J. Phys. Ther. Sci. 29: 1426–1428, 2017

The Journal of Physical Therapy Science

Original Article

Center of mass with the use of smartphone during walking in healthy individuals

Bora An, BHSc[1)], Youngkeun Woo, PhD[2)*]

[1)] *Department of Physical Therapy, Raon Hue Hospital, Republic of Korea*
[2)] *Department of Physical Therapy, College of Medical Sciences, Jeonju University: 303 Cheonjam-ro, Wansan-gu, Jeonju 560-759, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to measure the center of mass using a smartphone application during walking in healthy. [Subjects and Methods] Forty eight healthy participants volunteered for this study. Measurements of center of mass were obtained by gait analysis application using smartphone while subjects performed 6 meter walking test. The measured data were automatically calculated by the application, subjects performed three trial walks to get a more accurate data analysis. [Results] There were no significant differences among subjects or between genders during the three trials in the vertical and lateral displacement of COM, and the results of the Kolmogorov-Simirnov test showed no differences in vertical and lateral displacement of COM in all subjects or between genders. However, the vertical displacement of COM significantly varied in male subjects than in female subjects, but the lateral displacement of COM did not significantly differ between the male and female subjects. [Conclusion] We can use the Smartphone application to measure the COM for walking; however more studies comparing advanced technological instruments with the smartphone application are needed.
Key words: Center of mass, Smartphone application, Walk

(This article was submitted Apr. 13, 2017, and was accepted May 26, 2017)

INTRODUCTION

Center of mass (COM) is the central point on the human body[1)]. During standing or walking, maintaining a COM within a Base of support (BOS) is an essential ability in healthy people, older adults as well as patients[2, 3)]. Therefore, knowledge of the COM motion is one of importance for analysis or for understanding walking patterns[4)]. Gutierrez et al.[5)] conducted studies using COM excursion during normal walking, while Ortega and Farley[6)] studied how COM affects metabolic cost during walking.

Generally, measuring COM is used with accelerometers and foot pressure systems[7)], kinematic models such as force plates and motion capture systems[8)]. Among these methods, accelerometers are easy to use and provide repeatable and suitable data for clinicians[9)].

Recently, Jung et al.[10)] analyzed COM using a Samsung Galaxy S II with an Accelerometer Monitor application built for normal walking. The limitation of their study is that the application uses raw signals from an accelerometer, which indirectly shows the COM during walking. Therefore, in this study we measured COM directly using a smartphone application, to assess its feasibility in measuring walking in normal healthy subjects.

SUBJECTS AND METHODS

We enrolled 48 healthy participants (13 male and 35 female) for this study and obtained written informed consent from

*Corresponding author. Youngkeun Woo (E-mail: ykwoo92@empas.com)

Table 1. General characteristics of the participants (N=48)

	Total	Male (n=13)	Female (n=35)
Age (yrs)	24.5 ± 4.0	26.9 ± 15.9	23.7 ± 2.7
Height (cm)	165.8 ± 7.4	174.3 ± 4.7	162.6 ± 5.4*
Weight (kg)	59.2 ± 10.8	72.9 ± 5.9	54.1 ± 7.2*

Data are presented as mean ± standard deviation.
*p<0.05 for comparison between male and female

Table 2. Repeated one-way ANOVA among 3 trial walking performances

Parameters		Total	Male	Female
Vertical COM displacement (cm)	1st	2.93 ± 0.71	3.19 ± 0.56	2.83 ± 0.74
	2nd	3.02 ± 0.70	3.42 ± 0.79	2.87 ± 0.61
	3rd	2.98 ± 0.68	3.34 ± 0.72	2.85 ± 0.63
Lateral COM displacement (cm)	1st	1.80 ± 0.74	1.91 ± 0.80	1.76 ± 0.73
	2nd	1.82 ± 0.68	1.90 ± 0.62	1.79 ± 0.71
	3rd	1.80 ± 0.72	1.78 ± 0.55	1.81 ± 0.78

Data are presented as mean ± standard deviation.

Table 3. Independent t-test between men and women and Kolmogorov-Simirnov test for normality

Parameters		Total	Male	Female
Vertical COM displacement (cm)	M ± SD	2.98 ± 0.62	3.32 ± 0.62	2.85 ± 0.58*
	Z	0.090	0.117	0.084
	p	0.200§	0.200	0.200
Lateral COM displacement (cm)	M ± SD	1.81 ± 0.68	1.86 ± 0.62	1.79 ± 0.71
	Z	0.088	0.146	0.108
	p	0.200	0.200	0.200

Data are presented as mean ± standard deviation.
*p<0.05 for comparison between male and female
§Result of Kolmogorov-Simirnov test for normality data

all participants following the Declaration of Helsinki principles. If subjects want to stop experiment or want to not use their data for this study, we excluded data in this study. The 48 subjects had no other musculoskeletal, cardiopulmonary, or neuromuscular disorders, and no history of any physical therapy in the last six months prior to recruitment. Table 1 describes the general characteristics of the participants. There was a significant difference between male and female subjects in the height and weight ($p<0.05$).

During the 6 meter walking test (6MWT), displacement of the COM was measured using gait analysis (YTA, K.K., Japan) of the smartphone application. COM data were measured with vertical and lateral displacement. The smartphone used was an iPhone 6S (Apple Inc., CA, USA) attached to the 5th lumbar vertebra and tightened with Velcro™. The date was automatically calculated by the application, and the sampling rate was 100 Hz. Subjects performed three trial walks to get a more accurate reading and reliability for data analysis.

Descriptive statistics were used to describe the participants and the independent t-test was used to determine the significance between male and female subjects in age, height, weight, and COM displacement. Repeated one-way analysis of variance (ANOVA) was used to determine the reliability among the three trials, and a Kolmogorov-Simirnov test was used to determine the normality in COM displacement. The p value was set at 0.05 for all statistical tests.

RESULTS

There were no significant differences among subjects or between genders during the three trials in the vertical and lateral displacement of COM ($p>0.05$) (Table 2).

In addition, the results of the Kolmogorov-Simirnov test showed no differences in vertical and lateral displacement of COM in all subjects or between genders ($p>0.05$). Lastly, the vertical displacement of COM significantly varied in male subjects than in female subjects ($p<0.05$), but the lateral displacement of COM did not significantly differ between the male and female subjects ($p>0.05$) (Table 3).

DISCUSSION

The purpose of this study was to investigate the COM directly using a smartphone application in healthy subjects. The results suggest that COM measured by this application shows consistency within three trials in both men and women. In addition, there are significant differences in displacement of the vertical COM between genders.

During three trial walking performances, there are no significant differences in displacement of the vertical and lateral COM. In addition, the displacement of COM had normality based on analysis with a Kolmogorov-Simirnov test in men and women. These results indicate that COM measured by a smartphone application had consistency and provide feasible walking data in normal subjects. Based on the data, the vertical displacement of COM is 2.98 ± 0.62 cm, and the lateral displacement of COM is 1.81 ± 0.68 cm. Generally, the vertical displacement of COM is 5 cm and the lateral displacement of COM is 4 cm[11]. However, these are based on the motion of point in the head. Orendurff et al.[12] revealed a vertical displacement of COM between 4.89 ± 1.03 cm to 2.74 ± 0.52 cm, and a lateral displacement of COM between 3.29 ± 1.29 cm to 6.99 ± 1.34 cm. This depends on the walking speed based on inverse dynamic kinematical models by a motion capture system. We measured COM based on around the 5th lumbar vertebra during walking. These differences in values are based on different measuring points with earlier studies and our study. Furthermore, our data revealed smaller values of height and weight in subject's anthropometric data. Our results showed a difference in the vertical displacement of COM in men and women, which may be because of the differences in height and weight between men and women. Zijlstra and Hof[4] also reported that the vertical displacement of COM depends on a subject's stride length. Hernándeza et al.[2] also reported differences in younger and older healthy adults. Our results reflect the different COM values in men and women seen in earlier studies and agree that the differences depend on anthropometrical and measuring methods.

In clinical situations, clinicians easily, reliably, and efficiently measure the ability of patients for the following: outcomes, progress, and prognosis for their interventions. The patients have to walk safely. Walking is a fundamental function for people in their activity of daily livings (ADLs). Therefore, based on our results, measuring COM by a smartphone application is a feasible method and easy to implement in patients, as well as in a clinical setting.

A limitation of this study was that only the Smartphone application was used, and there is no technical support for our data results. Furthermore, there is no direct comparison with the patient's data using this application. Therefore, further studies need to compare the difference from the smarphone application for providing feasibility of Smartphone application in analyzing walking.

In conclusion, our results suggest that we can use the Smartphone application to measure the COM for walking. However more studies using and evaluating the application are needed. In addition, more studies comparing advanced technological instruments with the smartphone application are needed as well, for proof of their effectiveness.

REFERENCES

1) Morioka S, Miyaoto S, Aee M: Relationship between the center of gravity point in spontaneous standing and the middle point calculated from the center of gravity shifting distance to the non-paralytic and paralytic sides in hemiplegics after stroke. J Phys Ther Sci, 2003, 15: 99–103. [CrossRef]
2) Hernández A, Silder A, Heiderscheit BC, et al.: Effect of age on center of mass motion during human walking. Gait Posture, 2009, 30: 217–222. [Medline] [CrossRef]
3) Titianova EB, Pitkänen K, Pääkkönen A, et al.: Gait characteristics and functional ambulation profile in patients with chronic unilateral stroke. Am J Phys Med Rehabil, 2003, 82: 778–786, quiz 787–789, 823. [Medline] [CrossRef]
4) Zijlstra W, Hof AL: Displacement of the pelvis during human walking: experimental data and model predictions. Gait Posture, 1997, 6: 249–262. [CrossRef]
5) Gutierrez EM, Bartonek A, Haglund-Akerlind Y, et al.: Centre of mass motion during gait in persons with myelomeningocele. Gait Posture, 2003, 18: 37–46. [Medline] [CrossRef]
6) Ortega JD, Farley CT: Minimizing center of mass vertical movement increases metabolic cost in walking. J Appl Physiol 1985, 2005, 99: 2099–2107. [Medline] [CrossRef]
7) Park G, Woo Y: Comparison between a center of mass and a foot pressure sensor system for measuring gait parameters in healty adults. J Phys Ther Sci, 2015, 25: 1467–1470.
8) Lafond D, Duarte M, Prince F: Comparison of three methods to estimate the center of mass during balance assessment. J Biomech, 2004, 37: 1421–1426. [Medline] [CrossRef]
9) Senden R, Grimm B, Heyligers IC, et al.: Acceleration-based gait test for healthy subjects: reliability and reference data. Gait Posture, 2009, 30: 192–196. [Medline] [CrossRef]
10) Jung S, Lee I, Yoon S, et al.: Analysis of walking using Smartphone application. J Korea PNF Assoc, 2015, 13: 39–46.
11) Neumann DA: Kinesiology of the musculoskeletal system: foundations for rehabilitation, 2nd ed. St. Louis: Mosby, 2010, pp 627–681.
12) Orendurff MS, Segal AD, Klute GK, et al.: The effect of walking speed on center of mass displacement. J Rehabil Res Dev, 2004, 41: 829–834. [Medline] [CrossRef]