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Reliability and validity of a smartphone-based assessment of gait parameters across walking speed and smartphone locations: Body, bag, belt, hand, and pocket

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ABSTRACT

The assessment of spatiotemporal gait parameters is a useful clinical indicator of health status. Unfortunately, most assessment tools require controlled laboratory environments which can be expensive and time consuming. As smartphones with embedded sensors are becoming ubiquitous, this technology can provide a cost-effective, easily deployable method for assessing gait. Therefore, the purpose of this study was to assess the reliability and validity of a smartphone-based accelerometer in quantifying spatiotemporal gait parameters when attached to the body or in a bag, belt, hand, and pocket. Thirty-four healthy adults were asked to walk at self-selected comfortable, slow, and fast speeds over a 10-m walkway while carrying a smartphone. Step length, step time, gait velocity, and cadence were computed from smartphone-based accelerometers and validated with GAITRite. Across all walking speeds, smartphone data had excellent reliability ($ICC_{2,1} \geq 0.90$) for the body and belt locations, with bag, hand, and pocket locations having good to excellent reliability ($ICC_{2,1} \geq 0.69$). Correlations between the smartphone-based and GAITRite-based systems were very high for the body ($r = 0.89$, 0.98, 0.96, and 0.87 for step length, step time, gait velocity, and cadence, respectively). Similarly, Bland-Altman analysis demonstrated that the bias approached zero, particularly in the body, bag, and belt conditions under comfortable and fast speeds. Thus, smartphone-based assessments of gait are most valid when placed on the body, in a bag, or on a belt. The use of a smartphone to assess gait can provide relevant data to clinicians without encumbering the user and allow for data collection in the free-living environment.

1. Introduction

Assessment of gait spatiotemporal parameters can provide valuable insight regarding overall health [1], cognitive performance [2], quality of life [3], and mortality [4]. The majority of gait assessments utilize optoelectronic motion capture systems, force plates, and instrumented walkways such as the GAITRite [5,6]. Although these instruments are highly accurate, they require controlled laboratory environments, are bulky, expensive, and involve tremendous time investment for setup and analysis. Furthermore, these tools are not available in all clinical settings, and cannot measure gait across more than a few steps or in home-based environments. Nonetheless, due to their high reliability and validity, these devices are frequently used as a gold standard for gait assessment [7].

Recently, tri-axial accelerometers have been used in gait analysis as an alternative to laboratory assessments. Not only can accelerometers accurately quantify spatiotemporal gait parameters, but they also have a number of advantages including a lower cost, portability, and ease of use. Furthermore, accelerometer-based devices can collect data from many gait cycles and allow measurements in more challenging contexts [8]. Previous studies have demonstrated the validity of body-worn accelerometers to quantify activities [9], steps [10], and gait parameters [7]. Utilizing an accelerometer placed on the lower back, Hartmann and colleagues [11] demonstrated excellent concurrent validity for assessing walking speed, cadence, step duration, and step length among older adults. However, accelerometer-based systems have a number of disadvantages [12]. First, they usually attach directly onto the body (e.g. trunk, wrist, ankle) which can lead to discomfort. Second, problems with memory and recall can reduce compliance. Lastly, the cost of commercial software packages is relatively high.

As smartphones are becoming ubiquitous across age groups, utilizing embedded sensors to assess gait is cost-effective, convenient, and user-friendly. Instead of attaching directly onto the body, a smartphone device can be engaged in the user's hands, bag, belt, or pocket [13].

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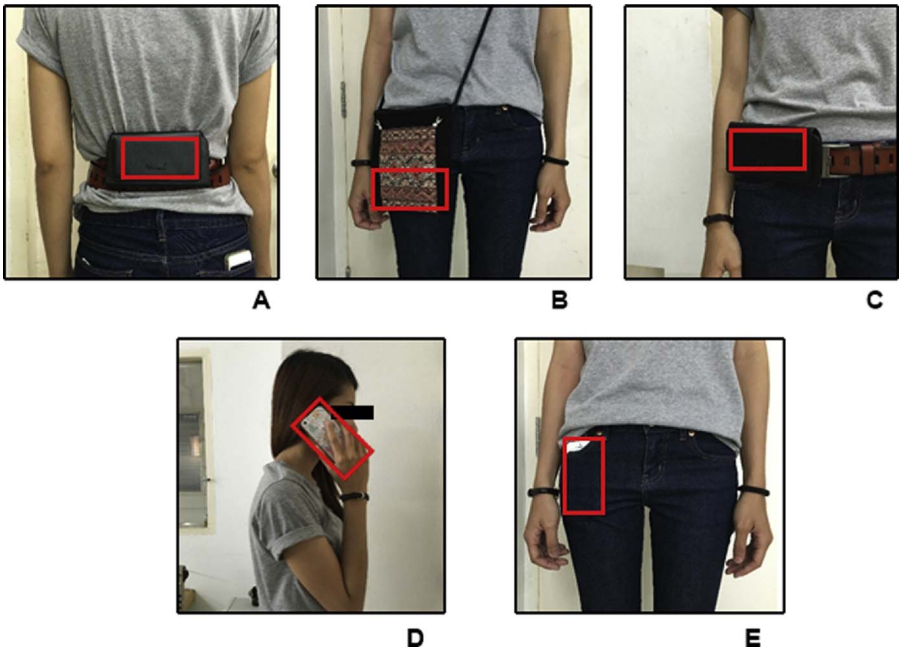

Fig. 1. Location of the smartphone during all walking trials: body (A), bag (B), belt (C), hand (D), and pocket (E). The rectangular border indicates the orientation and placement of the smartphone in each condition.

Furthermore, measuring gait from smartphones is a practical solution for lowering cost as well as improving accessibility, convenience, and portability. Furrer and colleagues [14] have examined the intra-session reliability and concurrent validity of the center of mass displacement derived from the smartphone accelerometer, attached to the third lumbar vertebrae, during level walking. Fair to excellent reliability (ICC: 0.49–0.86) with moderate to strong correlations (Pearson r: 0.61–0.92) between smartphone and motion capture measurements indicates that the use of a smartphone-based assessment can be valid and feasible. Additionally, varying the placement of a smartphone on the individual's attire (i.e. hands, pockets, belt, or bag) has been found to be valid for assessing the type of activity an individual is performing [13].

To our knowledge, however, the ability to assess spatiotemporal gait parameters based on a smartphone-based accelerometer is unknown. Since people carry phones differently in everyday life, the effects of varying placement of a smartphone on the body or attire while assessing spatiotemporal gait parameters also needs to be investigated. Hence, the aims of this study are: 1) to quantify the reliability and validity of a smartphone-based tri-axial accelerometer in determining gait characteristics (i.e. step length, step time, gait velocity, and cadence) when attached to the body and when placed in a bag, belt, hand, or pocket; and 2) to assess the validity of smartphone-based gait parameters during slow, comfortable, and fast walking speeds. We hypothesized that the use of a smartphone to evaluate gait spatiotemporal variables will be reliable and valid across all gait speeds when attached to the body and belt. We further hypothesized that smartphone placement in a bag, hand, or pocket would result in reduced reliability and validity. Reference values for gait parameters were obtained from a GAITRite instrumented walkway.

2. Methods

2.1. Participants

This investigation included 12 healthy young adults (1 male; mean ± SD age 22.7 ± 0.9 years; body mass index (BMI) 21.2 ± 4.1 kg/m^2) and 22 healthy older adults (7 males; age 73.9 ± 5.6 years; BMI 23.7 ± 3.6 kg/m^2) who were able to walk continuously for at least ten meters without the assistance of another person or a walking aid. Participants were excluded if they presented with an unstable medical condition such as uncontrolled hypertension or diabetes, reported severe neurological, musculoskeletal, or cardiopulmonary problems, had visual impairment uncorrectable with conventional lenses, or had a lower limb amputation or arthroplasty.

All adults were recruited into the study through flyers posted in the surrounding communities and by an announcement through community leaders and primary health care providers. The study was approved by the University's Research Ethics Committee (Number 271/2016). Written informed consent for the study protocol was obtained from each participant prior to enrollment into the study.

2.2. Experimental design

Participants were asked to walk barefoot along a 10-m walkway at their self-selected walking speeds. Two markers were placed on the ground to indicate the start and end of the 10-m path, with the GAITRite (CIR Systems Inc., Sparta, NJ, USA) walkway placed in the middle of this path. To measure steady-state gait, only the middle 4.27-m active sensor area of the GAITRite was used to examine gait parameters.

During all walking trials, participants carried a smartphone (Vivo X5; Android 4.4.4; 143.3 mm × 71.1 mm × 6.3 mm; 141grams) in one of five locations: 1) attached with a belt to the body above the third lumbar vertebrae in the horizontal orientation; 2) in a shoulder bag (15 cm × 18 cm) placed in a horizontal orientation, with the non-adjustable strap placed over the left shoulder and the pouch on the right hip; 3) on a belt attached above the front right pant pocket in a horizontal orientation; 4) in the right hand, held in a telephone speaking position; 5) in the front right pant pocket placed in a vertical orientation (Fig. 1). Participants were first asked to walk at their self-selected comfortable walking speed over the 10-m walkway. After completing all comfortable gait speed trials, participants were asked to walk at fast and slow speeds. The location of the smartphone and order of fast and slow trials were randomized. To assess reliability, two trials were performed for each condition, with a total of 30 trials completed per participant. To ensure only steps that were collected concurrently by the smartphone and GAITRite were analyzed, a digital video camera was used to record all walking trials, with both systems reset after each walking trial. To assess validity, all trials were utilized, with the average value taken across all steps during each trial.