Validity of a Wearable Sensor System for Assessing Balance in High-Functioning Lower-Limb Prosthesis Users

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INTRODUCTION

Over half of individuals with lower-limb loss are at risk of falls and fall-related injuries (Miller, 2001) resulting from impaired gait and balance (Kamali, 2013). Common clinical measures assessing balance lack the detail and specificity to capture underlying movement factors, but innovations in wearable technology permit clinically applicable means of quantifying various balance-related performance measures. This study assessed the validity of the Mobility Lab (APDM, Portland, OR) for measuring balance in lower-limb prosthesis users (LLPUs).

METHOD

Subjects: 22 LLPUs (45±16yrs.; 91±15kg; 179±7cm. Level: 11 transtibial, eight transfemoral, two knee disarticulations, one proximal femoral focal deficiency. Etiology: 13 trauma, two dysvascular, three congenital, four other (21 unilateral, one bilateral); and 24 able-bodied controls (32±13yrs; 79±17kg; 176±10cm).

Apparatus: The Mobility Lab consists of inertial sensors fixed to the torso, lumbar, wrists, and feet. Data on body-segment orientation, acceleration, and velocity are used to estimate performance during defined tasks. Perceived mobility and balance confidence of LLPUs were measured with the 12-item Prosthetic Limb Users Survey of Mobility (PLUS-M) (Hafner, 2016) and Activities-specific Balance Confidence (ABC) Scale (Powell, 1995), respectively.

Procedures: After obtaining informed consent, subject characteristics were collected and the PLUS-M and ABC Scale were administered. Sensors were then attached, and subjects performed two trials of the Instrumented Stand and Walk Test, which involved standing quietly for 30 seconds and then walking 7m forward, turning 180°, and walking back along the same path. The second trial involved performing the 180° turn in the opposite direction. A practice trial and rest as needed were provided.

Data Analysis: Thirty-one measures assessing standing postural control, gait parameters, and trunk dynamics were analyzed. Data normality was assessed with the Shapiro-Wilk Test ($\alpha=0.05$). Two validation analyses were performed: (1) Known-groups: Data between cohorts were compared using a t-test (normal data) or Mann-Whitney U test (non-normal); and (2) Correlation: Relationships between the sensor data and ABC Scale and PLUS-M (T-score) were assessed by estimating the Spearman's ρ. A correction factor to account for Type-I error was not used due to the exploratory nature of this study.

RESULTS

Table 1 displays only statistically significant results. First step range-of-motion (ROM) data were analyzed for 13 LLPUs and 23 controls as the sensors were unable to collect these data for all subjects. The ABC Scale and PLUS-M were strongly correlated ($\rho=0.887$; $p<0.001$). The mean (±SD) ABC score and PLUS-M T-score were 96.0±4.9 and 64.4.9±6.1, respectively.

	Measure	*Control (mean±SD)*	*LLPU (mean±SD)*	*p-value*
Known-groups	First step ROM (°)	34.0±6.9	45.1±4.7	<0.001
Known-groups	Trunk coronal ROM (°)	5.4±2.0	7.5±2.8	0.006
Known-groups	Trunk transverse ROM (°)	7.7 ±1.4	10.8 ± 2.1	<0.001
Correlation	*Measure*	ρ		*p-value*
Correlation	Coronal Postural Sway-Centroidal Frequency (Hz)	ABC: -0.509 PLUS-M: -0.586		ABC: 0.016 PLUS-M: 0.004
Correlation	Sagittal Postural Sway-Sway Area Radius (°)	ABC: 0.422 PLUS-M: 0.451		ABC: 0.051 PLUS-M: 0.035

Table 1. Statistically significant results.

DISCUSSION

Due to the convenience sampling, participants were high-functioning LLPUs as evidenced by the high ABC and PLUS-M scores. However, the Mobility Lab recorded three sensitive functional balance measures distinguishing LLPUs from controls. The finding of greater first step ROM in LLPUs is reasonable due to the need for generating momentum when leading with the prosthetic limb. Larger LLPU trunk ROM may aid forward ambulation when using prostheses with limited propulsion, but it produces greater body mass excursion. The negative relationships of perceived mobility and balance confidence to postural sway frequency suggest that higher functioning LLPUs implement less rapid postural adjustments, while the positive relationships to postural sway area suggest that higher functioning LLPUs may be more capable of exploring their standing ROM.

CONCLUSION

The results provide partial validation of the Mobility Lab to measure LLPU mobility and balance. Future research should test a wider range of user mobility levels.

CLINICAL APPLICATIONS

Wearable sensor systems may provide an efficient and effective method of characterizing functional balance of LLPUs in clinical settings.

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