# Evaluating the Impact of Wearable Sensor Location on Gait Event Detection Algorithms

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## Introduction

The use of wearable sensors such as Inertial Measurement Units (IMUs) to quantify gait characteristics in both healthy and clinical populations is increasing. As such, algorithms to interpret these wearable data are emerging. There are several algorithms that use the 3D acceleration and/or rotational velocity vectors from IMU sensors to identify gait events (i.e. toe-off and heel-strike). These gait events are then used to derive temporal gait metrics that can inform clinical diagnoses or assessment. However, a clear understanding of how sensor location on the body effects the accuracy of gait event detection algorithms is lacking.

**Purpose:**
To conduct a robust, systematic evaluation of the impact of sensor location on the accuracy of five common gait event detection algorithms.

## Materials and Methods

<u>Participants</u>

- N = 7 individuals with no known gait impairments (4M/3F; 26.0 ± 4.0 years of age)
- Provided written informed consent

<u>Participant preparation</u>

- Five inertial measurement units (IMUs) from the Xsens MTw Awinda system were placed on the lower leg of participants (Fig 1)

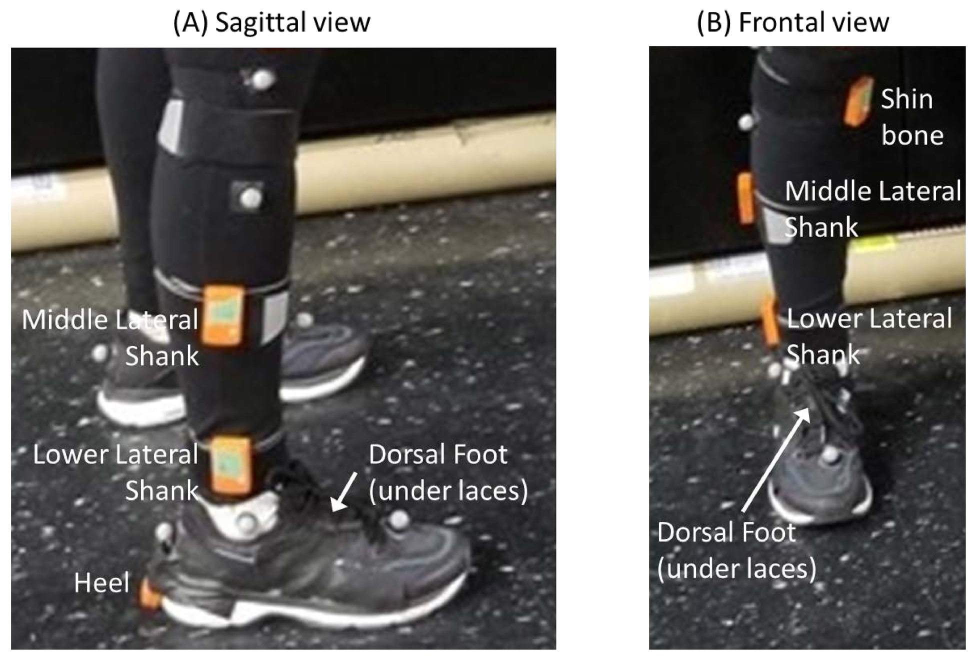


**Figure 1:** IMU placements on the lower leg.

## Materials and Methods (cont.)

<u>Data collection</u>

- Participants were asked to walk at a self-selected pace across a 16' pressure sensing walkway (Protokinetics Zeno walkway) six times
- Pressure data capturing heel strike (HS) and toe-off (TO) gait events were captured from pressure walkway (Fig 2)
- 3D accelerometer and rotational velocity were captured from all five IMU sensors

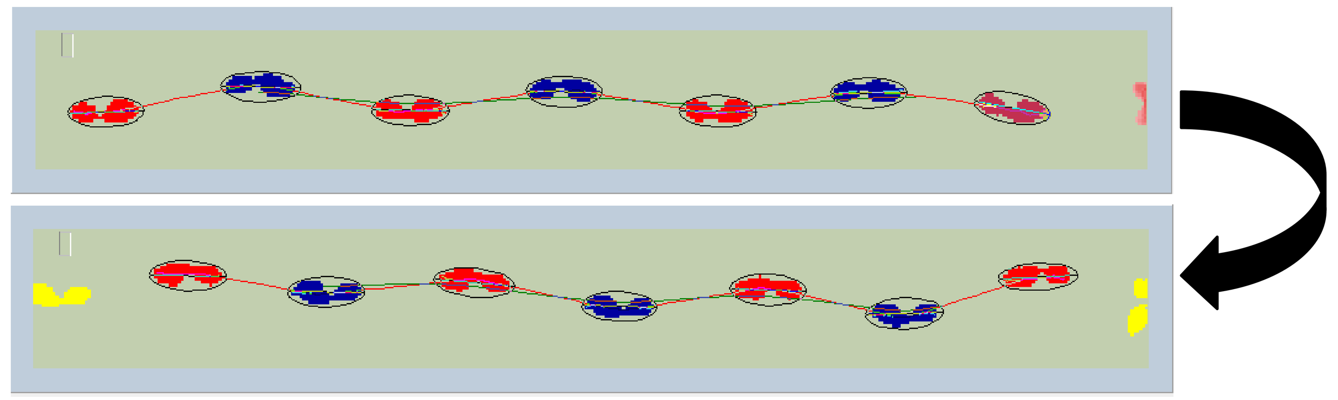

**Figure 2:** Sample Zeno Walkway data showing right (red) and left (blue) footfalls during the task

<u>Data analysis</u>

- Five different algorithms were applied to the IMU data to derive HS and TO gait events:
  1) Rotational velocity minima (medial-lateral axis)
  2) Rotational velocity zero crossing (medial-lateral axis)
  3) SIacc/APacc (HS → superior-interior acceleration minima; TO → anterior-posterior acceleration minima)
  4) MLvel/APacc (HS → medial-lateral rotational velocity minima; TO → anterior-posterior acceleration minima)
  5) APacc/MLvel (HS → anterior-posterior acceleration maximum w/in window; TO → medial-lateral rotational velocity minima)
- Three gait metrics were calculated using the reference pressure walkway and IMU data:
  - Stride time → time between subsequent HSs
  - Stance time → time between HS and TO
  - Swing time → time between TO and HS
- Root Mean Square error (RMSe) and mean absolute bias between reference system and IMU-derived gait metrics for each algorithm were calculated

## Results

| | | Stance Time | | | | |
|---|---|---|---|---|---|---|
| Algorithm Type | | Dorsal Foot | Heel | Lower Lateral Shank | Middle Lateral Shank | Shin Bone |
| (1) Velocity Minima | RMSE | 90.3 | 74.7 | 58.6 | 56.3 | 65.9 |
| | Abs Bias | 87.6(22.1) | 71.7(20.8) | 52.5(26) | 52.8(19.3) | 61(24.9) |
| (2) Velocity Zero Crossing | RMSE | 61.8 | 64.2 | 87.3 | 92.6 | 90.3 |
| | Abs Bias | 58.5(20) | 60.2(22.1) | 84.9(20.3) | 90.7(18.6) | 88.5(17.7) |
| (3) SIacc/APacc | RMSE | 40.3 | 206.9 | 58.7 | 51.7 | 51.8 |
| | Abs Bias | 34.4(21) | 190.6(80.6) | 41.5(41.5) | 40.9(31.6) | 45.6(24.5) |
| (4) MLvel/APacc | RMSE | 50.9 | 221.8 | 28.9 | 22.2 | 40.6 |
| | Abs Bias | 45.7(22.4) | 196.9(102.3) | 22(18.7) | 17.9(13.2) | 32.4(24.5) |
| (5) APacc/MLvel | RMSE | 40.2 | 47.5 | 74.8 | 69.4 | 48.9 |
| | Abs Bias | 36.8(16.2) | 44.9(15.5) | 62.5(41.0) | 64.0(26.9) | 46.4(15.5) |

**Table 1.** Stance time RMSE and mean absolute bias values (standard deviation) for the straight over ground walking task reported in milliseconds. Algorithm type is represented by each row; sensor location is represented in each column.

| | | Swing Time | | | | |
|---|---|---|---|---|---|---|
| Algorithm Type | | Dorsal Foot | Heel | Lower Lateral Shank | Middle Lateral Shank | Shin Bone |
| (1) Velocity Minima | RMSE | 93.1 | 72.4 | 60 | 53.7 | 61.4 |
| | Abs Bias | 91.3(18.1) | 69.5(20.4) | 51.9(30.1) | 50.9(17.1) | 57.6(21.5) |
| (2) Velocity Zero Crossing | RMSE | 62 | 64.3 | 87.5 | 92.7 | 90.2 |
| | Abs Bias | 59.5(17.6) | 60.9(20.5) | 85.5(18.6) | 91.3(16) | 88.9(15.3) |
| (3) SIacc/APacc | RMSE | 43.5 | 207.8 | 50.9 | 50 | 52.9 |
| | Abs Bias | 36.4(23.9) | 191.5(80.6) | 35.2(36.8) | 40.6(29.2) | 47.8(22.7) |
| (4) MLvel/APacc | RMSE | 51.2 | 219.5 | 30 | 23.7 | 36.3 |
| | Abs Bias | 46.3(22) | 195.9(99.0) | 23.3(19.0) | 18.9(14.3) | 28.9(21.9) |
| (5) APacc/MLvel | RMSE | 37.8 | 49.5 | 70.6 | 75.7 | 52.4 |
| | Abs Bias | 34.8(14.7) | 47.3(14.4) | 58.3(39.7) | 70.0(28.9) | 50.2(14.9) |

**Table 2.** Swing time RMSE and mean absolute bias values (standard deviation) for the straight over ground walking task reported in milliseconds. Algorithm type is represented by each row; sensor location is represented in each column.

| | | Stride Time | | | | |
|---|---|---|---|---|---|---|
| Algorithm Type | | Dorsal Foot | Heel | Lower Lateral Shank | Middle Lateral Shank | Shin Bone |
| (1) Velocity Minima | RMSE | 17.2 | 9.2 | 28.3 | 12.1 | 15.7 |
| | Abs Bias | 11.5(12.8) | 7.2(5.6) | 18.6(21.4) | 9.4(7.6) | 10.7(11.5) |
| (2) Velocity Zero Crossing | RMSE | 12.3 | 12.4 | 12.6 | 12.8 | 12.8 |
| | Abs Bias | 9.7(7.5) | 9.9(7.5) | 10.1(7.6) | 10.2(7.7) | 10.2(7.6) |
| (3) SIacc/APacc | RMSE | 35 | 33.6 | 45.5 | 53.3 | 28 |
| | Abs Bias | 21.8(27.4) | 23.3(24.2) | 29.6(34.6) | 40.6(34.6) | 21.4(18.1) |
| (4) MLvel/APacc | RMSE | 14.8 | 13.4 | 11.7 | 10.7 | 34.6 |
| | Abs Bias | 10.5(10.5) | 9.8(9.1) | 9.4(6.9) | 8.8(6.1) | 24.9(24.1) |
| (5) APacc/MLvel | RMSE | 29.1 | 20.1 | 70.4 | 52.9 | 52.3 |
| | Abs Bias | 18.6(22.4) | 11.0(16.8) | 51.9(47.5) | 33.3(41.0) | 33.7(40.0) |

**Table 3.** Stride time RMSE and mean absolute bias values (standard deviation) for the straight over ground walking task reported in milliseconds. Algorithm type is represented by each row; sensor location is represented in each column.

*<u>Key Takeaways</u>*

- *Despite the extremely high RMSE and mean absolute bias values for the MLvel/APacc algorithm (type 4) at the heel location, this algorithm appears to be the most robust against sensor location.*
- *The middle lateral shank and heel location produced some of the lowest RMSE values for stride, stance, and swing times.*

## Conclusion

- Results show both the robustness and degradation of certain algorithms as a function of sensor location.
- Understanding how certain types of algorithms perform for given sensor locations can inform clinical protocol development using wearable technology to characterize gait in both laboratory and real-world settings.
- Based on the results presented for straight over ground walking, the MLvel/APacc algorithm (type 4) used with a sensor mounted on the middle lateral shank location may produce the lowest error overall.

## Acknowledgements & Disclaimers

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The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the U.S. FDA Institutional Review Board (# 2019-CDRH-002).

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