Concurrent Validity of a Belt-Type IMU for Postural Sway Measurement: A Pilot Comparison with a Force Plate and Vision-Based System

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벨트형 IMU 기기의 자세동요 측정 동시타당도: 힘판 및 비전 기반 시스템과의 예비 비교 연구

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This pilot study assessed the concurrent validity of a self-developed belt-type IMU system (100 Hz, MPU-9250) by comparing its postural sway measurements with those from a PhysioSensing force plate and an Intel RealSense D405 vision-based system. Three healthy adults performed static standing (Romberg stance) under eyes-open (EO) and eyes-closed (EC) conditions (30 s × 5 trials each). Pearson correlation, linear regression (R^2), and ICC(2,1) analyses were conducted at the trial level (N=15 trials/condition). IMU-derived sway parameters showed strong correlations with the force plate (r=0.869–0.904) and vision system (r=0.882–0.939). R^2 values ranged from 0.75 to 0.88. These preliminary findings support further large-scale validation of the belt-type IMU as an accessible alternative for clinical postural sway assessment. Keywords: Concurrent Validity; Inertial Measurement Unit; Postural Sway; Force Plate; Balance Assessment

1. Introduction

Postural sway analysis is a widely used biomechanical indicator for quantitatively evaluating balance control and fall risk. Force plates are the gold standard for measuring center of pressure (COP) displacement, but their high cost and limited portability restrict clinical use. IMU sensors — integrating accelerometers, gyroscopes, and magnetometers — offer compact, wearable alternatives. However, concurrent validity between IMU-derived sway and standard laboratory systems remains incompletely characterized. This pilot study aimed to compare a novel belt-type IMU system with both a force plate and a vision-based system under standardized static standing conditions.

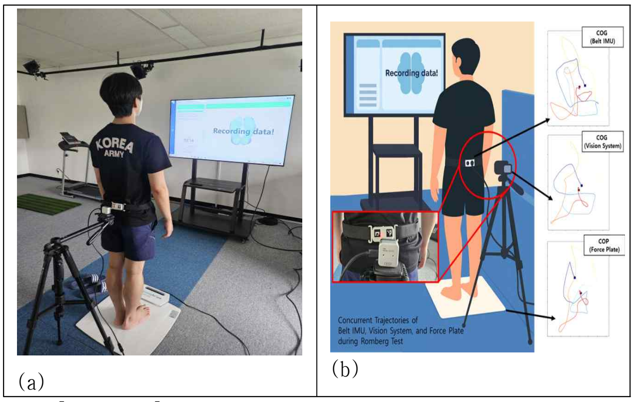
2. Methods

2.1 Participants and Devices

Three healthy male adults (mean age 32.7±8.1 years; height 178.7±4.7 cm; weight 89.0±7.9 kg) participated. Three systems were used simultaneously: (1) Belt-type IMU (9-axis MPU-9250, 100 Hz, inverted pendulum model at S2 level); (2) Force plate (PhysioSensing PS-01, 30 Hz, COP measurement); (3) Vision-based system (Intel RealSense D405, 30 Hz, ArUco marker tracking)(Figure 1). IRB approval was obtained (KNUT-2025-HR-11-33).

2.2 Protocol and Analysis

Participants stood barefoot in Romberg stance under EO and EC conditions (30 s × 5 trials). Sway length (mm) and mean velocity (mm/s) were computed. IMU signals were filtered (accelerometer: 2 Hz low-pass; gyroscope: 1 Hz high-pass; 8th-order Butterworth) and downsampled to 30 Hz for comparison. Pearson r, R^2, ICC(2,1), and Bland-Altman analysis were performed at the trial level.



(a) (b)

[Figure 1] Experimental setup and data acquisition. (a) Measurement environment in Romberg stance. (b) Its schematic representation illustrating the system configuration and data flow.

3. Result

All three systems showed significant correlations under both conditions (Table 1).

[Table 1] Correlation coefficients between measurement systems (N=15 trials per condition)

Comparison	Condition	r	R^2	p
IMU vs Force Plate	EC	0.869	0.75	<0.001
IMU vs Vision	EC	0.939	0.88	<0.001
Vision vs Force Plate	EC	0.876	0.77	<0.001
IMU vs Force Plate	EO	0.904	0.82	<0.001
IMU vs Vision	EO	0.882	0.78	<0.001
Vision vs Force Plate	EO	0.938	0.88	<0.001

EC = Eyes Closed; EO = Eyes Open

4. Discussion and Conclusion

The belt-type IMU system produced postural sway metrics strongly correlated with both laboratory-grade reference systems. The highest correlations were observed under EC conditions (r=0.939 vs vision; r=0.869 vs force plate), where sway magnitude was larger and more discriminable. These findings support the clinical potential of the IMU system as an accessible, portable tool for balance assessment in community and clinical settings. The inverted pendulum model at the S2 level effectively converted angular displacement into COG trajectories comparable to COP measurements. Larger-scale validation studies across diverse populations are needed before clinical adoption.

References

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