Wearable Sensors in Ecological Rehabilitation Environments

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Technology for Rehabilitation

Ecological Environments
Patients with injuries often receive inpatient rehabilitation services to regain independence. Simulated environments closely resemble home and community settings, enabling a more representative view of an individual's abilities.

The Need for Mobility Assessment Tools
Therapists use experience to qualitatively assess progress. Since human movement is complex, quantifying mobility details throughout rehabilitation provides more information and insights than human observation alone.

Proposed Technological Solution
Wireless inertial sensors provide movement data, are relatively inexpensive, do not interfere with natural movement, are portable, and integrate well with mobile platforms.

Wearable Sensor Platform

Three Shimmer Inertial Measurement Units (IMU)

- Bluetooth communication and SD card logging
- Sampling rate set to 51.2 Hz

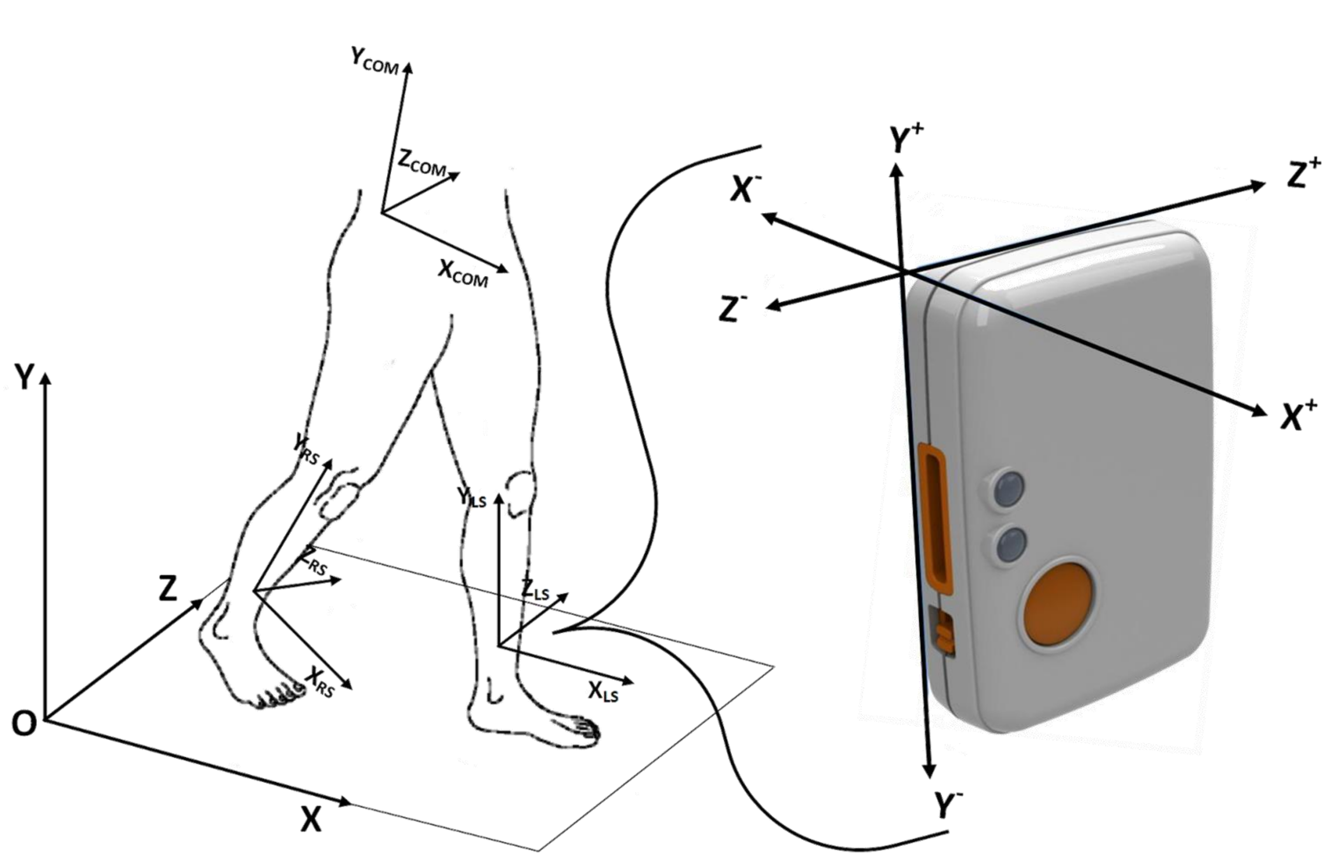

Figure 1. Sensor Placement. Sensor units were mounted on the center of mass (COM), left shank (LS), and right shank (RS).

Tri-axial Accelerometer

- Measures acceleration m/s^2
- COM range: ± 2g
- Shank range: ± 4g
- 1g = ~9.8 m/s^2

Tri-axial Gyroscope

- Measures angular velocity in deg/sec
- COM range: 250 deg/sec
- Shank range: 500 deg/sec

References: [1] Wolff Smith and Beretvas, 2009. [2] Chen, 2013. [3] Salarian et al., 2004. [4] Greene et al., 2010. [5] Tao et al., 2012.

Experimental Design

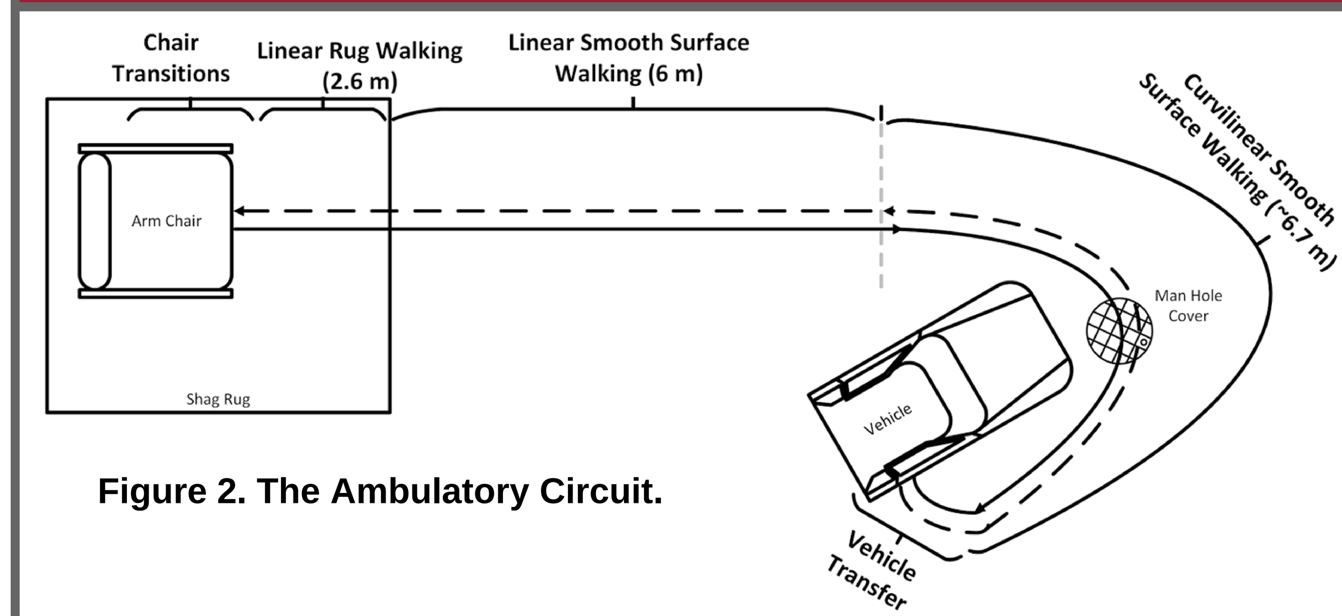

Figure 2. The Ambulatory Circuit.

Participants performed an ambulatory circuit (AC) in an indoor, simulated community. The AC consists of rising from a chair in a hotel lobby, walking to the passenger side of an SUV, transferring into and then out of the vehicle, returning to the chair, and sitting down.

Figure 3. Sensor Signals Recorded During the AC. The COM (top figure: accelerometer) and shank (bottom figure: gyroscope) sensor signals were segmented into corresponding AC components to quantify the rehabilitative progress.

Quantitative Changes Exhibited

The first test session (S1) was conducted shortly after the participant was physically able to perform the AC. S1 includes trial one (T1) and trial two (T2). The second test session (S2) was conducted one week later, including trial three (T3) and trial four (T4).

Figures 4-6 show select metrics quantifying ambulation. The data collected from a reference population are denoted with REF. As illustrated by the absence in S1, S2, and REF distribution overlaps, IMU metrics are suitable for distinguishing between healthy and patient populations.

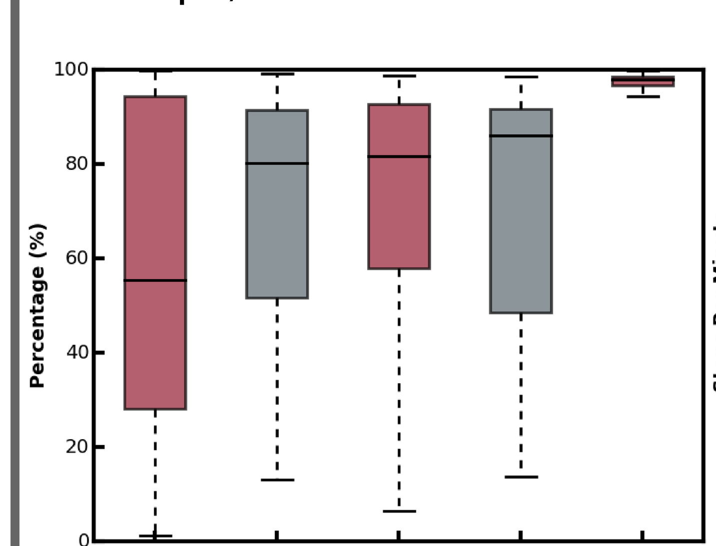

Figure 4. Step Symmetry Results. The metric indicates the step consistency while walking. Participants show improvement within each session.

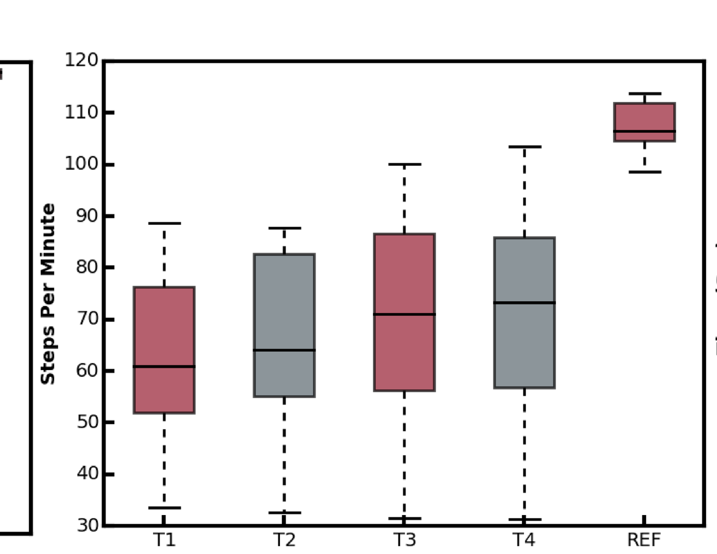

Figure 5. Cadence. The metric represents the number of steps per minute. Between S1 and S2 participants are increasing their step rate.

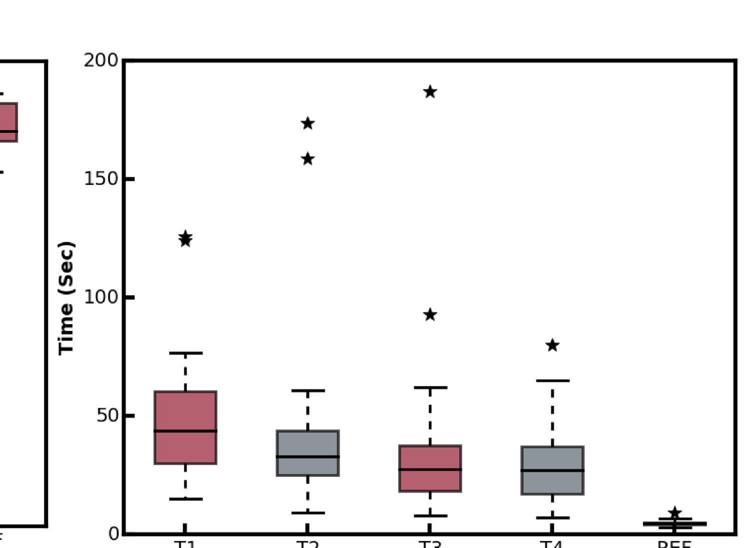

Figure 6. Vehicle Challenge Duration. This metric corresponds to the total time to perform a transfer into and then out of the SUV.

Clinical Significance

Clinical significance for each metric was computed with the following statistical methods:

- Standardized mean difference effect size (ES) for repeated measures (RM) design [1]:

$$ES_{RM} = \frac{\bar{X}_{post} - \bar{X}_{pre}}{S_D}, S_{\bar{D}} = s_{pre}\sqrt{2(1-r)}, S_{\bar{D}} = \sqrt{s_{pre}^2 + s_{post}^2 - 2r s_{pre} s_{post}}$$

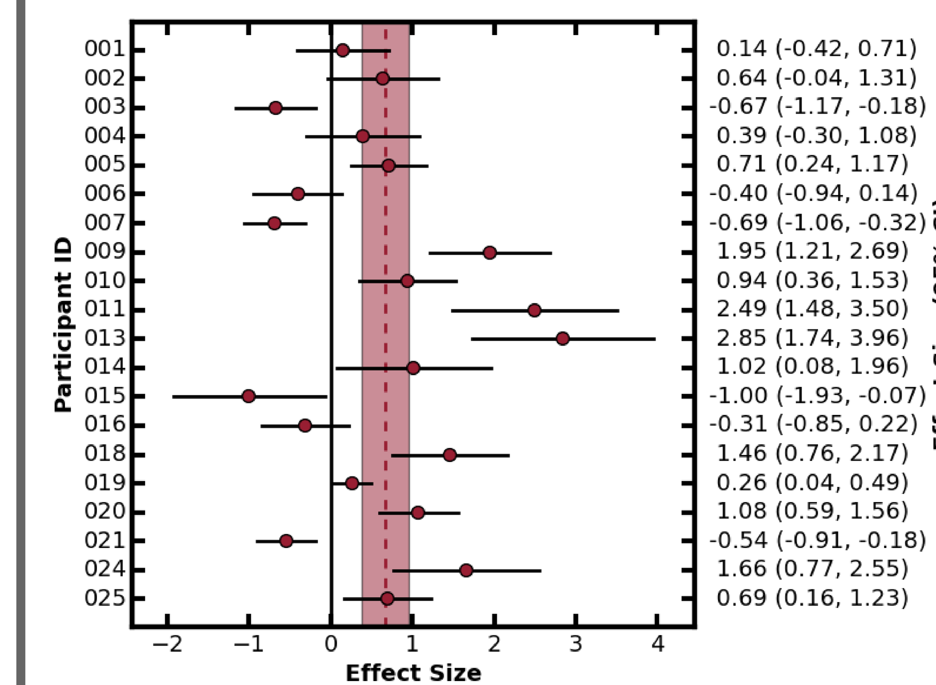

Figure 7. Range of motion (ROM) ES. The left shank ROM exhibits a significant ES at the group level. Individual ES are quite varied due to the complexity of the injury, comorbidities, and recovery process.

- Reliable Change Index (RCI):

$$RCI = \frac{x_{post} - x_{pre}}{\sqrt{2 S_D{}^2}}$$

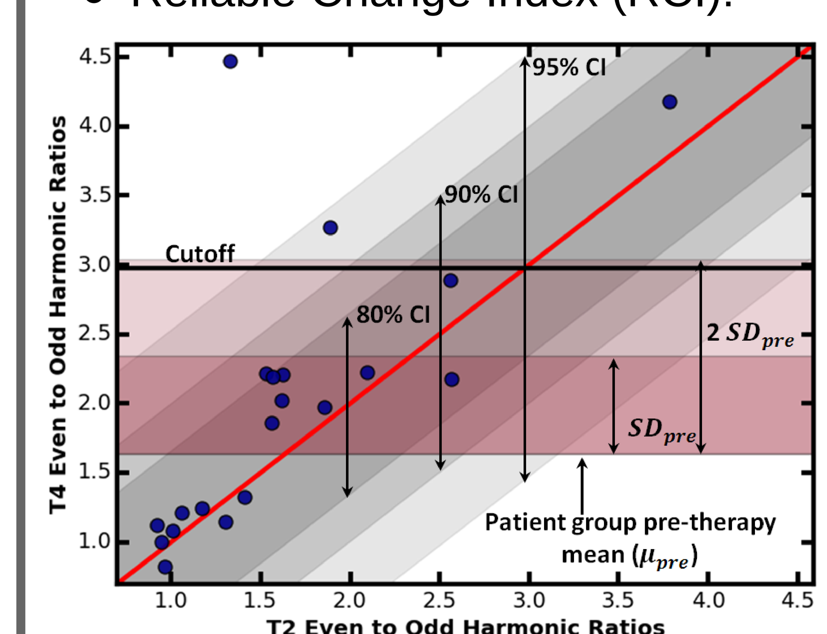

Figure 8. RCI visualization of smoothness index. One participant demonstrated they are on their way to improvement with change just outside the 80% CI. Two participants showed substantial improvements in the smoothness of their walking.

Data Processing

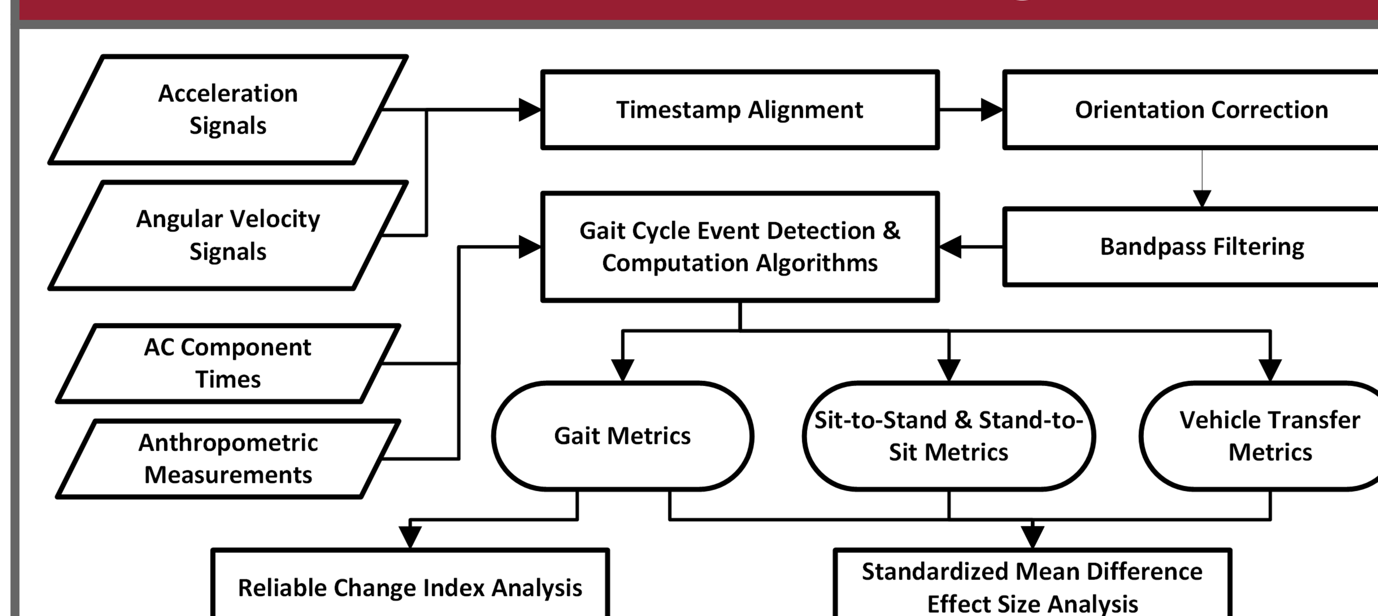

Figure 9. Signal Processing. Sensor data were aligned, oriented [2], filtered, and segmented prior to computing AC metrics [3-5].

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