

Comparison between a center of mass and a foot pressure sensor system for measuring gait parameters in healthy adults

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Abstract. [Purpose] The purpose of this study was to determine the relationship between an accelerometer system and a foot pressure sensor system for measuring gait characteristics during walking in healthy adults. [Subjects and Methods] Thirty-five healthy participants with no neurological, musculoskeletal, or cardiopulmonary disorders volunteered for this study. Gait characteristics were measured while participants walked freely along a 10-m walkway using two different measurement systems simultaneously. The first analysis system was based on center of mass using a wireless tri-axial accelerometer and the second system was a foot pressure sensor system. [Results] There was a significant and high correlation between the two systems with respect to gait velocity and cadence. The stride length as a percentage of the stride height measured with the center of mass system was significantly and highly correlated with stride length and stride velocity that was measured with the foot pressure system. Furthermore, stride length from the center of mass system was significantly and highly correlated with stride length and stride velocity from the foot pressure system. [Conclusion] A gait analysis based on a center of mass system is a valid method to assess the effectiveness of therapeutic interventions in a clinical setting.

Key words: Accelerometer, Center of mass, Gait

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INTRODUCTION

Evaluating and analyzing gait performance is necessary for the clinician to determine the level of disability in patients or for assessing the effectiveness of a rehabilitation intervention¹⁾. Analyzing gait is an important process, especially in patients who may have problems with the central nervous system such as patients with stroke^{2, 3)}. However, analyzing gait in the clinic has traditionally been limited by the use of subjective scales or assessment tools⁴⁾. Furthermore, these tests only measure gait speeds over a small distance (e.g., a 10-m walking test) which is not necessarily indicative of the walking tasks that occur in real-life situations (e.g., walking outdoors, different walking speeds)⁵⁾.

Recently, a gait analysis system has become commercially available that allows the user to perform a simple quantitative evaluation of the spatial-temporal characteristics during gait and has been used to assess the effect of training on pathological gait^{6, 7)}. Most gait analysis techniques utilize foot pressure or motion capture systems to detect changes

in the gait characteristics; these systems have been validated and are highly reliable for clinical use^{8, 9)}. Furthermore, these systems are capable of being synchronized with other instruments that are used to evaluate walking^{10, 11)}. Despite these benefits, it is still difficult to collect gait data that are representative of outdoor walking or activities of daily living^{12, 13)}.

Therefore, a gait analysis system that is easy to use, convenient, and portable is necessary for evaluating gait in the clinic. Accelerometers are an instrument that can be used to collect center of mass (COM) data during walking and, given their small size and wireless capabilities (i.e., Bluetooth), can be attached to patients to evaluate outdoor walking¹⁴⁾. Therefore, accelerometers are regularly used for researching and evaluating walking in patient groups¹⁵⁾. Although evaluating gait using an accelerometer is relatively easy, the accelerometer measures the center of mass of the body and therefore only indirectly measures gait, unlike the direct methods described above. Therefore, the purpose of this study was to determine the relationship between an accelerometer system and a foot pressure sensor system for measuring gait characteristics in healthy adults while walking freely on a 10-m walkway.

SUBJECTS AND METHODS

Thirty-five healthy participants (9 males and 26 females) with no neurological, musculoskeletal, or cardiopulmonary

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Table 1. General characteristics of the participants

Characteristics	Subjects ^a (N=35)
Gender (N, males/females)	9/26
Age (yrs)	26.3±4.2
Height (cm)	165.8±7.0
Weight (kg)	58.4±8.6
Leg length (cm)	84.1±4.5

^aData are presented as mean±SD, unless otherwise indicated

Table 2. Correlation between the center of mass and foot pressure sensor systems for measuring gait parameters in normal adults

	Speed ^a	Cadence ^a
Velocity	0.848**	0.680**
Step count	-0.606**	-0.188
Cadence	0.608**	0.943**
Functional ambulation profile	-0.609**	-0.659**

^a r-value, **p<0.001. COM: center of mass; FPS; foot pressure system

Table 3. Correlation between the center of mass and foot pressure sensor systems for measuring spatial-temporal gait parameters in normal adults

	Stride length as a percentage of the stride height ^a	Stride length ^a	Gait cycle duration ^a
Cycle time	-0.458** / -0.382*	-0.373* / -0.305	0.960** / 0.886**
Stride length	0.726** / 0.714**	0.756** / 0.757**	-0.245 / -0.255
Swing time	-0.335* / -0.202	-0.281 / -0.148	0.803** / 0.797**
Stance time	-0.464** / -0.428*	-0.374* / -0.349*	0.919** / 0.846**
Single support time	-0.307 / -0.238	-0.237 / -0.199	0.828** / 0.760**
Double support time	-0.402* / -0.437**	-0.318 / -0.354*	0.708** / 0.651**
Stride velocity	0.760** / 0.720**	0.741** / 0.714**	-0.683** / -0.663**

^a r-value, **p<0.001, *p<0.05.

Date are presented as left/right.

disorders volunteered for this study and written informed consent was obtained from all participants. Prior to recruitment, approval of the study protocol was obtained from the Jeonju University Institutional Review Board (jjIRB-2015-0406). Table 1 describes the general characteristics of the participants. Gait characteristics were measured while participants walked freely along a 10-m walkway using two different measurement systems simultaneously. The first analysis system was based on center of mass using a wireless tri-axial accelerometer (G-Walk, BTS Bioengineering S.p.A., Italy) that was attached to the 5th lumbar vertebra and tightened with Velcro™. The accelerometer data were wirelessly transferred by a Bluetooth system and analyzed with BTS G-studio software (BTS Bioengineering S.p.A., Italy) on a laptop computer. The weight of the accelerometer was 62 g, with dimensions of 78 × 48 × 20 mm. The second system was a foot pressure sensor system (FPS) (GAITrite, CIR system Inc., USA). The FPS system was placed on the floor and the data was directly transferred to a laptop computer. The FPS was 366 cm long by 61 cm wide with a height of 6 cm and consisted of a 13,824 sensor walkway covered with a carpeted surface. The sampling rate was 120 Hz and data were collected in three successive trials for each condition. The mean value of the three trials was used for data analysis. Velocity, cadence of comfortable walking, stride length as a percentage of the stride height, stride length, and gait cycle duration of each side (left and right) were calculated from the COM system. The spatiotemporal parameters analyzed from the FPS system were velocity, step count, cadence, functional ambulation profile of comfortable walking, cycle time, stride length, swing time, stance time, single support

time, double support time, and stride velocity of each side. Descriptive statistics were used to describe the general characteristics of the participants and a Pearson correlation analysis was used to determine the correlation between COM and FPS system for the gait parameters. Alpha was set at 0.05 for all statistical tests.

RESULTS

There was a significant (p<0.001) and high correlation between the two systems with respect to gait velocity (r=0.848) and cadence (r=0.943). Furthermore, gait velocity (r= -0.609) and cadence (r= -0.659) calculated from the COM system were significantly correlated with the functional ambulation profiles measured from the FPS system (p<0.001) (Table 2). The stride length as a percentage of the stride height measured with the COM system was significantly and highly correlated with stride length (left side r=0.726, right side r=0.714) and stride velocity (left side r=0.760, right side r=0.720) measured with the FPS system (p<0.001). Furthermore, stride length from the COM system was significantly and highly correlated with stride length (left side r=0.756, right side r=0.757) and stride velocity (left side r=0.741, right side r=0.714) from the FPS system (p<0.001). Finally, gait cycle duration measured with the COM system was significantly and highly correlated with cycle time (left side r=0.960, right side r=0.886), swing time (left side r=0.803, right side r=0.797), stance time (left side r=0.919, right side r=0.846), single support time (left side r=0.828, right side r=0.760), double support time (left side r=0.708, right side r=0.651), and stride velocity (left side r=

-0.683, right side $r = -0.663$) that was extracted from the FPS system (Table 3).

DISCUSSION

The purpose of this study was to determine the relationship between gait parameters using a COM and an FPS system during walking in healthy adults. The results suggest that the primary gait parameters were highly correlated between the two systems, though some of the secondary relationships showed low correlations.

In this study, gait characteristics collected with a COM system were compared to those collected by an FPS system to determine the suitability of using a COM system in a clinical setting. Traditionally, gait analysis in the clinic is difficult, as it requires a three-dimensional motion analysis system that uses cameras to capture the motion of body segments during walking that can be difficult to set up and apply to clinical patients¹⁶). A COM system based on the acceleration (measured with a tri-axial accelerometer) of the pelvis or lower body during walking was assessed here for clinical use. Acceleration is defined as the rate of change of velocity over a specified time¹⁷) and because the COM of the body undergoes cyclic three-dimensional movements during gait an accelerometer is an attractive tool to predict the body's movements¹⁸). Zijlstra and Hof¹⁹) have suggested that the peak acceleration of the trunk occurs during heel strike and that after the heel strike, acceleration of the trunk will decrease. Therefore, the typical patterns of the trunk COM allow for the prediction of stride length, step length, and walking velocity. Zijlstra and Hof²⁰) have also reported that the motion of the pelvis can provide useful data for comparing normal and pathological walking patterns. Furthermore, it has been shown that the acceleration of the body's COM moves in a three-dimensional pattern and can be represented as an inverted pendulum model to estimate the spatial-temporal characteristics of gait.

A typical COM gait analysis uses accelerometers in a rehabilitation setting, and our study used an accelerometer that was commercially designed by G-walk (BTS Bioengineering, Italy). Although Pau et al.²¹) and Bugane et al.²²) used the same accelerometers that were used here, they did not report the validity or reliability of the instrumentation. Hartman and Luzi²³) compared COM data collected with a DynaPort system to that of a GAITRite FPS system and reported excellent concurrent validity with respect to velocity and cadence in older adults. In addition, step duration had moderate reported validity, and step length had low validity in older adults.

Accelerometers are easy to use and therefore, provide a simple way to measure gait characteristics in a real life environment (i.e., outdoor walking) as opposed to the traditional method of collected data in a laboratory setting^{23, 24}). Chung and Ng¹⁶) have strongly recommended that an accelerometer is a simple instrument for detecting motion in the clinic. The accelerometer detects movement during walking slower than three-dimensional motion analysis systems, but it has good reliability for measuring movement¹⁶).

One of the limitations of this study was that the COM data were measured from the L5 vertebrae and compared to

FPS data that were measured at the foot, which means that. The COM and FPS systems had different data conversion analysis systems. COM data are based on three-dimensional motions of body, whereas FPS data are based on one-dimensional foot pressure during walking.

In conclusion, for a gait analysis to be effective it must be applicable in a clinical setting. This means that it needs to be easy to measure and to apply in a variety of life situations, it needs to be objective, and it must correlate with other gait analysis systems or clinical scales. In light of the results presented here, a gait analysis based on a COM system is a valid method to assess the effectiveness of therapeutic interventions in a clinical setting.

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