Causal Analysis of Inertial Body Sensors for Enhancing Gait Assessment Separability towards Multiple Sclerosis Diagnosis

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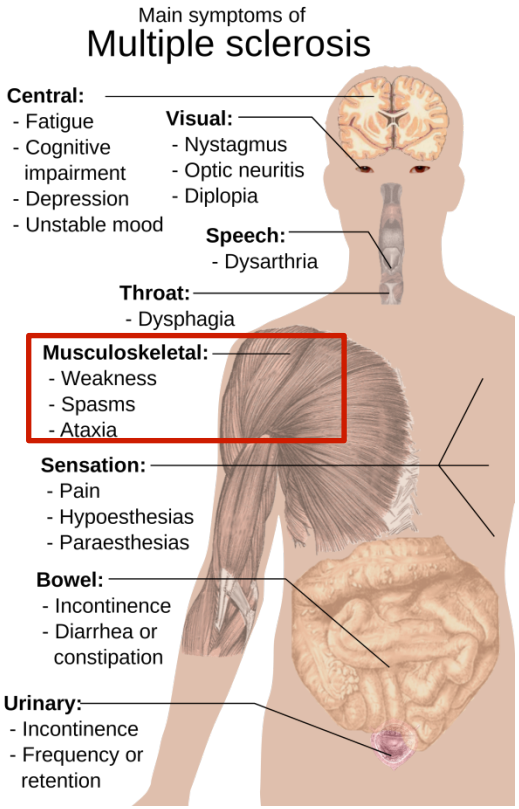
Multiple Sclerosis (MS): Chronic autoimmune disorder of the central nervous system (CNS)



6-minute walk (6MW)

source: www.nature.com

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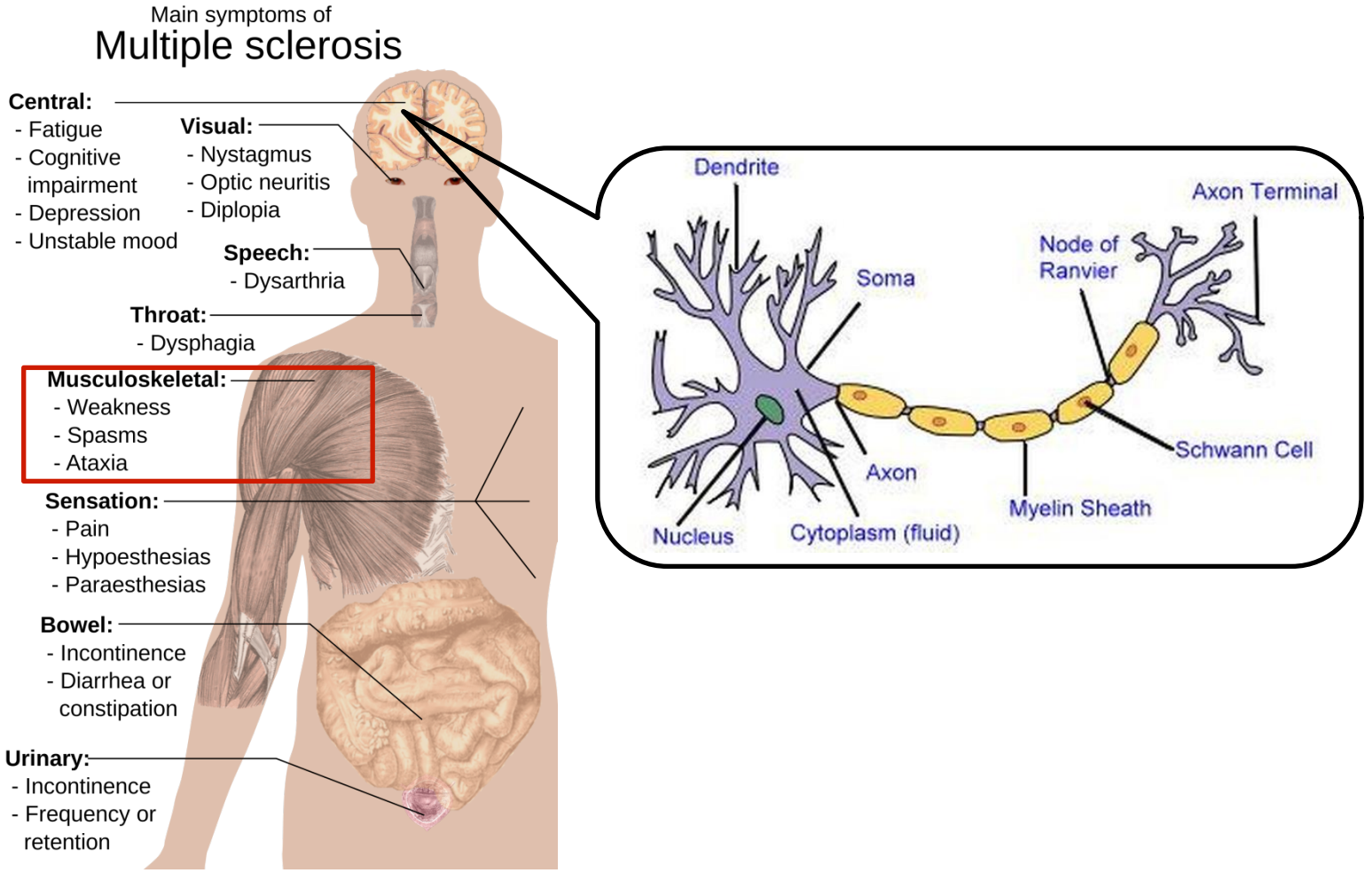
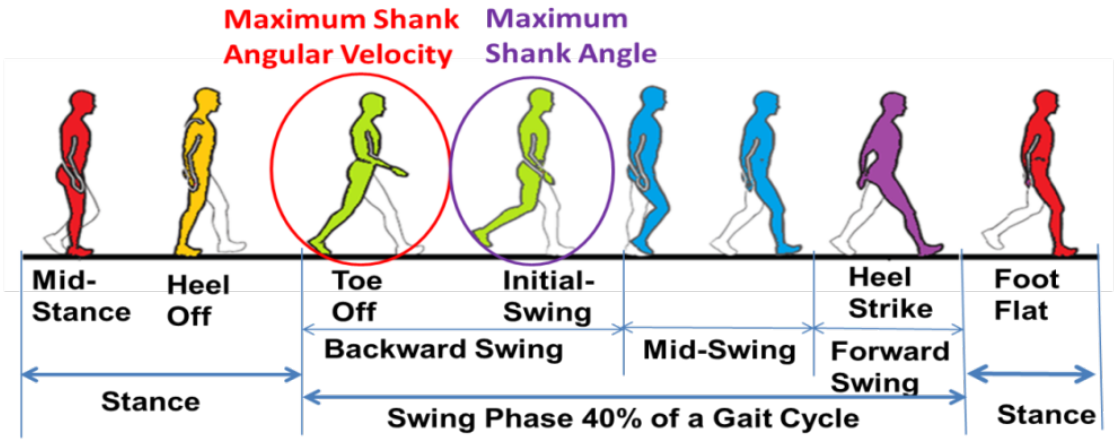
Musculoskeletal attack from MS varies depending on the person and affects different body parts in different individuals



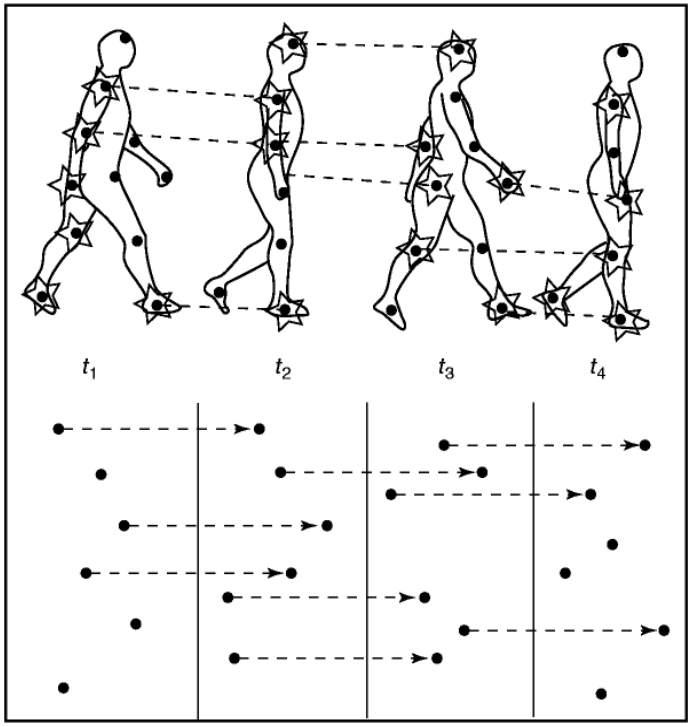
Previous motion assessments lack of comprehensive understanding of body motions

6-minute walk (6MW)

source: www.nature.com



Human motion consists of not only the spatial-temporal evolution of individual body parts, but also the interactions among body parts.



[1] Neri, Peter, M. Concetta Morrone, and David C. Burr. "Seeing biological motion." ***Nature*** 395, no. 6705 (1998): 894-896.

The interactions among body parts contain rich information of body motion.

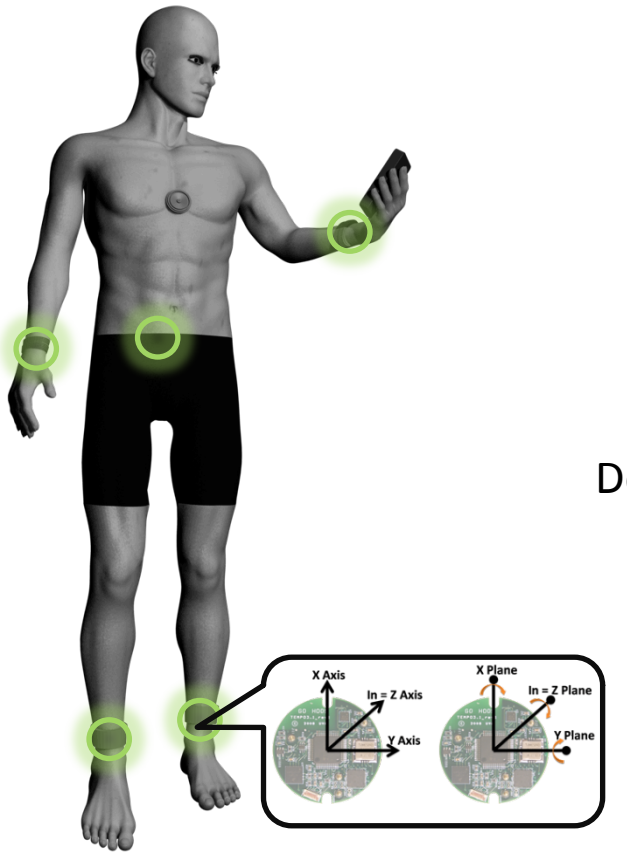
Knowledge from Experts in MS: Musculoskeletal attack from MS varies depending on the person and affect different body parts in different individuals.

Knowledge from Experts in Motion: The interactions among body parts contain rich information of body motion.

Hypothesis: the strength of interactions among body parts in healthy control subjects is stronger than in MS subjects

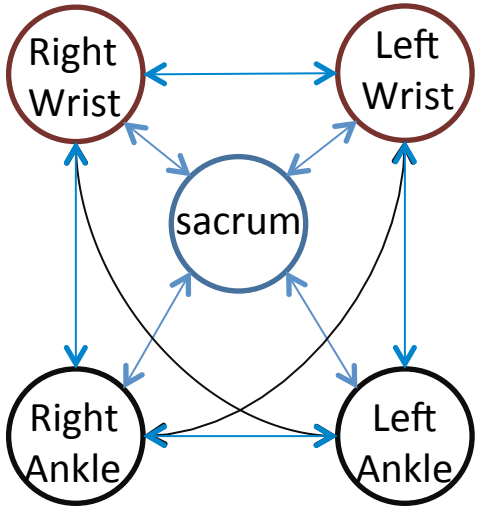
Methods: Generate causality based feature from inertial body sensors to represent the strength of interactions among body parts.

Pairwise Causality Graph is used to describe the interactions among body parts



Graphic

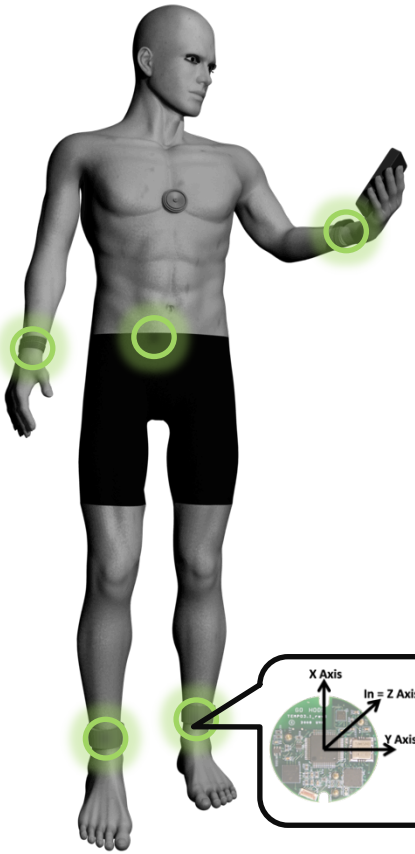
Demonstration



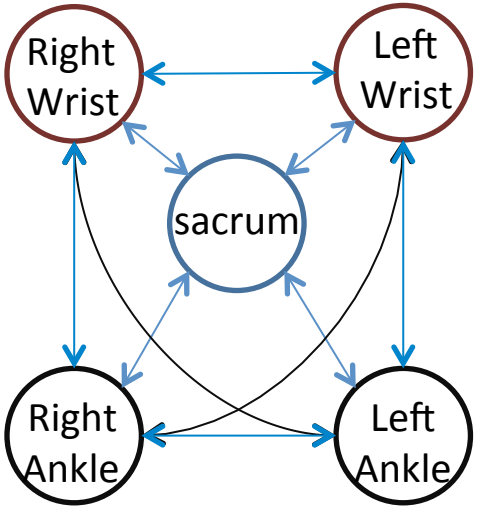
Pairwise Causality Graph

Central nervous system (CNS) drives and coordinates the body parts during walking.
Causality: Who is the driver, and who is the recipient?

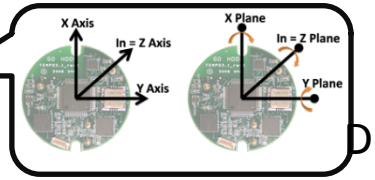
Pairwise Causality Matrix is used to represent the strength of the interactions among body parts.



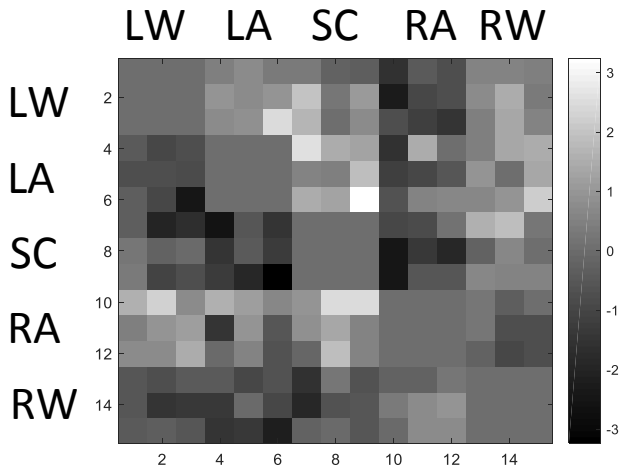
Graphic Demonstration



Pairwise Causality Graph



Matrix Demonstration

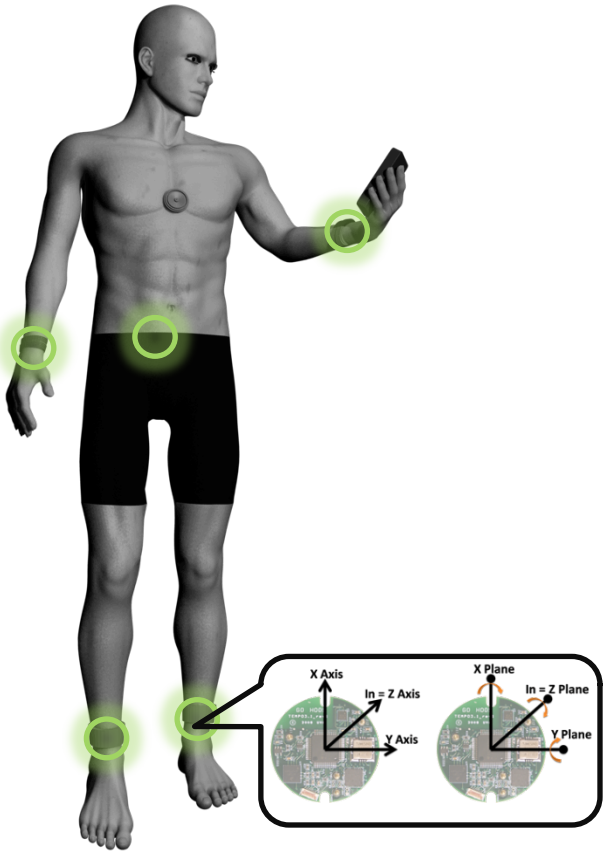


Pairwise Causality Matrix

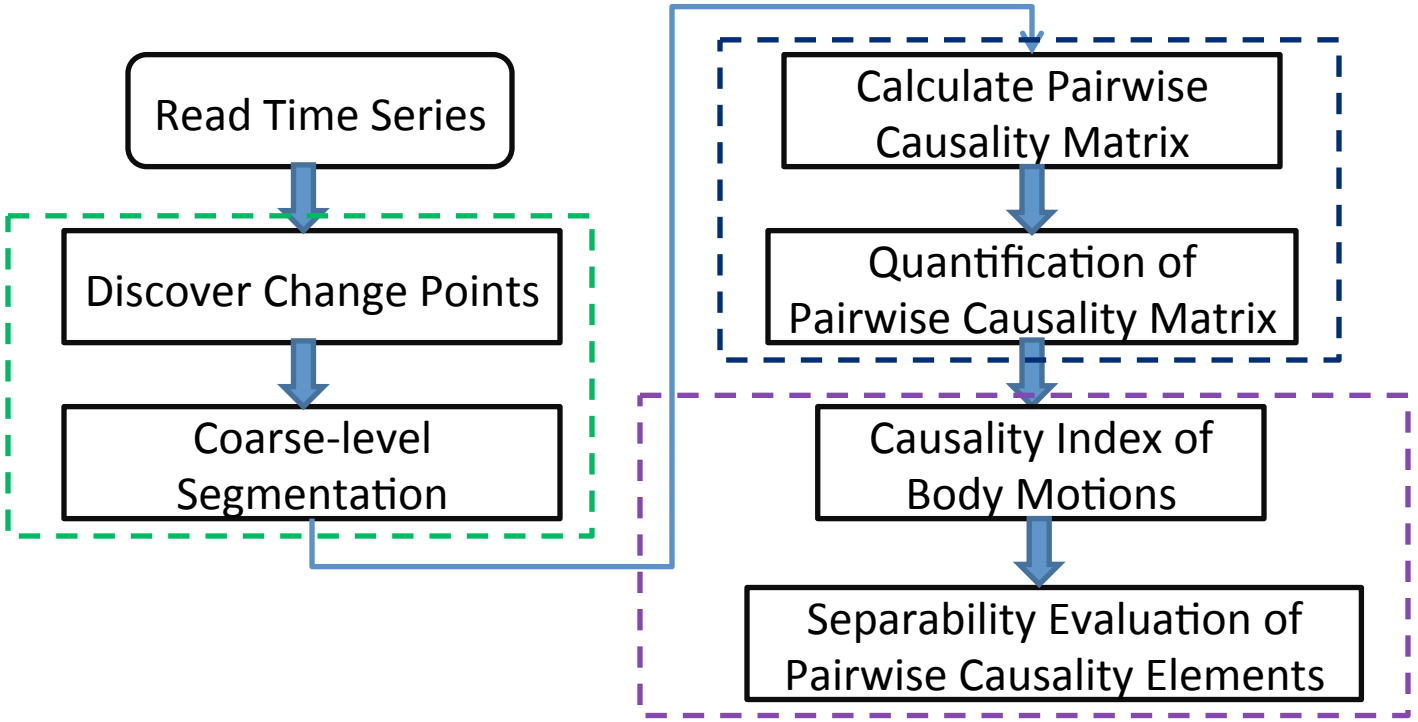
Experimental Setup

- 41 subjects (13 Healthy Control and 28 MS subject)
- 132 data sessions (11 failed: too much drop packets 6; timestamp error 3; calibration error 2)
- 128 sample per second
- 3-axis accelerometer and 3-axis gyroscope

source: www.nature.com



Algorithm Framework of Casual analysis for Inertial Body Sensor Data

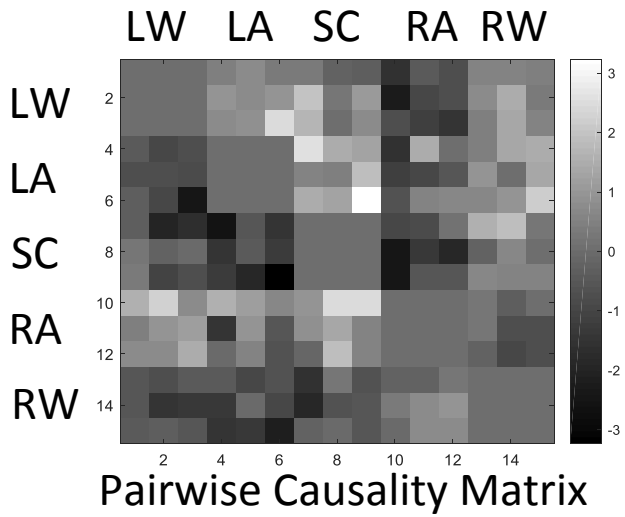


Because of its robustness to confounder factors, Phase Slope Index is used to estimate the causality.

Calculation based on Phase Slope Index(PSI)

- Consider signals $z\downarrow i\,[t]$ and $z\downarrow j\,[t]$. The cross spectrum between them is defined as follows:
  - $S\downarrow ij\,(f)=E[Z\downarrow i\,(f)Z\,\hat{}\,j\uparrow *\downarrow(f)\,]$ cross spectrum
  - $C\downarrow ij\,(f)=S\downarrow ij\,(f)/\sqrt{S\downarrow ii\,(f)S\downarrow jj\,(f)}$ complex coherence
  - $\Psi\downarrow ij=Imag(\sum f\in F\uparrow\blacksquare C\hat{}\,ij\uparrow *\downarrow(f)\,C\downarrow ij\,(f+\delta f)\;)$ unnormalized PSI
  - $\Psi\downarrow ij=\Psi\downarrow ij\,/std(\Psi\downarrow ij\,)$ normalized PSI

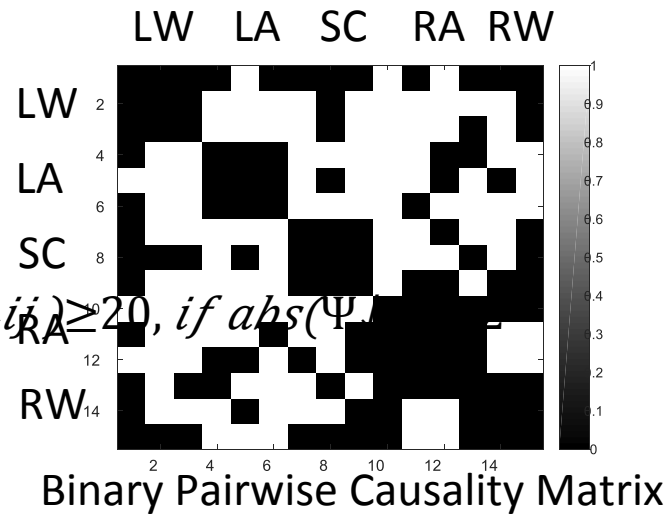
Pairwise Causality Matrix (PCM)



Pairwise Causality Matrix

threshold

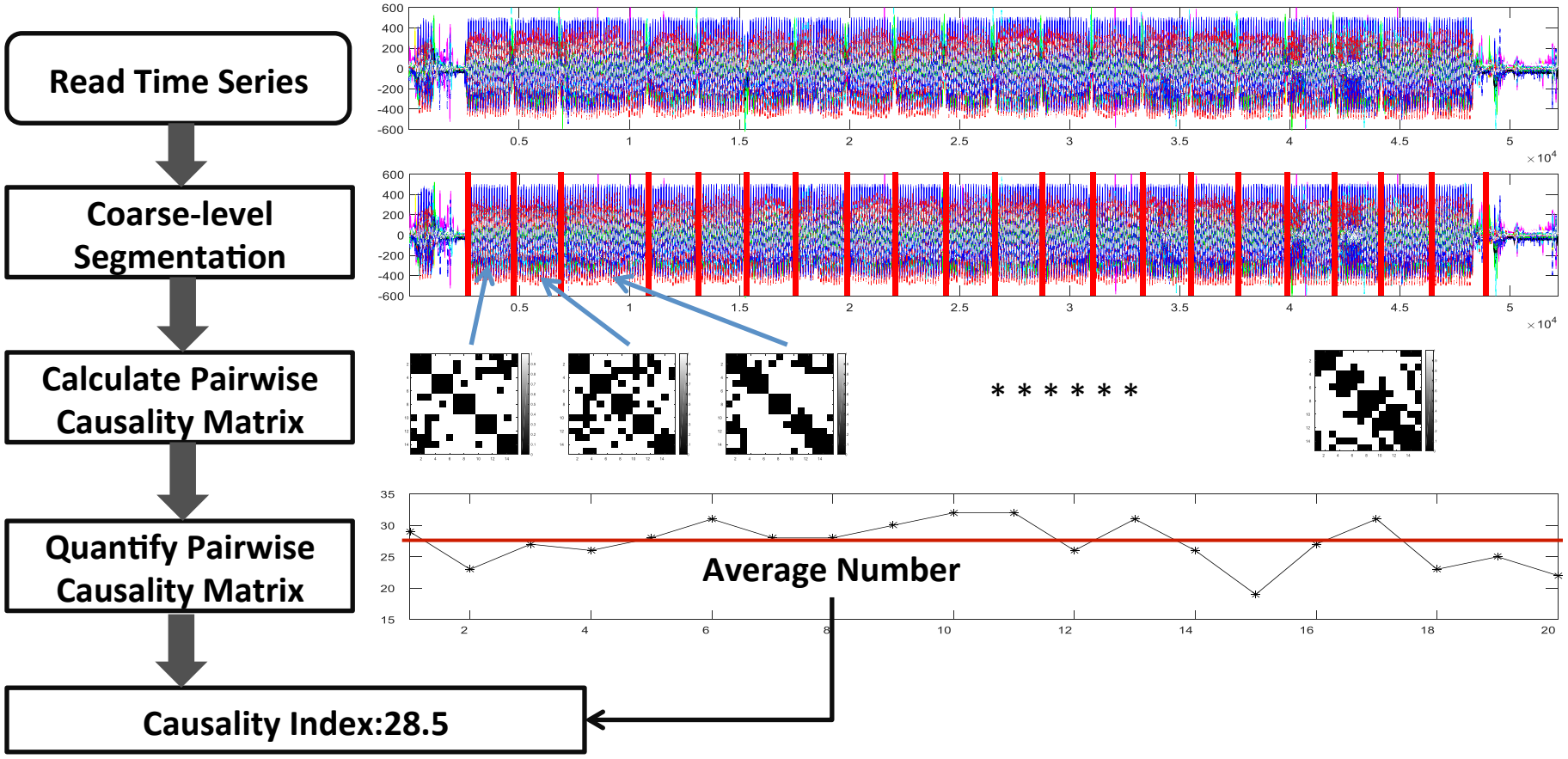
$$1, \{\blacksquare 1, if\ abs(\Psi\downarrow ij)\geq 20, if\ abs(\Psi$$



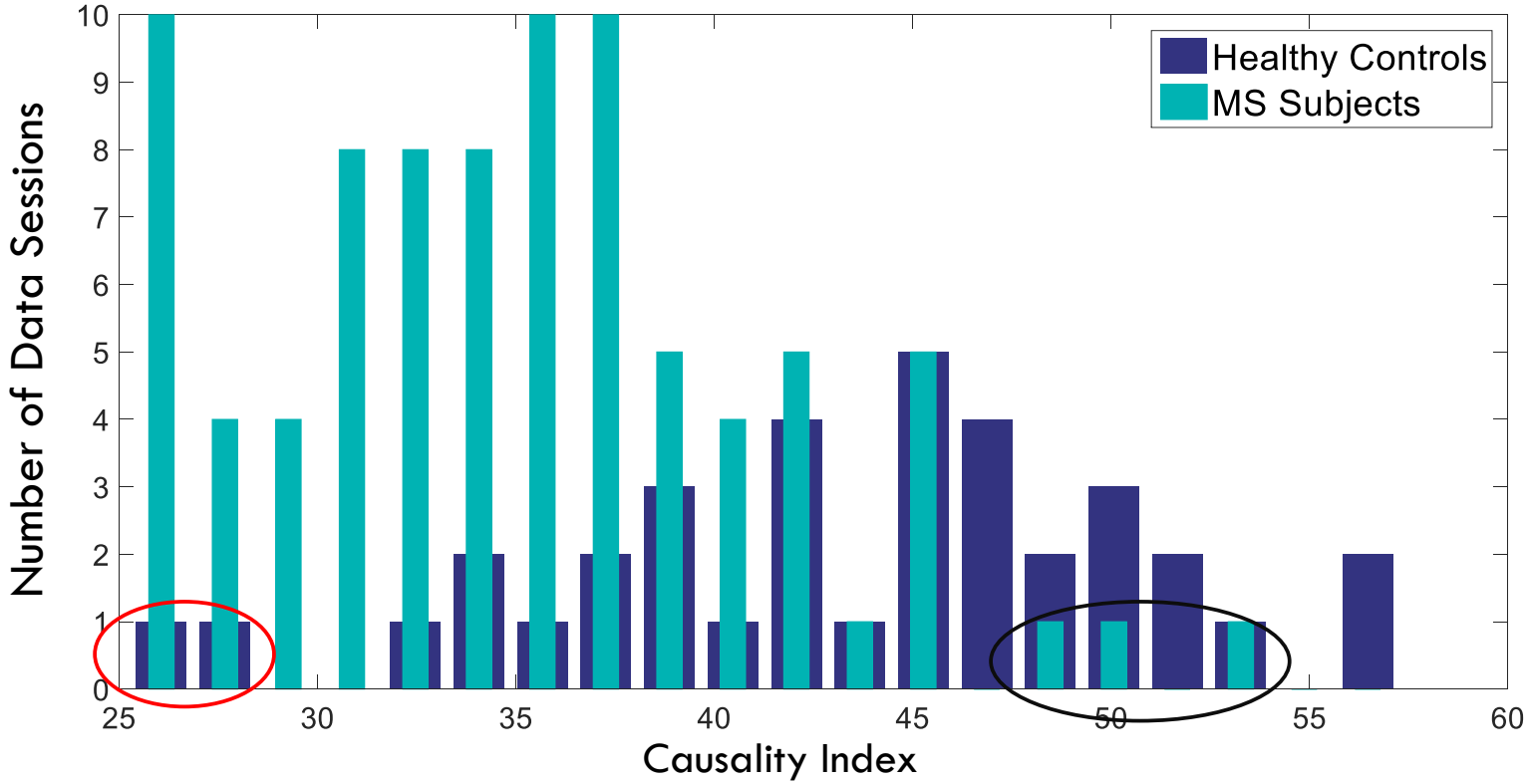
Binary Pairwise Causality Matrix

Quantification using threshold to select the strong causality
Left: (Pairwise Causality Matrix using Gyroscope Segments)

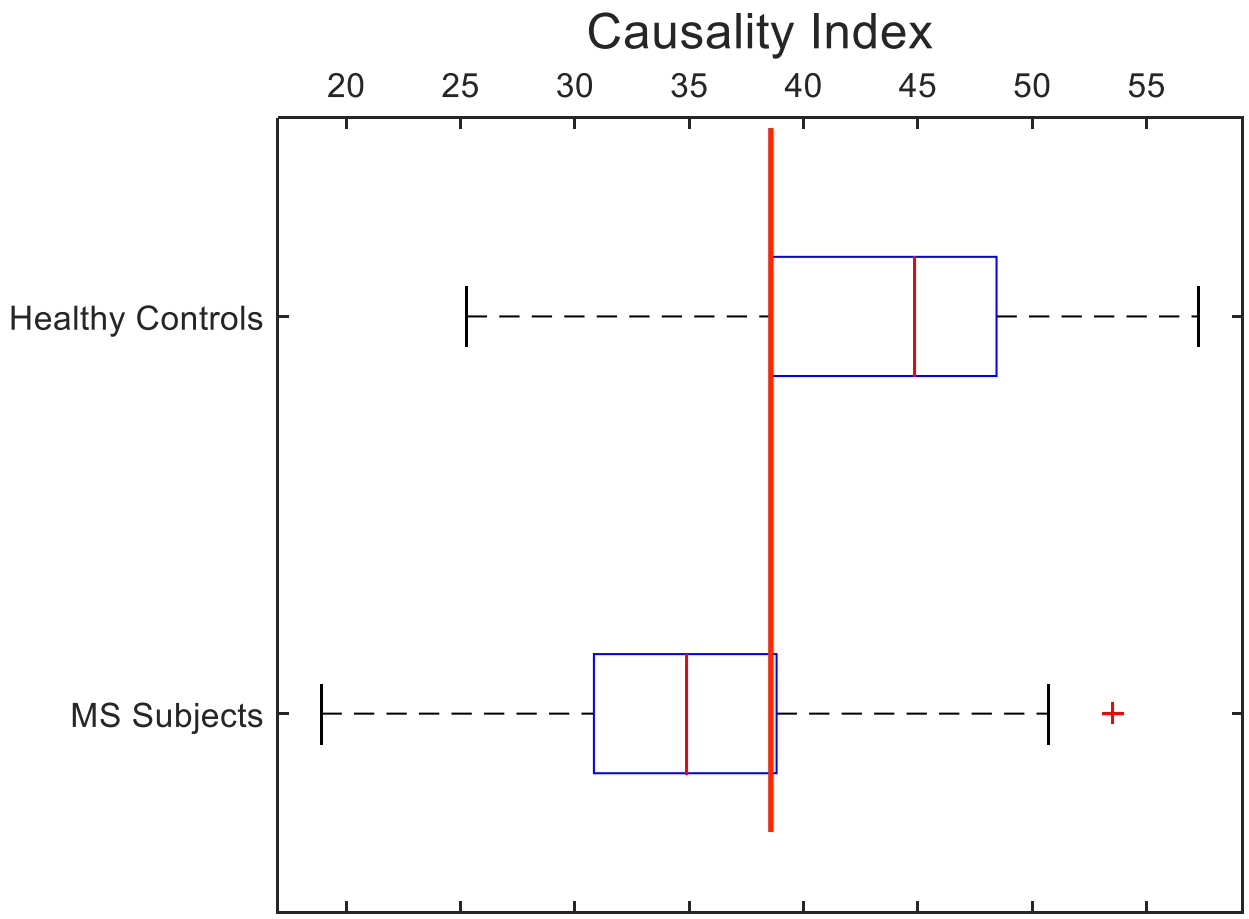
Computation Flow of Casual analysis for Inertial Body Sensor Data



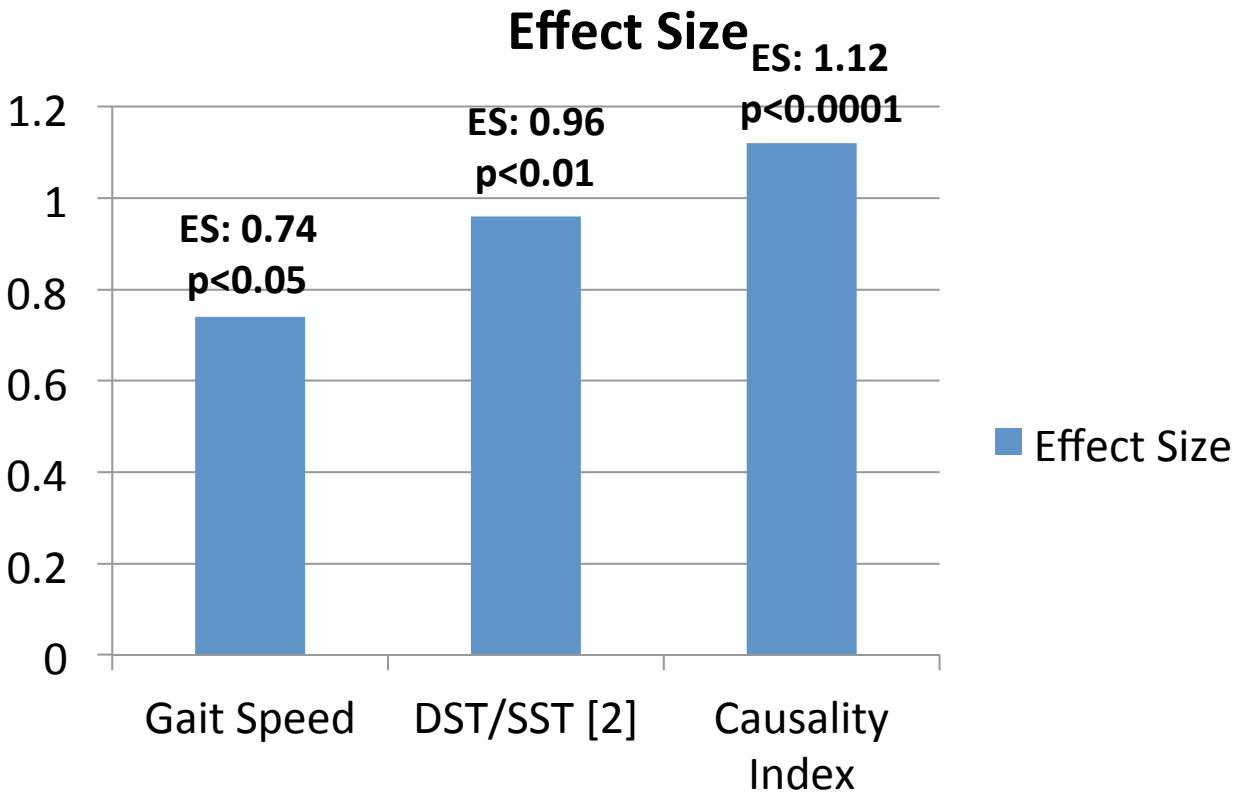
Results 1: Causality Index Distribution



Results 2: Causality Index Distribution (Threshold: 38)



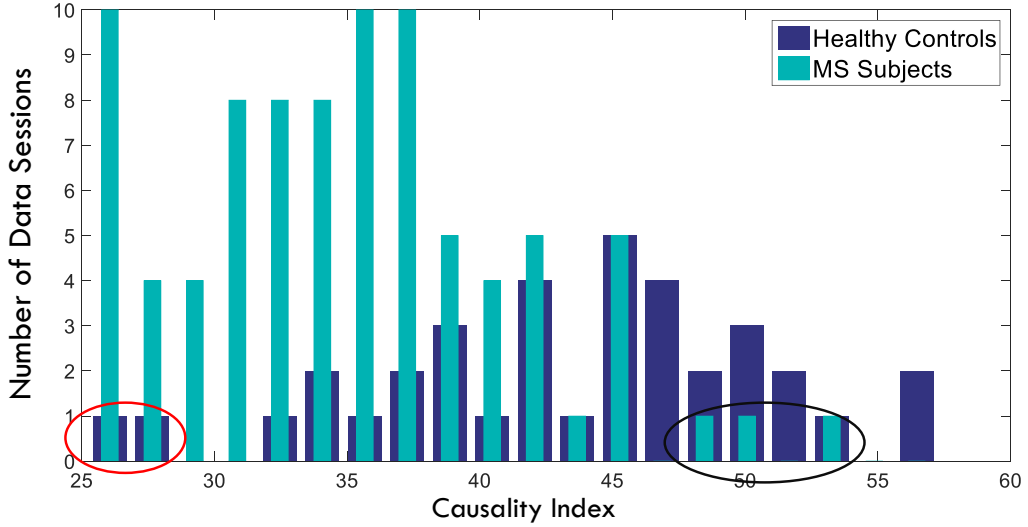
Results 3: Separability for two groups



[2] Shanshan Chen, Jiaqi Gong, John Lach, Myla D. Goldman, "Enhanced Multiple Sclerosis Gait Assessment using Inertial Sensors," Wireless Health Conference, Baltimore, MD, USA, Nov. 2013

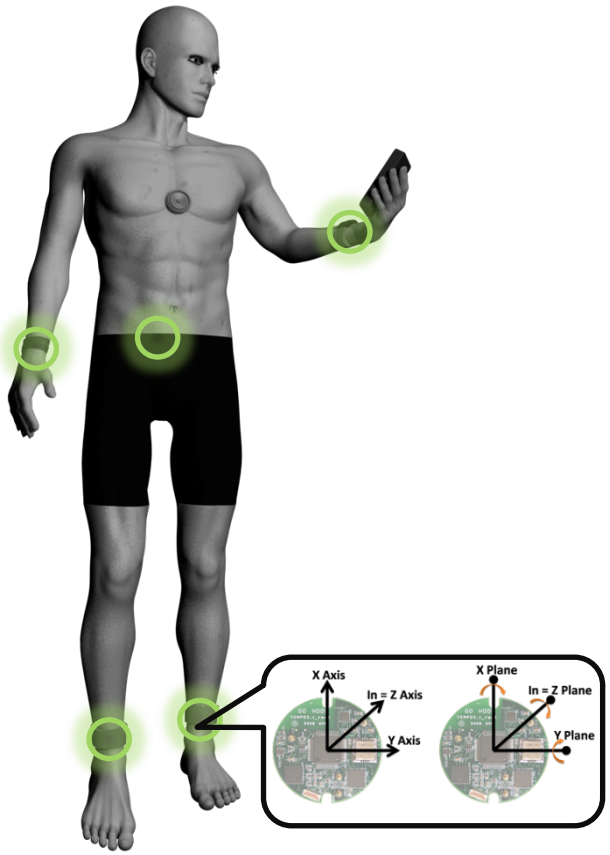
Recap

- Strong evidence proves the hypothesis
  - the strength of interactions between body parts in healthy control subjects during 6-minutes walking is stronger than in MS subjects
- Causality analysis can help for
  - Comprehensive assessment of body motions
  - Enhancing Multiple Sclerosis diagnosis



Q&A

- Contact us with any question you have
  - Jiaqi Gong: **jgong@virginia.edu**



source: www.nature.com