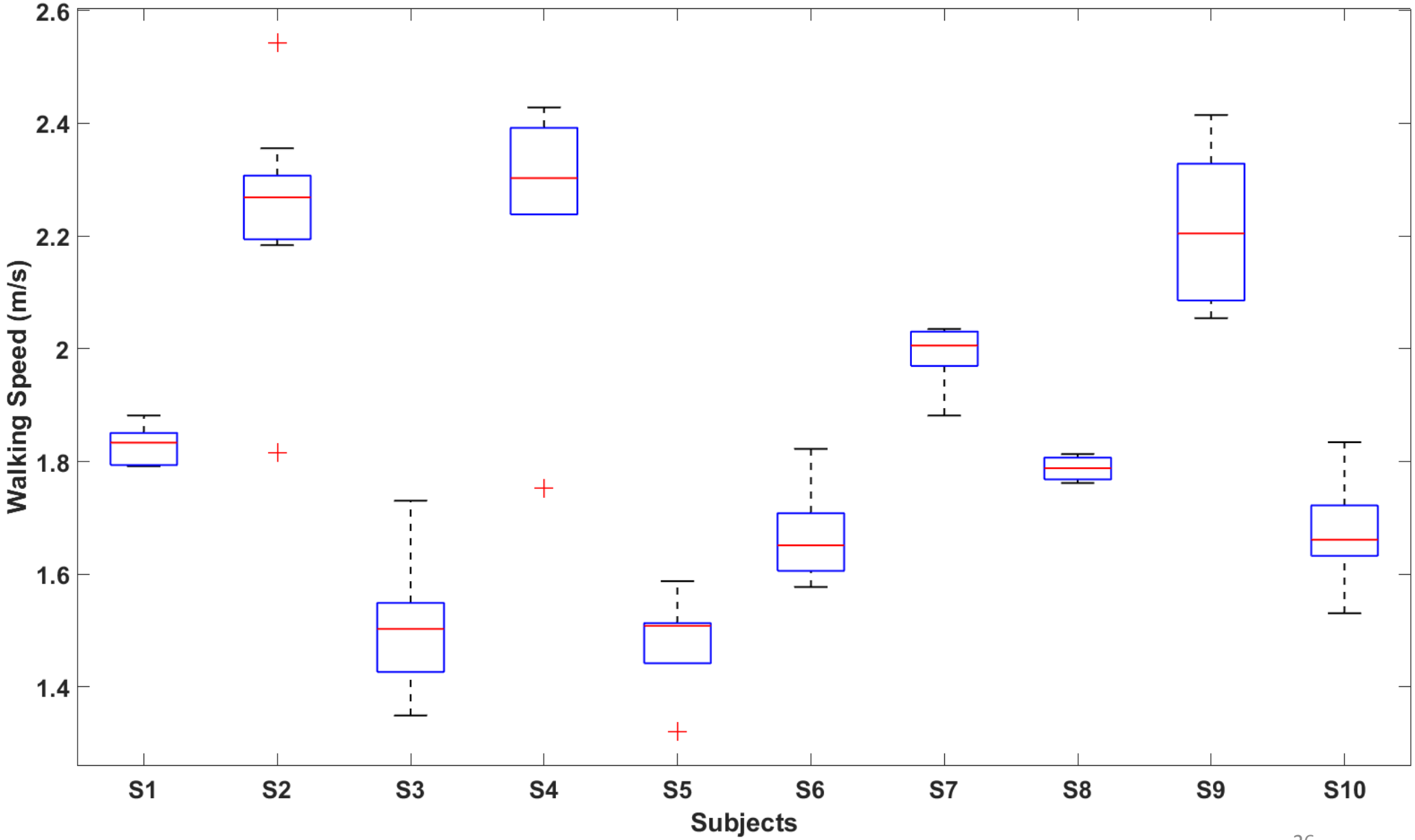
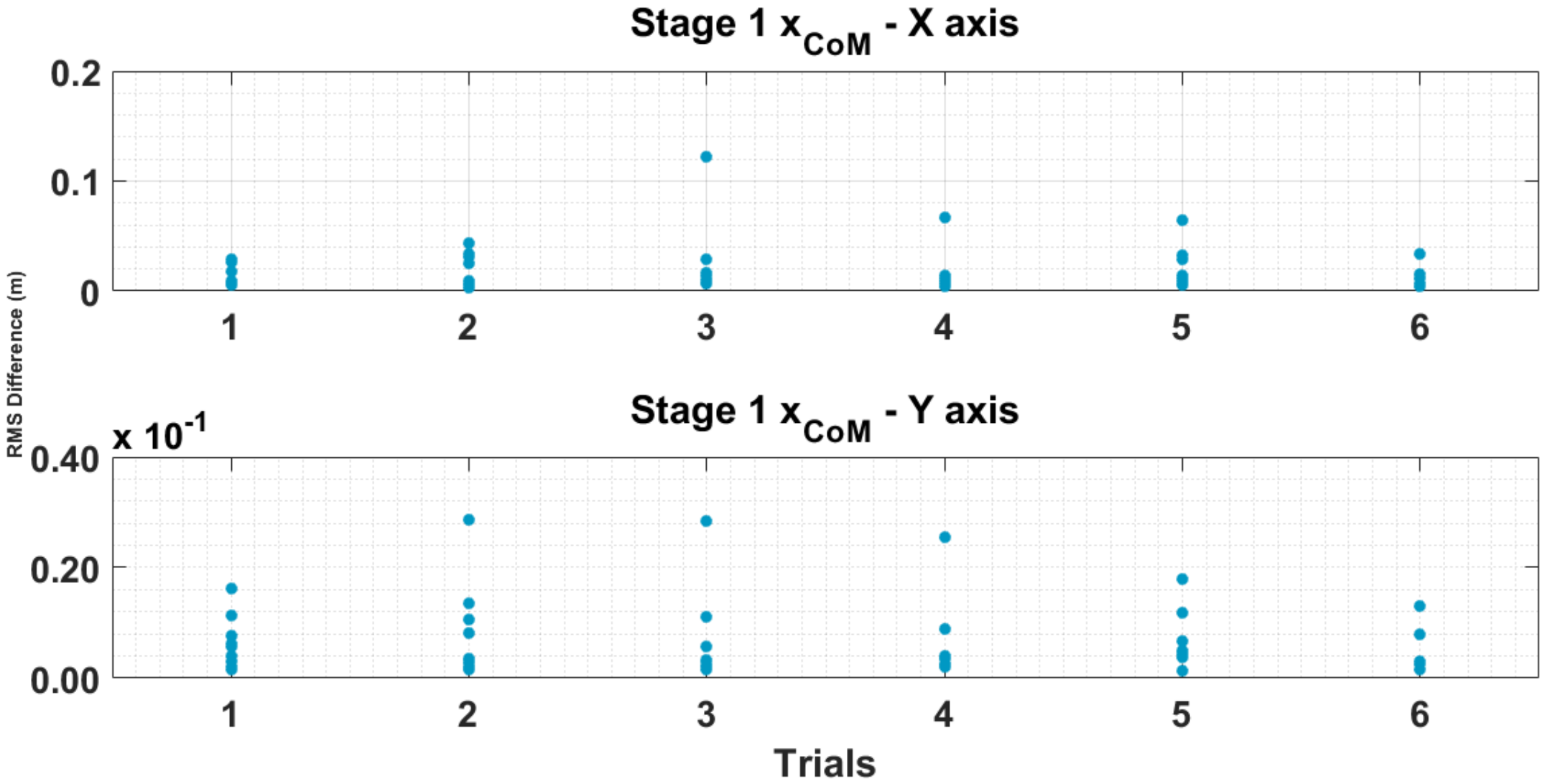
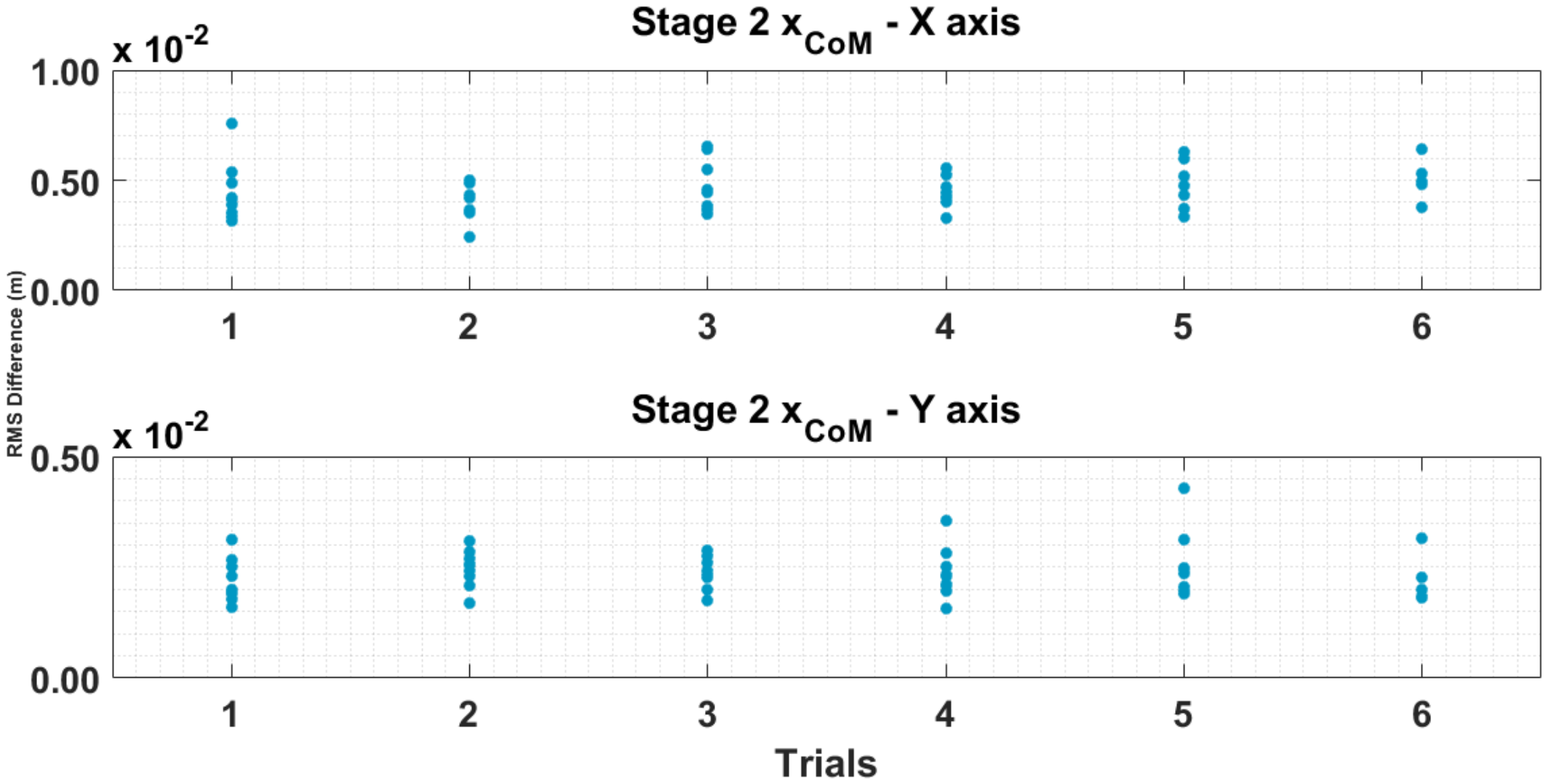
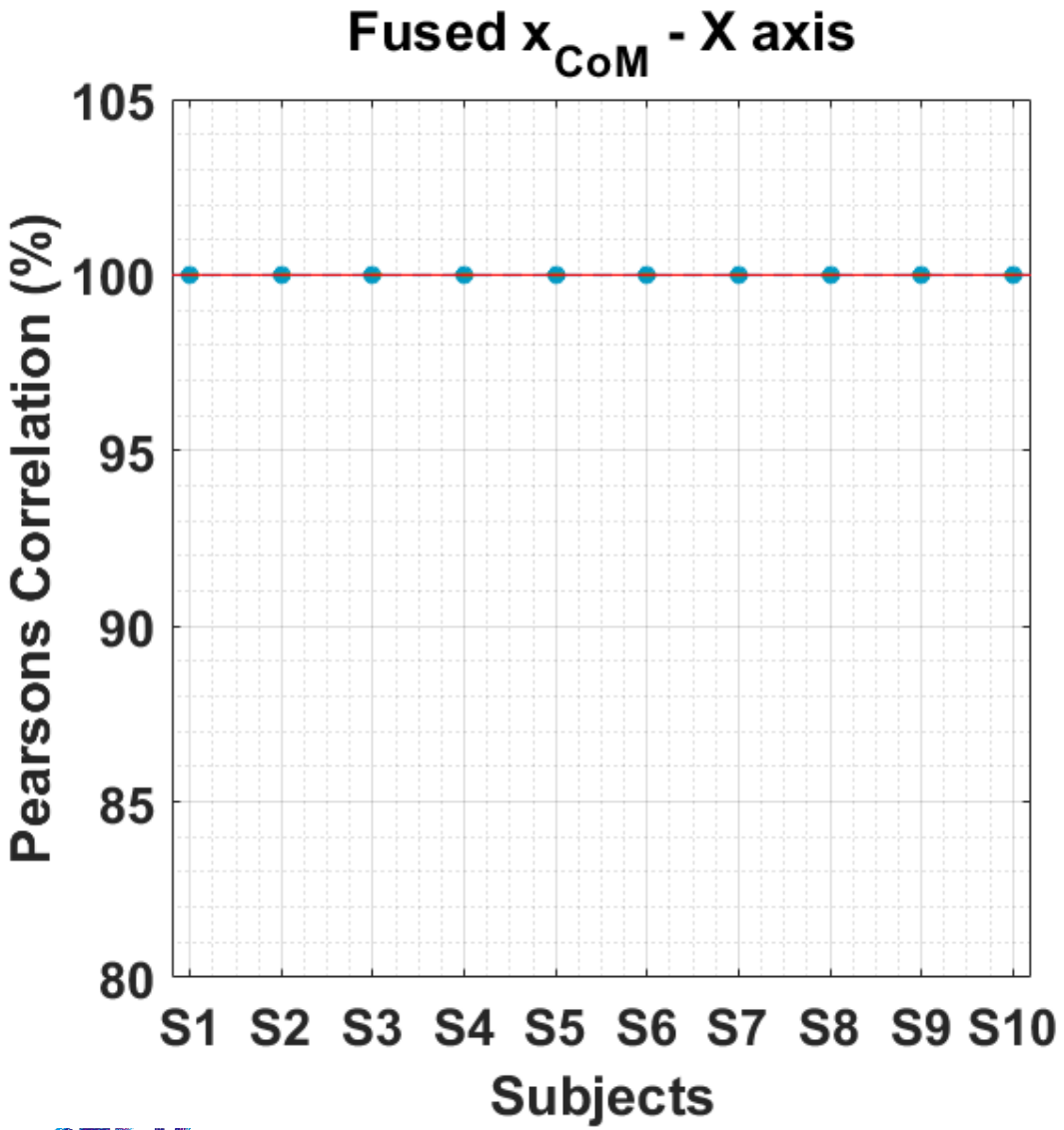
Experimental Study

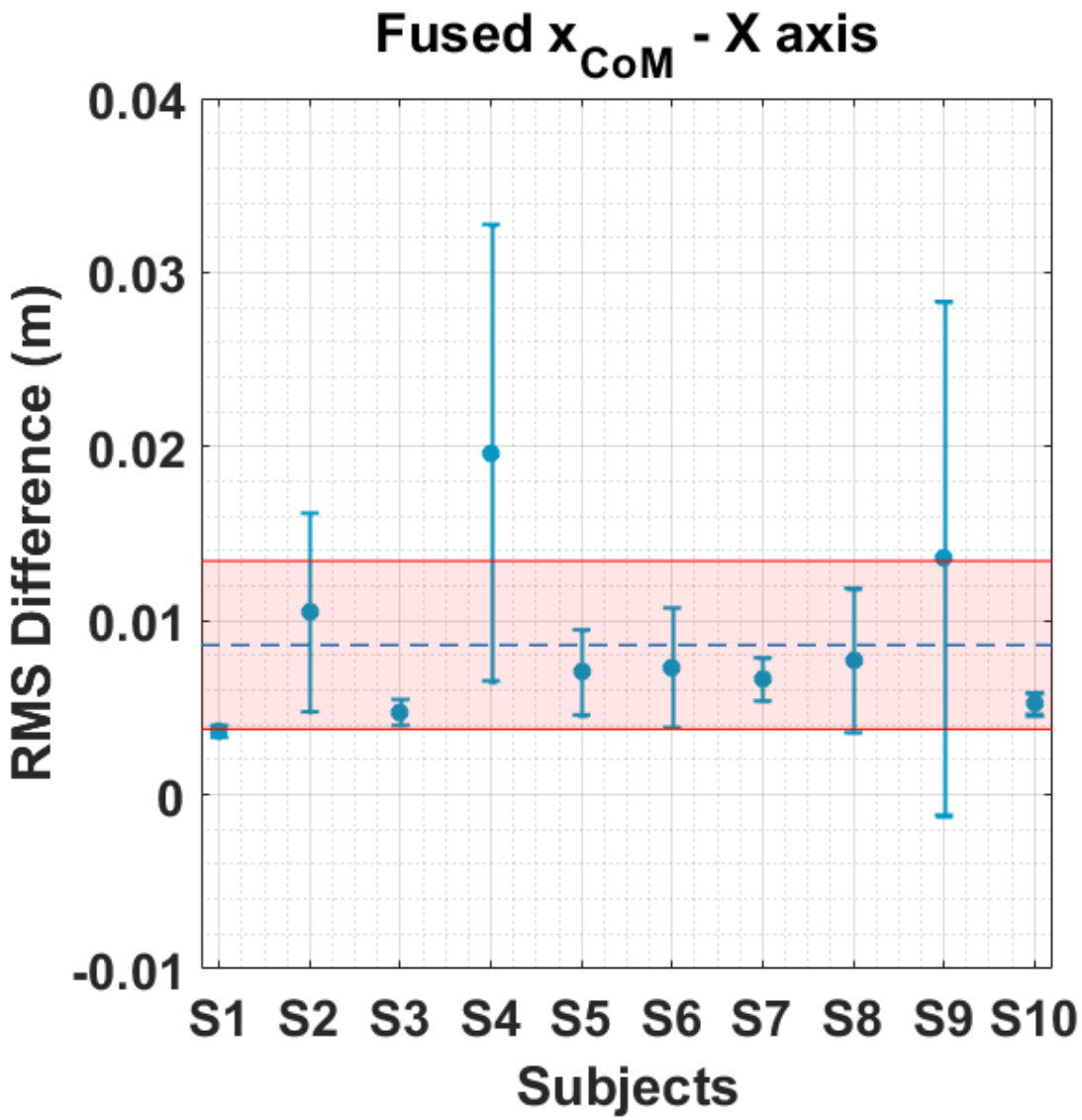
- 10 Subjects wore ForceShoes™ along with Pressure Insole
  - Medilogic System (RRD)
  - ~150 Resistive Sensors
- Shoe size 44
- Average Weight: 76 ± 6 kg, Height: 1.77 ± 0.05 m, Age = 25 ± 2 years.
- 10 m Straight line walking
- Preferred Walking speed
- Sampled at 50 Hz

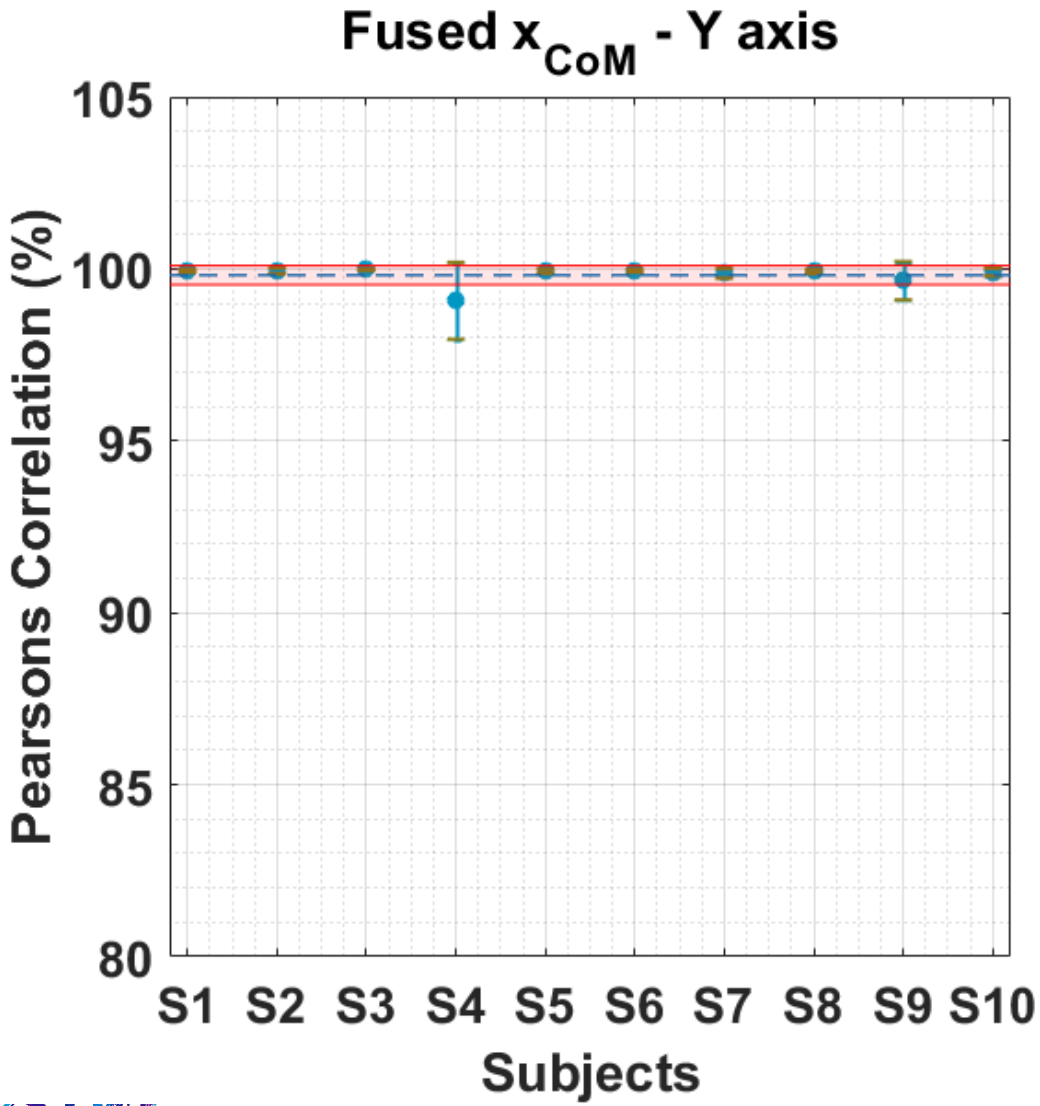

Walking Speed (m/s)
2.6
2.4
2.2
2
1.8
1.6
1.4
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
Subjects

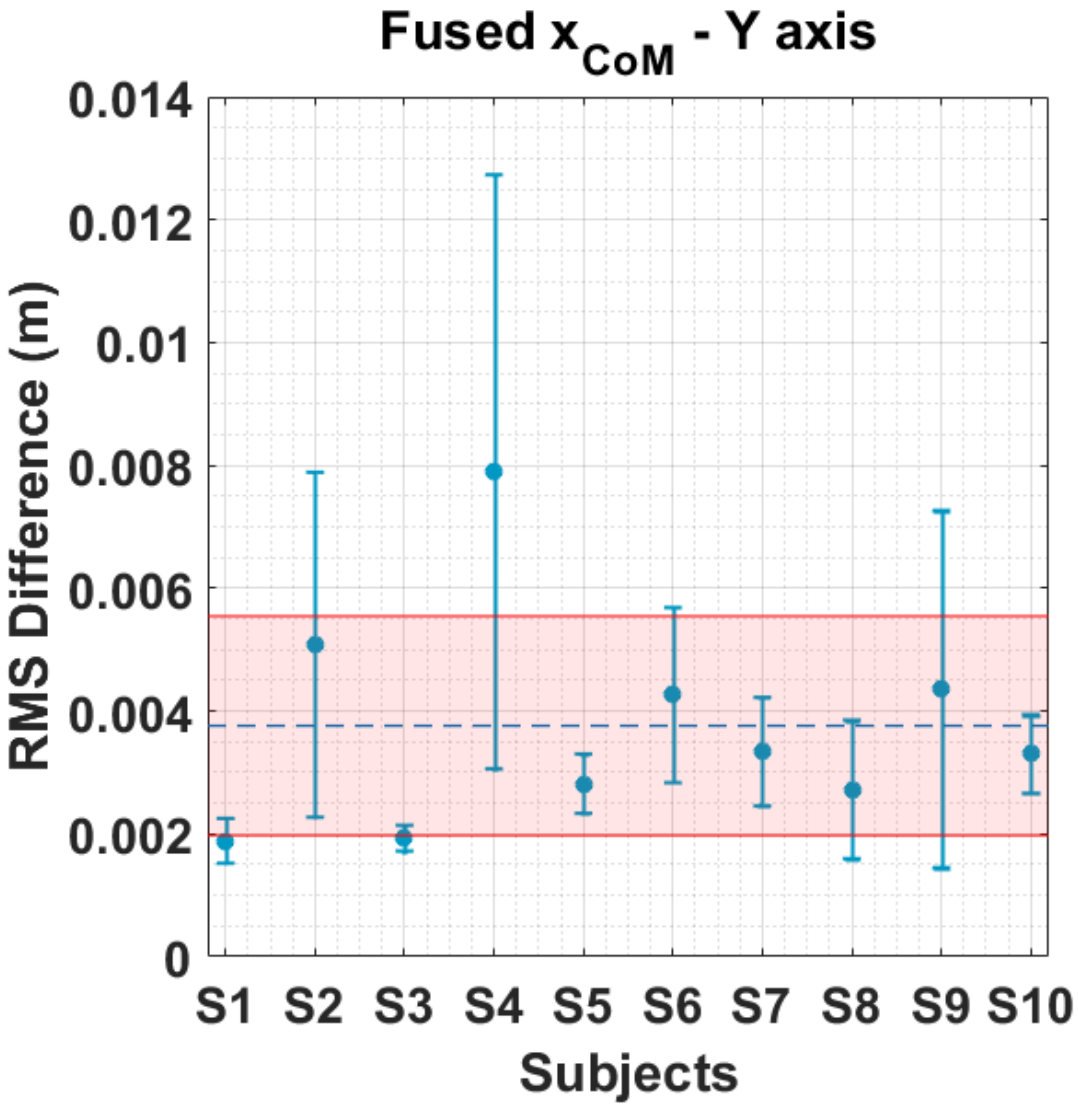

Stage 1 x_CoM - X axis
RMS Difference (m)
0.2
0.1
0
1
2
3
4
5
6
Stage 1 x_CoM - Y axis
x 10^-1
0.40
0.20
0.00
1
2
3
4
5
6
Trials

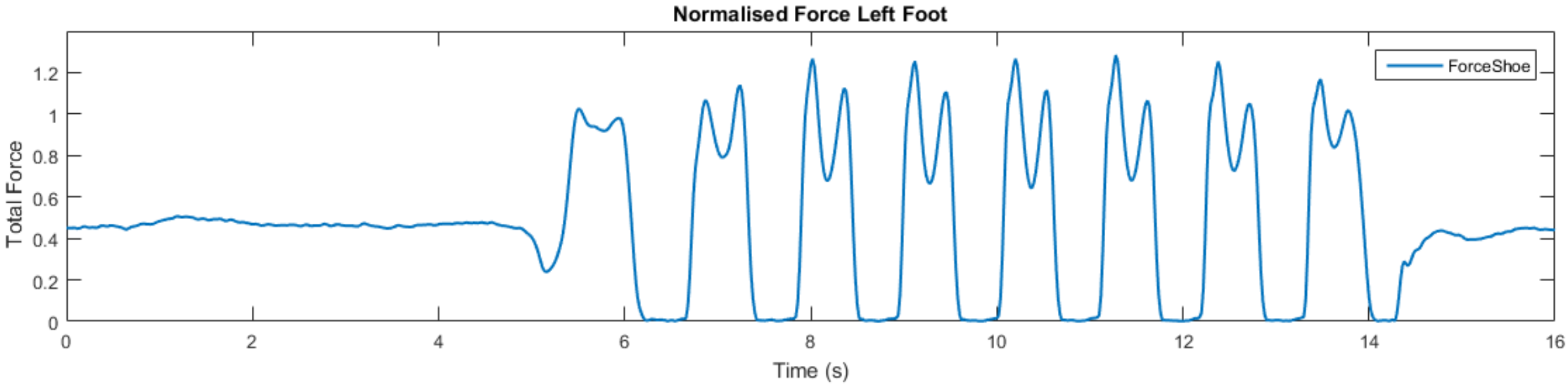

Stage 2 x_{CoM} - X axis
x 10^-2
1.00
0.50
0.00
RMS Difference (m)
1
2
3
4
5
6
Stage 2 x_{CoM} - Y axis
x 10^-2
0.50
0.00
1
2
3
4
5
6
Trials

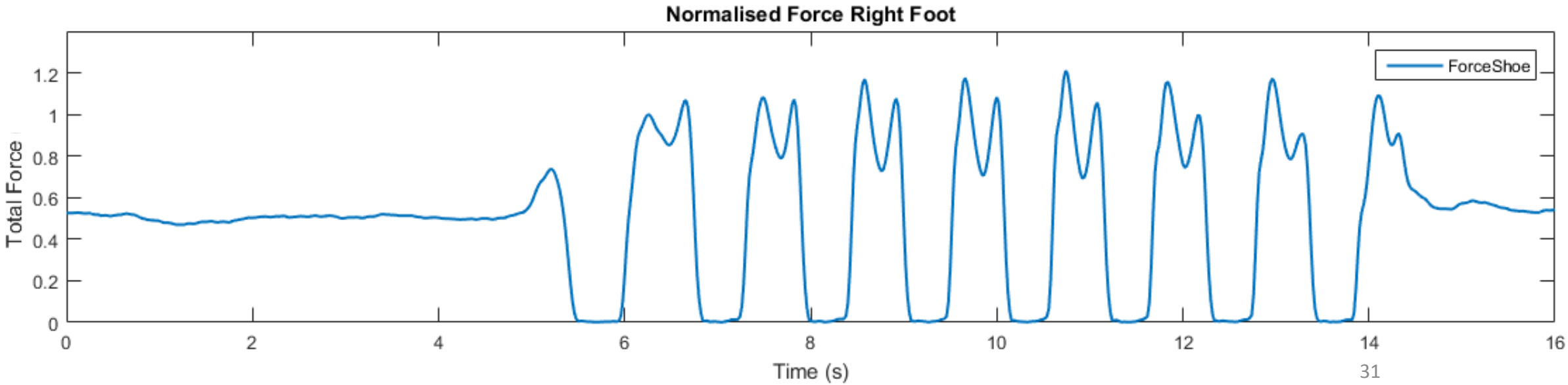

Fused x_{CoM} - X axis
Pearsons Correlation (%)
105
100
95
90
85
80
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10
Subjects


Fused x_{CoM} - X axis
RMS Difference (m)
0.04
0.03
0.02
0.01
0
-0.01
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10
Subjects

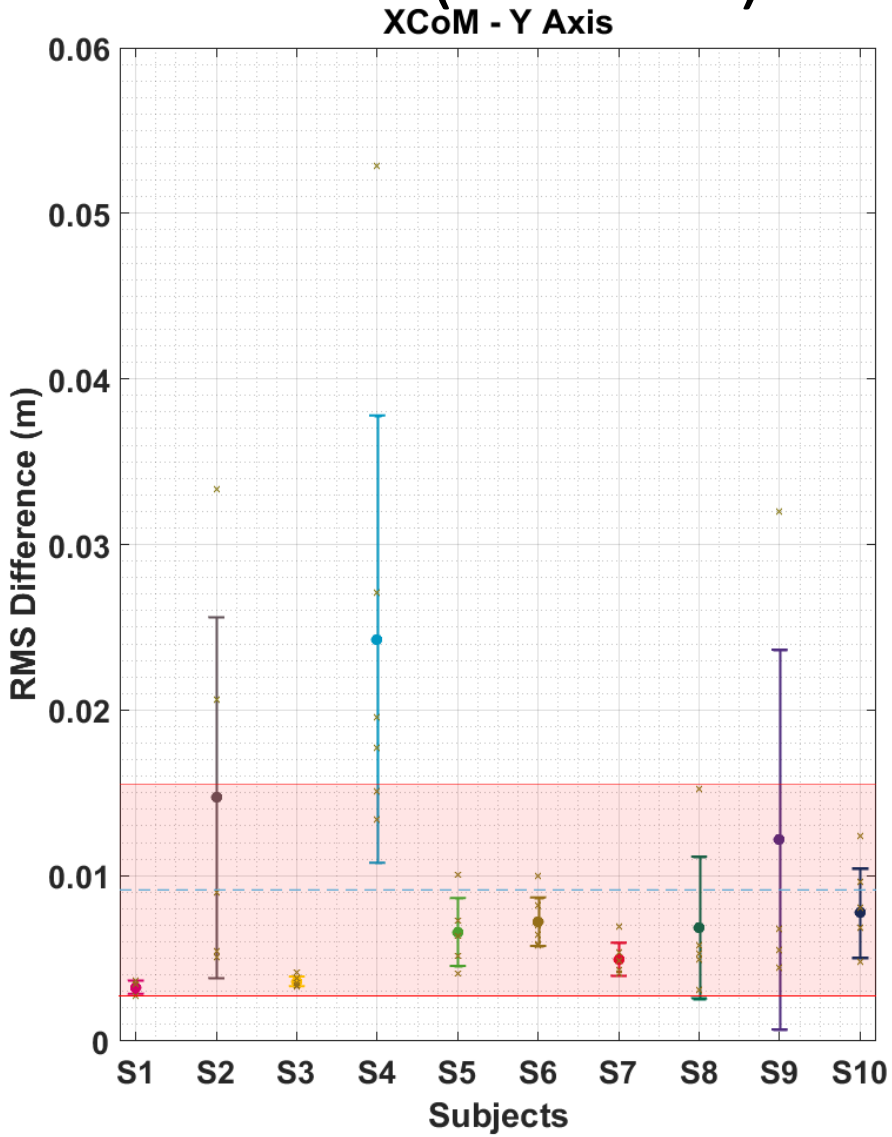

Fused x_{CoM} - Y axis
Pearsons Correlation (%)
105
100
95
90
85
80
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10
Subjects


Fused x_{CoM} - Y axis
RMS Difference (m)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10
Subjects


Normalised Force Left Foot
ForceShoe
Total Force
Time (s)
0
0.2
0.4
0.6
0.8
1
1.2
0
2
4
6
8
10
12
14
16


Normalised Force Right Foot
ForceShoe
Total Force
Time (s)
0
0.2
0.4
0.6
0.8
1
1.2
0
2
4
6
8
10
12
14
16

Extrapolated Center of Mass (XCoM)



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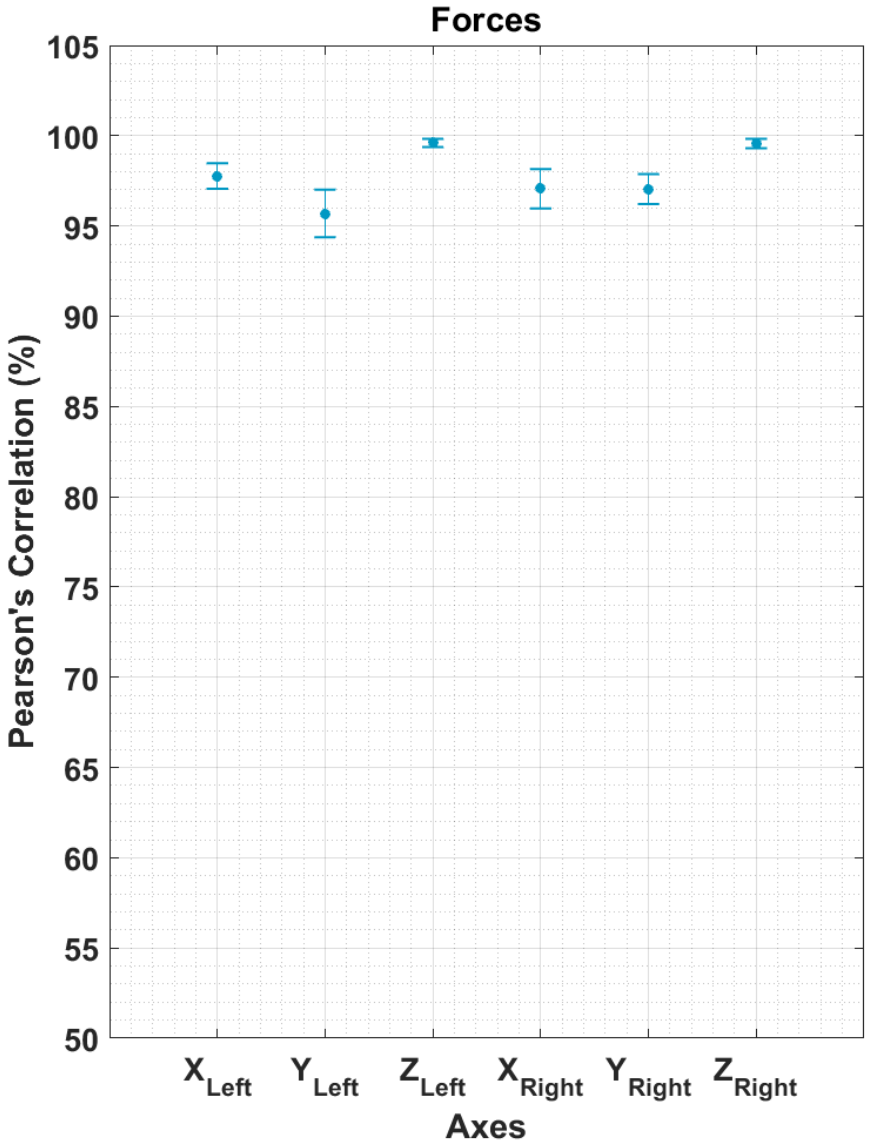
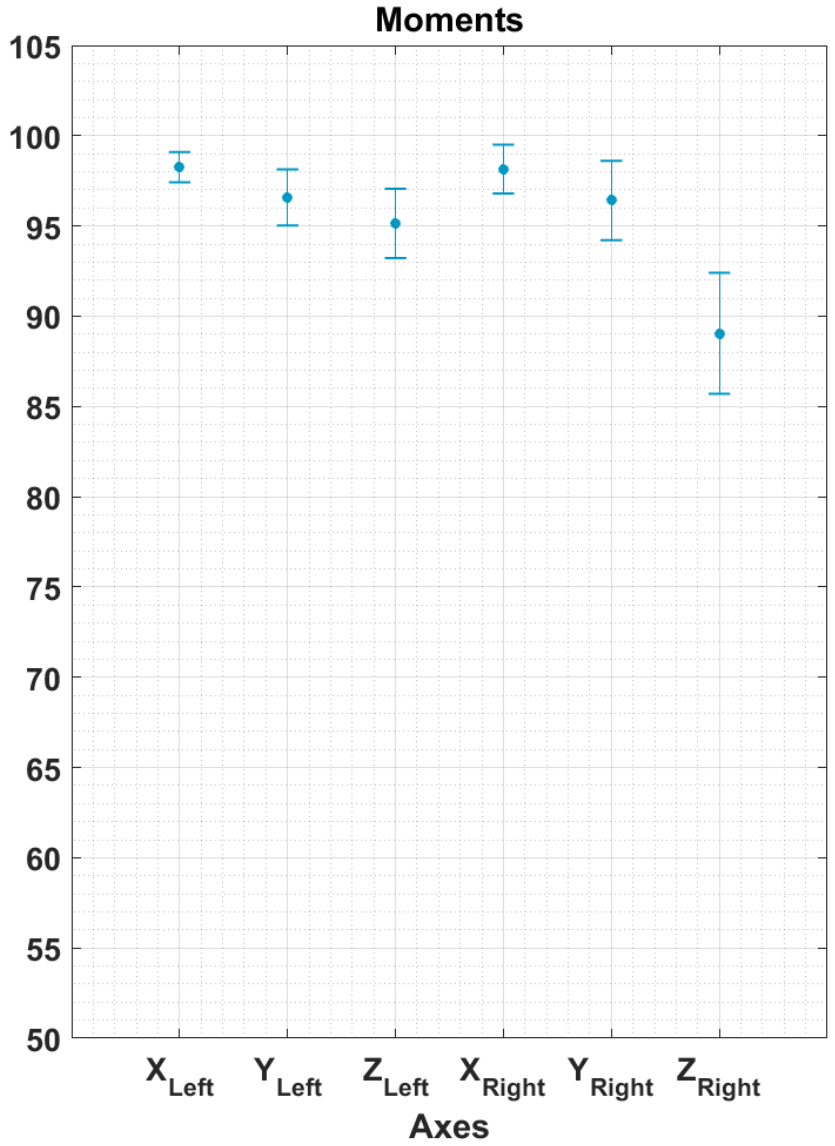
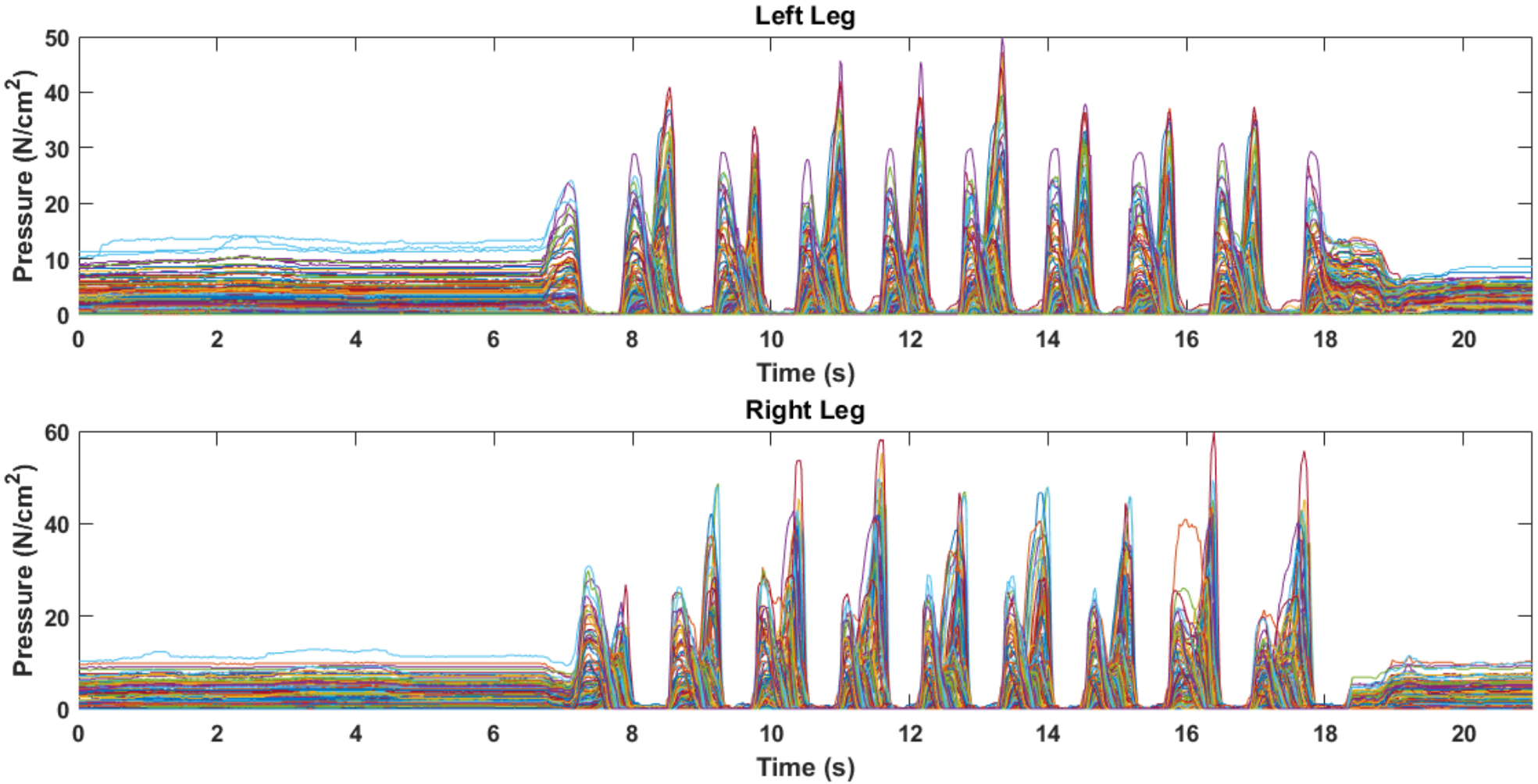
3D Forces and Moments






Left Leg
Pressure (N/cm^2)
Time (s)
Right Leg
Pressure (N/cm^2)
Time (s)