# CHAPTER 5

## Discussion

The goal of this study was to assess the validity of a smartphone-based accelerometer in determining gait characteristics when attached to the body as well as when placed in a bag, belt, hand, and pocket. The main findings of this study are the high to very high validity of a smartphone-based gait assessment, particularly when a smartphone was placed on the body, and in a bag. In support of our hypothesis, the body conditions demonstrated high to very high validity, with biases approaching zero for all gait variables. Results of step length, step time, and gait velocity were comparable to those reported previously for a smartphone camera-based assessment (21). Results from a validity study comparing accelerometer-based sensors placed on the lumbar vertebrae versus GAITRite were also similar to the current study for step length (r= 0.880), step time (r= 0.997), and step velocity (r= 0.900) (25). The mean difference between systems further demonstrates the validity of the smartphone-based method, as the step length bias (-1.3cm) was within the spatial accuracy reported by GAITRite (1.27 cm) (35, 36). Similarly, small biases of 2ms and 2.2cm/s were demonstrated for step time and gait velocity, respectively.

Contrary to our hypothesis, the bag condition revealed high to very high validity. While the bag chosen in this study is not representative of all bags, it is possible that a single-shoulder bag in which the phone is held in a fixed position might yield good results. Of note is the size of the bag (15cm width) in relation to our phone (14.33cm length), and having no other objects in the bag, allowing for an undisturbed snug fit without extraneous movement applied to the smartphone. The belt, hand, and pocket conditions, however, did reveal relatively worse results. Reduced correlations in the belt condition, compared to the body condition, may be due to the lateral placement of the smartphone in relation to the center of mass as well as increased adipose tissue in the belt region compared to the lumbar region. As the smartphone is placed over the ASIS in the belt condition, pelvic movement during gait may also contribute to the relatively poorer correlation compared

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to the body condition (37-39). Alternatively, in support of our hypothesis, the belt condition did demonstrate biases approaching zero, especially for the gait velocity.

Moreover, the results from the repeated measures ANOVA revealed that gait parameters derived from the two systems were comparable across all locations, except when carrying a smartphone in the hand. During the hand condition, natural movement of the arm while walking may reduce the validity of the gait measures. Additionally, in this condition, the smartphone is kept in a speaking position, thus the vertical location of the phone is far from the body center of mass. Therefore, step length and gait velocity derived from the two systems vary greatly when the phone is located in the hand. Based on these results, use of commercial activity monitors which are placed on the wrist are of questionable validity.

Our findings from GAITRite revealed that when a smartphone was placed in the pocket, older adults walked with a shorter step length, longer step time, and slower gait velocity, compared with other locations. There are several explanations for these results. First, carrying a smartphone in the front right pant pocket interferes with leg movement, by limiting the angle of the hip joint while walking. Second, it is possible that participants are afraid of dropping the smartphone if they walk too fast or with a longer step length. Third, unlike the body and bag locations which had snug fits, placing the smartphone in the pocket allows for extraneous movement. However, the spatiotemporal gait measures derived from the smartphone-based accelerometer system revealed reduced step length and gait velocity when participants carried a smartphone in the hand compared with other locations. Consistent with a previous study, Antos et al. (23) examined the accuracy of activity tracking using a smartphone-based accelerometer when positioned at four locations (i.e. hand, belt, pants pocket, and bag) while carrying out five activities (i.e. sitting, standing, walking, and transition between sitting and standing). The hand location was found to have the lowest tracking accuracy, compared to the pocket, belt, or bag.

The current study has several limitations. First, only five to nine steps were investigated per trial, with participants asked to walk in a straight line over a level surface. Although trials were short, Orendurff and colleagues (40) demonstrated that 40% of walking bouts last for fewer than 12 steps, with possibly greater validity in longer duration trials (41). Furthermore, as it is recommended that a greater number of steps be used to

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assess variability (42), due to space constraints of GAITRite, evaluation of gait variability from longer duration trials was not feasible. Second, knowledge of the phone location is known a priori. While methods for detecting the location of an accelerometer have been investigated (43), implementing these algorithms was beyond the scope of this study. Additionally, we utilized identical algorithms for each trial, therefore knowledge of location would not affect the presented results. Third, participants were asked to walk at their comfortable self-selected walking speed, thus the validity of walking at different speeds is unknown. Finally, the current investigation only utilized a single phone (i.e. Vivo X5) using a single Android version (i.e. 4.4.4 KitKat). Thus, no conclusions can be made for other smartphone brands or Android versions.

Further investigation of task difficulty such as varying speed, turning, walking on uneven or sloped surfaces, as well as maneuvering around environmental hazards and crowds is needed. To ensure a smartphone can be used as a stand-alone, field-based gait tool, investigation needs to be performed both in the laboratory-based and free-living environments. Additionally, future work should investigate the generalizability of smartphone-based assessments for persons of varying weight or gait pathology. Assessment of compliance and validity across populations can allow for robust community-based monitoring and clinical intervention. Finally, inter-device and inter-operating system validity requires additional examination.

In conclusion, results of this study reveal that smartphone-based assessments of gait are valid, particularly when placed on the body or bag conditions at comfortable speed. While reduced correlations are shown in the belt, hand, and pocket conditions, the use of a smartphone to assess gait velocity in these common locations still has high validity. Smartphone sensors can provide relevant home-based walking data without the need for expensive instrumentation. Due to the ubiquity of smartphones, cost and complexity of distribution and analysis is minimized allowing for greater access to robust evaluations for clinicians and patients alike.

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