Wearable Low-cost Motion Trackers for Dynamic Stability Parameters – Calibration based on Artificial Intelligence

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BACKGROUND

Motion analysis of gait and balance is valuable but costly and ***not accessible in clinical settings***

Gold-standard optical systems

- e.g. Vicon, Qualysis
- ≈1 mm accuracy
- But expensive >AUD200k / GBP100k

Wearable motion trackers

- Low cost ≈AUD200 / GBP100 (Ultimate Trackers)
- But larger errors (≈30 mm) *(He et al., 2026)*

AI (e.g. deep learning) has potential to **improve accuracy** of low-cost systems for balance and gait parameters

AIM

To examine if AI (deep learning) can improve accuracy of low-cost motion trackers to estimate dynamic stability parameters.

METHODS

Participants

- 10 (5M / 5F) healthy adults
- Age 32±7 yr, BMI 23±2 kg/m²

Experimental Setup

- Walking on a treadmill (0.5-2.0 m/s)
- **Concurrent capture:**
  - 8-Vicon cameras (100 Hz) Full-body (39 markers)
  - 3 trackers on sacrum and feet (HTC VIVE Ultimate Trackers, 100 Hz)

Gait and Dynamic Stability Parameters

- Step height, length, width, foot clearance
- Margin of stability (MoS)

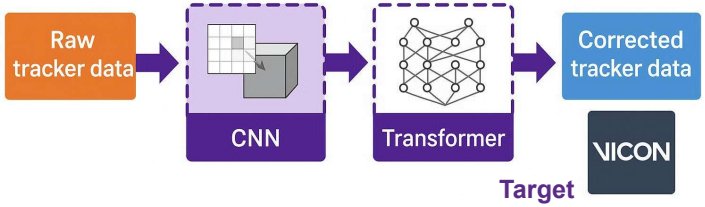
Distance between the body's extrapolated center of mass (CoM) and the base of support (BoS) boundary

👉How stable a person is at the movement

(Hof et al., 2004)

AI Model Training

- **Training data**: ≥ 2700 steps



Target

- **Features:** Coordinate axis directions, spatial magnitude, tracker locations, speeds (task 1) + pelvis thickness (task 2)
- **Task 1** Improves accuracy of **raw sacrum and feet data**
- **Task 2** Estimate whole-body **CoM** from a sacrum tracker
- **Cross-validation:** Leave-one-person-out method (n = 10)

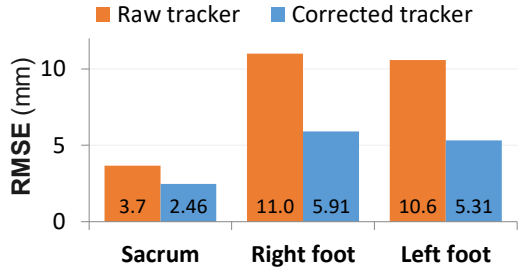
Statistical Analysis

- **RMSE & MAE**: how far tracker data is from Vicon
- **ICC**: how closely results match Vicon (ICC > 0.90 = excellent agreement)
- RMSE (Root Mean Square Error), MAE (Mean Absolute Error), ICC (Inter-Class Correlation)

RESULTS

Key Results of Task 1

- The AI model improved tracker accuracy by **28–55%**



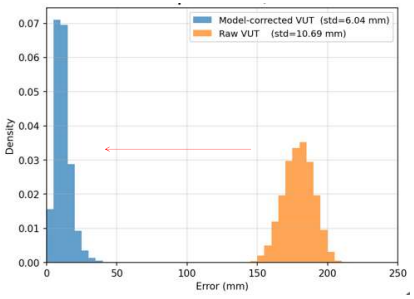
- **Gait parameters** based on the corrected tracker data showed **excellent agreement**

Parameter	MAE (mm)	ICC
Step height	0.24–0.71	**>0.99**
Step length	1.73–4.63	**>0.99**
Step width	0.15–0.95	**>0.99**
Foot clearance	0.26–0.88	**0.93–0.99**

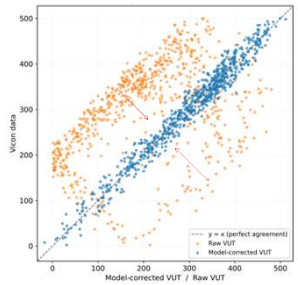
Key Results of Task 2

- The AI model improved **CoM** estimate based on the single sacrum tracker
  - RMSE reduced from ~104 mm to < 9 mm
  - ICC increased from 0.09–0.80 → >0.99
- Margin of stability's ICC improved 0.65 → >0.99

CoM Error Distribution



Margin of Stability



DISCUSSION

Primary Findings

- **AI model substantially improved accuracy of low-cost motion trackers (up to ~55%), approaching gold standard**
- Single sacrum sensor can approximate whole-body CoM
- Excellent agreement for gait and dynamic stability parameters (ICC > 0.90–0.99)

Clinical relevance

- Enables motion analysis accessible in clinics and community
- Reliable evaluation of gait impairment or treatment effects using low-cost motion trackers

Future directions

- Validate in larger and clinical populations
- Test overground, turning, and dual-task walking
- Develop real-time, event-aware models for clinical use

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