ESTIMATING STEP LENGTH OF LOWER LIMB PROSTHESIS USERS WITH A LOW-COST ACCELEROMETER

Major, M.J.[1], Raghavan, P.[1], Gard, S.A.[1,2]

[1]Northwestern University Prosthetics-Orthotics Center, Chicago, IL; [2]Jesse Brown VA Medical Center, Chicago, IL

INTRODUCTION

Inexpensive and clinically-accessible methods for the characterization of lower-limb prosthetic gait have the potential to allow clinicians to readily evaluate and monitor gait quality. Moreover, a device that has the capability of continuous measurement outside of a research laboratory may provide a more realistic representation of a prosthesis user's gait. Methods have been established that allow for the estimation of step length (SL) in able-bodied gait using body center-of-mass (BCoM) accelerations as provided by an accelerometer fixed to the lower back (Moe-Nilssen, 1998; Zijlstra, 2003). These methods have been implemented in commercial wearable accelerometer devices (e.g., G-Walk (BTS, Milan, Italy)), but remain expensive and often have not been validated for use with lower limb prosthesis users. The purpose of this study was to develop and assess a system for estimating SL in gait of lower limb prosthesis users using a low-cost accelerometer.

METHOD

Subjects: Five able-bodied individuals (3 male, 2 female) and 20 individuals with lower limb amputation (17 male, 3 female; 17 unilateral amputation (8 transfemoral, 9 transtibial), 3 bilateral amputation).

Apparatus: A 3-axis accelerometer (Model X6-2, Gulf Coast Data Concepts, Waveland, MS) and an 8-camera optical motion capture system (Motion Analysis Corporation, Santa Rosa, CA).

Procedures: Approximated BCoM accelerations and motion of the heels and toes of both feet were collected concurrently on able-bodied subjects with the accelerometer (at 160 Hz) strapped to the back at the L4 region, and motion capture system (at 120 Hz), respectively. Able-bodied subjects performed two sets of 5 walking trials across a straight 10 meter walkway that were separated by the event of doffing and donning the accelerometer. Only BCoM accelerations were collected for amputee subjects as they walked along a straight 20 meter path (subjects started and stopped at the ends of this path).

Data Analysis: SL was estimated from the acceleration data using established methods (Moe-Nilssen, 1998; Zijlstra, 2003) and from the motion capture data with custom software in Matlab (Mathworks, Natick, MA). Test-retest reliability was assessed by comparing average able-bodied SL between each set of five trials as estimated from the accelerometer system, and quantified using the Intraclass correlation coefficient (ICC(2,1)). Concurrent validity of the accelerometer system was assessed by comparing individual able-bodied SLs as estimated from the accelerometer system and motion capture across all 10 trials. The accelerometer system was validated for amputee subjects by comparing the total distance walked as estimated from the accelerometer system (summation of step lengths) to the actual walked distance of 20 meters. The accelerometer method was optimized through identifying a correction factor for each subject group that minimized the error in SL and total distance walked, respectively.

RESULTS

Regarding test-retest reliability, the ICC value was 0.952. Table 1 displays the validation results.

	ABLE-BODIED	AMPUTEE
Correction Factor	1.165	1.005
Average Error (%)	14%	12%
Average SL (m)	0.74	Unilateral: 0.57 (S); 0.67 (P) Bilateral: 0.64

Table 1. Validation results; Error values are for SL and distance walked for able-bodied and amputee subject groups, respectively, after applying the correction factor. S=sound side, P=prosthetic side.

DISCUSSION

The accelerometer system demonstrated high test-retest reliability, supporting its clinical suitability. The accelerometer system consistently underestimated SL for able-bodied individuals, but demonstrated a close match with motion capture estimations following application of a correction factor, with SL values that agree with the literature (Perry, 2010). Across amputee subjects, the average absolute error of total distance walked was relatively large (approximately 3-4 steps), with the accelerometer system both over and underestimating this distance. Average error in the amputee group did not appear to be affected by amputation level or number of limbs involved.

CONCLUSION

Evaluation of the accelerometer system demonstrated adequate test-retest reliability and concurrent validity of this technique for able-bodied individuals. Further refinement and evaluation of this system is warranted for use with lower limb prosthesis users.

CLINICAL APPLICATIONS

Inexpensive and clinically-accessible techniques for evaluating gait quality in lower limb prosthesis users will facilitate monitoring of intervention effectiveness.

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