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Section: Technical Report

Article Title: Concurrent Validity of a Commercial Wireless Trunk Tri-Axial Accelerometer System for Gait Analysis

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Running Head: Concurrent validity of the G-walk sensor system

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Concurrent validity of a commercial wireless trunk tri-axial accelerometer system for gait analysis

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Abstract

Context*:* Wearable sensor devices have notable advantages, such as cost effectiveness, easy-to-use and real-time feedback. Wirelessness ensures full body motion which is required during movement in a challenging environment such as during sports. Research on the reliability and validity of commercially available systems, however, is indispensable. **Objective**: To confirm the test-retest reliability and concurrent validity of a commercially available body worn sensor - BTS G-WALK® sensor system - for spatio-temporal gait parameters with the GAITRite® walkway system as golden standard. **Design***:* Reliability and concurrent validity study. **Setting***:* Laboratory setting. **Participants***:* Thirty healthy subjects. **Main outcome measures***:* Spatiotemporal parameters: speed, cadence, stride length, stride duration, stance duration, swing duration, double support, and single support. **Results***:* In terms of test-retest reliability of the BTS G-WALK® sensor system, ICC values for both the spatial and temporal parameters were excellent between consecutive measurements on the same day with ICC-values ranging from 0.85 – 0.99. In terms of validity, ICC values between measurement systems showed excellent levels of agreement for speed, cadence, stride length, and stride duration (range 0.88 – 0.97). Poor to moderate levels of agreement (range 0.12 – 0.52), however, were found for single/double support and swing/stance duration. Bland Altman plots showed overall % bias values equal to or smaller than 3% with limits of agreement ≤ 15% (speed, cadence, stride length, stride duration, swing duration and stride duration). Only for single and double support, the limits of agreement were higher with respectively -15,4 to 19.5% and -48.0 to 51.4 %. **Conclusion***:* The BTS G-WALK® sensor system is reliable for all measured spatio-temporal parameters. In terms of validity, excellent concurrent validity was shown for speed, cadence, stride length and stride duration. Cautious interpretation is necessary for temporal parameters based on final foot contact (stance, swing and single/double support time).

Introduction

Wearable sensor devices have notable advantages, such as cost effectiveness, easy-to-use and real-time feedback. Wirelessness ensures full body motion which is required during movement in a challenging environment such as during sports. These technology systems allow clinicians to benefit from data gathered during the performance of everyday activities or sports and data recorded under controlled conditions in clinical settings.[1] For gait analysis, such wearables are potentially useful for assessing abnormal gait and evaluating the effectiveness of rehabilitation approaches and therapeutic interventions.

It has been demonstrated that spatio-temporal gait parameters can be determined during overground walking using only one tri-axial trunk accelerometer.[2] However, to overcome some associated critical issues as the need for gravity compensation and the presence of drift error in the position data, data fusion of linear acceleration (accelerometer) and angular velocity (gyroscope) combined in an inertial measurement unit (IMU) permits compensation.[3] Notwithstanding the closer the IMU is positioned to the point of contact (e.g. on the shank) the better gait events can be correctly detected[4], lower trunk acceleration patterns have been consistently associated with initial and final foot contact.[5] Recently, industry transfers technology development made in research[6] to implement it in clinical routine. For example, the G-WALK is a user-friendly device, without post-processing handling needed to obtain the gait parameters. This aspect is really important to facilitate technology adoption.[7] However, before using them for clinical interpretation, we need to define their reliability and validity. The latter can be done by comparing the spatio-temporal parameters of gait obtained from the IMU to a golden standard, such as the GAITRite® system with proven reliability and validity of spatio-temporal gait parameters.[8]

The purpose of this study was to confirm the test-retest reliability and concurrent validity of a commercially available body worn sensor - BTS G-WALK® sensor system - for spatio-temporal gait parameters in a healthy population with the GAITRite® walkway system as golden standard.

Methods

Subjects

Thirty healthy subjects (15 male, 15 female, mean age of 37.8 years with 20-56 range) volunteered to participate in this study. The average weight and height of the subjects is 73.8 ± 16.84 kg and 173.6 ± 9.42 cm, respectively. Subjects had to be healthy and were excluded if they reported to have any musculoskeletal, neurological or systemic pathology potentially affecting their gait. All participants were informed about study procedures prior to signing an institutionally approved informed consent. This study was approved by the ethical committee of the XXX (n°: BE670201526917).

Experimental approach and Materials

The BTS G-WALK® (BTS Bioengineering S.p.A. Italy) inertial sensor was placed on the lower back with the centre of the device at the fifth lumbar vertebrae (L5) (Fig 1). The inertial platform is equipped with 4-Sensor Fusion technology and consists out of a tri-axial accelerometer 16bit/axes (8g), a tri-axial magnetometer 13 bit (1200uT), a tri-axial gyroscope 16 bit/axes (250°/s) and a GPS Receiver. The BTS G-WALK® sensor system determines spatio-temporal parameters as well as pelvic rotations during gait and other movements real-time through a Bluetooth® 3.0 connection (G-Studio® software). For the current research question only spatio-temporal parameters were used for further analysis.

The GAITRite® walkway system used for this study measured 7.03 m x 0.89 m with an active sensor area of 6.13 m x 0.56 m. The sensors are triggered when mechanical pressure is applied at a used sampling rate of 100 Hz. Data is collected by on-board processors for a connected computer to receive through a serial port (GAITRite® Software).

Procedures

Each subject performed 5 walking trials on the GAITRite® sensor system. All subjects wore their own comfortable and non-restricting clothing. Every individual was instructed to walk towards the end of the walkway mat at their own everyday pace. During each trial, both the GAITRite® sensor system and the BTS G-WALK® sensor system (G-Studio® software) recorded equivalent parameters to be analyzed and compared. The parameters that were registered by both systems were speed (m/s), cadence (steps/min), stride length (m), stride duration (sec), stance duration (% of gait cycle (GC)), swing duration (%GC), double support (%GC), single support (%GC).

Data analysis and statistics

Based on comparison with the GAITRite® sensor system, the following methods were used to determine the reliability and validity of the BTS G-WALK® sensor system. For unilateral (left and right) outcome measures only the data from the right side was included for analysis. Normality of the data was verified using the Shapiro-Wilk test. The reliability of the BTS G-WALK® sensor system outcome measures across the five walking trials were examined using Intra Class Correlations (two-way mixed, absolute agreement). For establishing validity, means and standard deviations were calculated for each parameter for both sensor systems over the 5 walking trials. Then, Intra Class Correlations between the two methods were calculated. A paired sample T-test was performed to determine systematic differences between the two systems. Subsequently, Bland-Altman plots with 95% limits of agreement (LoA) (mean difference ± 1.96 SD) were generated to visualize the degree of agreement between the BTS G-WALK® sensor system and the GAITRite® sensor system measurements. Based on the Bland Altman plots the percentage bias was calculated with the GAITRite system as reference standard (((mean G-Walk – mean GAITRite)/ mean GAITRite)*100). Statistical significance for all tests was determined at the 5% level.

Results

Inter trial reliability

Reliability of all spatio-temporal gait variables recorded by means of the BTS G-WALK® sensor system across the 5 trials is presented in Table 1. Overall, excellent inter trial reliability (ICC values between 0.84 and 0.99) is shown.

Concurrent validity

Table 1 also displays comparative data for both gait analysis systems. ICC values showed excellent levels of agreement for speed, cadence, stride length, and stride duration (range 0.88 – 0.97). Poor to moderate levels of agreement (range 0.12 – 0.47), however, were found for the relative temporal parameters that divide the gait cycle in phases (single/double support and swing/stance duration). Paired *t*-tests revealed that there were no significant systematic differences for speed single and double support ($p>0.05$). Comparison for cadence ($p<0.001$), stride length ($p=0.031$) and stride ($p=0.0012$)/swing ($p=0.009$)/stance ($p=0.009$) duration did show a significant difference between devices (table 1). However, Bland Altman plots showed overall % bias values equal to or smaller than 3% with limits of agreement ≤ 15% (speed, cadence, stride length, stride duration, swing duration and stride duration) (Table1; Fig 2). Only for single and double support, the limits of agreement were higher with respectively -15,4 to 19.5% and -48.0 to 51.4 % (Table1; Fig 2).

Discussion

In terms of test-retest reliability of the BTS G-WALK® sensor system, ICC values for both the spatial and temporal parameters are excellent between consecutive measurements on the same day with ICC-values ranging from 0.85 – 0.99. This signifies that BTS G-WALK® sensor system is reliable for all measured parameters.

Concerning the validity, the results require some careful considerations. First of all, paired sample T-test did show significant differences between the two measurement devices for cadence, stride length and stride/swing/stance duration; with no differences for speed, single and double support. However, when taken the % bias into consideration, the overall % bias was equal to or lower than 3%, which is within clinically acceptable limits. Speed, cadence, stride length and stride duration showed excellent ICC values between test devices with Limits of Agreement for % bias ≤ 15%. For swing and stance duration termination moderate ICC values between devices were moderate to good, also with Limits of Agreement for % bias ≤ 15%. Poor ICC values with Limits of Agreement for % bias ≥15%, however, were observed for single and double support. This corresponds with Trojaniello et al. (2014) who evaluated several methods of single IMU's mounted on the lower trunk and showed an acceptable accuracy, sensitivity and robustness for temporal parameters based on the identification of the initial foot contact, i.e. step and stance duration.[9] The accuracy was lower for parameters based on final foot contact (stance, swing and double support time) as larger errors in event determination of final foot contact were observed. To improve validity, future research should focus on ameliorating IMU algorithms for identifying this final foot contact.

Limitations of the current study are that we are unaware of the precise algorithm used by this commercial IMU, which prohibits us from presenting a potential underlying explanation for the reported results. Furthermore, we measured spatio-temporal parameters at a rather homogenous speed in our sample and speed might have an impact on accuracy.[10] Spatio-temporal parameters were registered only over a short distance in a controlled setting and we only included healthy subjects. Reliability and validity (specific parameters) results suggest results that the BTS G-WALK® sensor system might be used in community and athletic settings or clinical studies evaluating treatment effects, however, research in these specific populations is warranted.

In conclusion, the BTS G-WALK® sensor system is a reliable IMU for all measured spatio-temporal parameters. In terms of validity, cautious interpretation is necessary for temporal parameters based on final foot contact (stance, swing and single/double support time). Excellent concurrent validity was shown for speed, cadence, stride length and stride duration.

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Figure 1.

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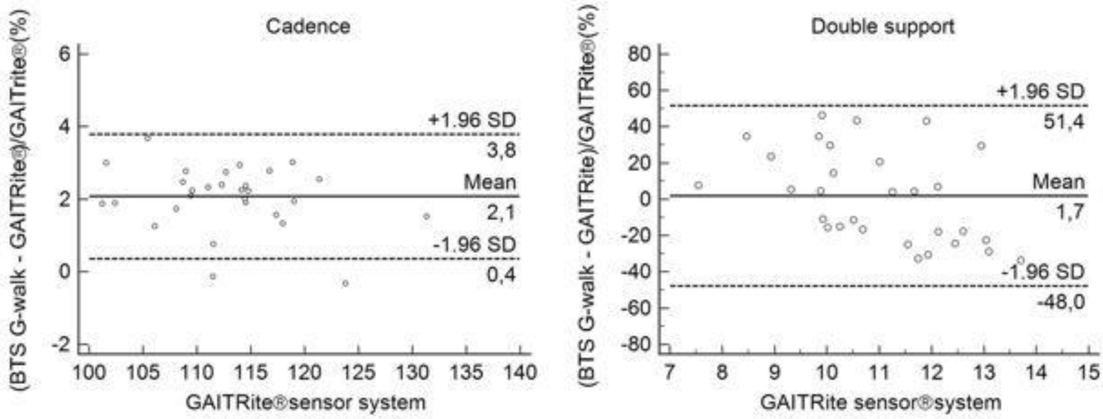

Figure 2.

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Table 1: Reliability of G-walk and Validity outcome measures between G-walk and Gaitrite measuring systems.

	G-walk Mean (SD)	GAITRite Mean (SD)	ICC G-walk (95%CI)	Paired sample T-test		Bias %	LoA%	ICC (95%)G-walk vs GAITRite
				Mean diff (95%CI)	P-value			
Speed (m/s)	1.42	1.44	0.99 (0.98-0.99)	-0.02 (-0.06;0.2)	0.277	-1.6	-15.1;	0.92 (0.83-0.96)
Cadance (st/min)	115.3	113.0	0.98 (0.97-0.99)	2.3 (2.0;2.7)	<0.001	2.1	0.4; 3.8	0.96 (0.02-0.99)
Stride length (m)	1.49	1.53	0.99 (0.98-0.99)	-0.04 (-0.08;-	0.031	-2.9	-15.7; 9.8	0.88 (0.73-0.94)
Stride duration (sec)	1.05	1.06	0.84 (0.73-0.92)	-0.02 (-0.03; -	0.012	-1.3	-6.7; 4.1	0.93 (0.83-0.97)
Single support	38.7 (3.2)	37.9 (1.3)	0.91 (0.85-0.95)	0.7 (-0.5; 2.0)	0.231	2.0	-15.4;	0.18 (-0.70-0.60)
Double support	11.0 (2.5)	11.0 (1.5)	0.89 (0.80-0.94)	0.02 (-1.0;1.1)	0.972	1.7	-48.0;	0.12 (-0.92-0.59)
Swing duration	39.3 (2.3)	38.1 (1.3)	0.85 (0.75-0.92)	1.1 (0.3; 1.9)	0.009	3.0	-8.5; 14.4	0.47 (-0.04-0.74)
Stance duration	60.8 (2.3)	61.8 (1.3)	0.85 (0.75-0.92)	-1.1 (-1.9;-0.3)	0.009	-1.8	-8.6; 5.0	0.47 (-0.36-0.74)

SD=standard deviation; CI=confidence interval; ICC=intraclass correlation coefficient; GC=gait cycle