Journal of Behavioral Health
www.scopemed.org
DOI: 10.5455/jbh.20170425072208

Original Research

Accelerometer methodology: Issues with attachment style at the waist

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Received: December 29, 2016
Accepted: April 08, 2017
Published: June 24, 2017

ABSTRACT

Objective: Investigate differences in ActiGraph GT9X vertical axis counts and step counts with monitors clipped onto the waistband at the hip compared to the three methods of attachment at the traditional waist placement. **Methods:** Three laboratory-based treadmill test conditions were utilized: (1) 3 mph in blue jeans, (2) 3 mph in athletic shorts, and (3) 6 mph in athletic shorts. Three monitors were attached in different methods to the traditional elastic belt (2 threaded options and 1 clipped), and one accelerometer was clipped onto waistband at the hip. **Results:** No differences were observed between attachment methods for step counts in any test condition ($P > 0.05$). When considering physical activity intensity classification accuracy, all attachment methods (100% of the time) generated counts within the same intensity category. **Conclusion:** Clipping the accelerometer to the waistband produces comparable data to that of the elastic belt (within any threading configuration) and may reduce participant burden.

KEY WORDS: ActiGraph, clipped, objective measurement, physical activity, step counts, treadmill

INTRODUCTION

Use of accelerometer methodology has increased dramatically over the past decade [1] and has been utilized in such studies as the Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey [2]. Given the limitations of self-report measures of physical activity (PA) (e.g., recall, item interpretation, and social desirability biases) [3], the use of accelerometers has improved our ability to more accurately estimate PA intensity, identify the prevalence meeting PA guidelines, determine factors that influence PA behavior and examine the relationship between PA and various health outcomes [4]. A recent study by Cerin *et al*. displayed poor agreement between self-report data and objectively produced accelerometer data regarding PA and sedentary behavior, with this non-agreement being heavily moderated by demographic factors [5]. Careful attention, however, has to be considered when comparing self-report to objectively-measured PA and sedentary behavior [6]. Ultimately, these findings highlight the need for reducing bias through objective accelerometer measured PA.

Similar to pedometers, an accelerometer is a wireless ambulatory monitoring device used to objectively measure PA. Accelerometers provide advantages over the use of pedometers because of the additional data derived (i.e., in addition to steps, assessments of frequency, intensity, and duration of PA are collected) and as such is often the method of choice for measuring PA in a non-laboratory environment [1].

As with the use of any technology, results are the product our methodology affords. As such, there are important methodological issues that have wrought research attention when working with accelerometers in the past, such as, proper cut-point selection [7], epoch length, non-wear criteria, pattern recognition capability [8], and reactivity to the device itself (i.e., Hawthorne effect) [9]. In addition to the previously cited issues, newer accelerometers (specifically the ActiGraph GT9X) have introduced novel concerns by offering options such as wrist-worn versus traditional waist wear and, at the waist, clip-on wear style versus using the traditional elastic belt to mount the accelerometer. These new methods of wear are, in part, due to attempts to increase the ease of wear, thereby increasing compliance with wear-time protocols. Traditional study protocols require at least 10 h (with some recommending 13+ h/day [10]) of participant wear per day for a minimum of 4 days for inclusion in any analytics [11]; participants not complying with these preset protocols are considered to have invalid data. Past study has shown as many as 30% of participants (20-59 years) provide this invalid and unusable data [12]. In the NHANES study, roughly 25% of participants provide the full 7 days of data and cite discomfort, inconvenience, and forgetfulness as the primary reasons for non-compliance [1]. Increasing compliance through the reduction of participant burden is imperative; however, it is equally important that the integrity of study findings is not compromised by these efforts. Investigation is warranted to ensure that the data derived are synonymous between these methods of wear. Comparison has been conducted between the wrist-worn option and the traditional method of wear at the waist resulting in non-comparable data in both free-living and laboratory setting [13]. Additional to the wrist option, the ActiGraph GT9X device allows for multiple methods of attachment to the elastic belt when worn at the waist (i.e., clip-on to waistband versus traditional attachment via an elastic belt). Of interest herein is waist-mounted accelerometry given that energy expenditure is proportional to movement at the center of mass [14].

ActiGraph recommends the device be worn at the wrist, clipped onto the elastic belt or clipped onto the participant's waistbands [1]. It is necessary that investigation be conducted to ensure comparability, not only between studies but also within studies, as participants or even different researchers may utilize different methods of attachment of these accelerometers to the body. Thus, the aim of this study was to investigate statistical differences in vertical axis counts (VAC) and step counts recorded by the ActiGraph GT9X accelerometer worn clipped onto clothing (Waistband and self-selected belt) at the hip compared to the criterion measure of the traditional elastic belt worn method at the waist. It is apparent, as seen in Figure 1 that there are multiple ways in which a researcher or participant could thread the accelerometer onto the elastic belt. Therefore, a secondary aim of this study was to evaluate the comparability of data produced by the different methods of attaching the device to the elastic belt. As stated, evaluating whether steps and VAC differ between (1) Accelerometer belt- or clip-affixed and (2) different possible ways in which the belt can be threaded through the clip is of critical importance, as employing different participant or research-initiated attachment methodologies could, in theory, render drastically different results, and ultimately, compromise internal validity and comparability with other studies.

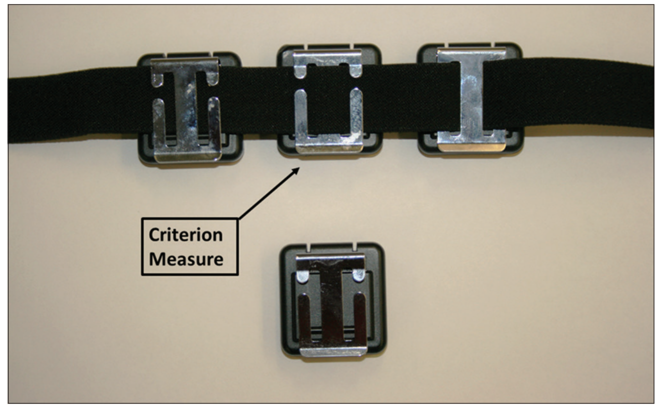

Figure 1: Accelerometer placement for Trial 1 of each test condition. The middle accelerometer on the elastic belt is identified as the criterion measure for comparisons as it is the most secure method of attachment

METHODS

Participants Procedures

Approval for this study was granted by the University's Institutional Review Board, and participant consent was obtained before any testing or measurement. Study participants were 10 ($n = 10$) male college students at least 18 years of age. Participants of the study shared similar phenotypic characteristics to reduce the introduction of confounding into the study's observations. As such, females were excluded from participation as adiposity at the hip, for example, has been identified as a significant predictor of accelerometer output in past study [15]. After written informed consent was obtained, participants completed the PA Readiness Questionnaire followed by the collection of anthropometric measurements. The entire participant visit took approximately 90 min to complete.

Accelerometers

ActiGraph GT9X Link accelerometers (ActiGraph LLC, Pensacola, FL, USA) were used in this study. All elastic attachment belts were purchased from the accelerometer manufacturer. Differing from the previous models, the ActiGraph GT9X link rests in a plastic cradle with a slotted clip on the back which is used to thread onto the traditional elastic belt or can be clipped onto an individual's clothing. It is common practice that ActiGraph accelerometers be worn on the elastic belt at the midaxillary line of the iliac crest. Because this study required the simultaneous wearing of multiple accelerometers, the devices were placed as close to the midaxillary line as possible without touching one another, 1 cm apart [Figure 1]. Placement was standardized to each participant's right hip, as evidence suggests leg dominance does not play a role in total counts produced, estimates of inactivity and time spent in differing PA intensities [16].

Protocol

Each participant completed a series of three laboratory-based test conditions (Treadmill tests) consisting of 4 trials each, for a total of 12 trials with speeds ranging from 3 to 6 mph. The same Woodway treadmill was used for each participant in attempts to control the influence of outside factors on accelerometer data. Each trial lasted 3 min, for a total 36 min. For each test condition the participant wore four accelerometers concurrently, (1) Threaded onto the elastic belt with the belt over the main support structure of the clip, (2) reverse threaded onto the elastic belt with the belt under the main support structure of the clip, (3) clipped onto the elastic belt, and (4) clipped onto the participants self-selected belt in condition 1 or onto the waistband for conditions 2 and 3 [Figure 1]. Accelerometers were assigned to their attachment method randomly for each trial to ensure the same monitors were not placed in the same position for each test. This would reduce the chance of significance do to deviation from the midaxillary line. Method one was chosen as a criterion measure for testing because it creates the most stable method of attachment to the elastic belt. Because accelerometers are primarily used to study PA in a non-laboratory setting, it was important for the laboratory test conditions to include apparel options (e.g., shorts and jeans) that the participant would likely choose during the entire free-living assessment period.

Condition 1: Walking at 3 mph where the individual wore a self-selected pair of blue jeans. Condition 2: Walking protocol of 3 mph where each individual wore self-selected athletic shorts reflecting a clothing choice during structured exercise. Condition 3: Jogging at 6 mph wearing the athletic shorts.

Trial 1 of each condition assessed differences in VAC generated by the accelerometers due to the method used to attach the device to the body. Possible attachment methods included threaded onto the traditional elastic belt in one of two ways, clipped onto the elastic belt, or worn clipped onto the participants clothing at the hip. Refer to Figure 1 for clarification of the accelerometer configuration for trial 1 of each condition. Trials 2-4 of each of the three test conditions established the intermonitor reliability between the four accelerometers used in each trial, with each of the accelerometers attached in the same method. That is, trial 2 consisted of all accelerometers threaded over the main support structure on the clip; trial 3 consisted of all accelerometers clipped onto the elastic belt; and trial 4 consisted of all accelerometers clipped to the waistband. This reliability testing was necessary to show that any potential significant differences observed in trial 1 were not a result of intramonitor non-reliability.

To ensure monitors used in the testing session were subject to the same experimental manipulation, each participant used a brand new elastic belt for their respective testing session. Furthermore, a ratio of waist circumference to belt tension was calculated to standardize the belt tension on each participant. This was done by fitting an elastic belt on a participant in a manner deemed appropriate by the researchers. The belt was then removed and placed on a table where it could be stretched to the point of becoming taut allowing for a measurement from end to end. The individual's waist circumference was then divided by the belt measurement thereby producing the ratio used, which was 1.135. For example, waist circumference 92.4 cm/belt length 81.4 cm = 1.135. Once the participant's waist circumference was assessed, this ratio could then be replicated easily using simple mathematics.

Analysis

All analyses were conducted using SPSS version 22 (SPSS Inc., Chicago, IL, USA) and Stata (version 12.0, College Station, TX, USA). All statistical testing utilized an alpha level of 0.05. The accelerometer metrics chosen for analysis in this study were step counts and counts produced in the VAC. The vertical axis was chosen as opposed to vector magnitude because the vertical axis has been utilized in the development of the majority of accelerometer-derived intensity-related activity count cut-points [17]. To produce these two metrics, the epoch was set at 1 s, and the first and last 30 s of each 3 min trial were removed to ensure the data reflected the participants normal gait pattern. Thus, 2 min of data per trial was analyzed. Counts from min 1 to 2 were summed and averaged to produce a single value reflecting counts per minute (CPM) for each accelerometer.

Repeated measures analysis of variance (ANOVA) was used to detect significant differences in counts produced by the four accelerometers worn in each of the trials. For trials where significance was observed, *post-hoc* analysis was used to identify which of the four methods of attachment differed from the criterion method. Bland–Altman plots were created to show the percentage of agreement, in both steps and VAC, between each monitor used in each trial. Each trial had four monitors, thus requiring six comparisons. Collectively, 144 Bland–Altman plots were examined. Furthermore, as another measure of absolute agreement, intraclass Correlation Coefficients (ICC) was calculated for the four attachment methods used in each test condition. Spearman's rho was used to report the relative correlation between both steps and VAC for each monitor used within each trial. For a measure of practical application, VAC between waist and clothing clipped accelerometers were evaluated regarding PA intensity classification. To do this, the Troiano cut-points were utilized were 2020 counts/min for moderate intensity and 5999 counts/min for vigorous intensity were applied [11].

RESULTS

Participants of this study were 10 males who were predominantly non-Hispanic whites with a mean body mass index of 25.5 kg/m^2 (mean = 25.5, standard deviation [SD] = 2.4). The age of participants ranged from 20 to 33 years with a mean age of 24.1 years (mean = 24.1, SD = 4.7). Mean self-selected belt width was 3.9 mm (mean = 3.9, SD = 1.0). One participant failed to provide complete data for the final trial of condition 3 due to voluntary withdrawal as a result of being unable to complete the 6 mph protocol.

With regard to step counts, laboratory testing provided convincing evidence that data produce by the accelerometers, regardless of attachment methodology, were similar. Table 1 displays the mean (SD) CPM for each of the 4 trials across the 3 conditions. For step counts, no statistically significant differences were observed between attachment methods for any of the test conditions; for condition 1 ($F = 0.623$, $P = 0.528$), condition 2, ($F = 1.238$, $P = 0.366$), and condition 3 ($F = 2.333$, $P = 0.160$). ICCs were 1.00, 0.999, and 1.00, respectively, for conditions 1, 2, and 3 [Table 2]. As determined from the Bland–Altman analysis, there was a high percentage of intermonitor agreement ranging from 80-100%, 90-100%, and 100% for conditions 1, 2, and 3, respectively. Thus, and as an example, for condition 2, at most, only 10% of the data was outside the limits of agreement, resulting in 90-100% of the data within the limits of agreement [Figure 2]. Likewise, the average correlations between step counts produced by the four accelerometers across the three conditions were extremely high at 0.998, 0.990, and 0.997, respectively. The intermonitor reliability trials produced similar test results suggesting proper reliability of the monitors.

Furthermore, analysis of VAC suggests comparability between data produced by the different attachment methods. Significant differences were observed for the first two test conditions at walking speeds of 3 mph ($F = 27.12$, $P < 0.001$) and ($F = 4.98$, $P = 0.042$), respectively [Table 2]. *Post-hoc* testing showed all attachment methods to significantly differ from the criterion method. Similarly, only the accelerometer clipped to the participant's waistband differed significantly from the criterion method in condition 2 [Table 1]. No significant difference was identified for condition 3 ($P = 0.227$) when the speed was increased from 3 to 6 mph. The Bland–Altman percentage of agreement between monitors used in each condition ranged from 90% to 100% % [Figure 2] with ICCs of 0.937, 0.933, and 0.988 for conditions 1, 2, and 3, respectively. The average correlation between monitors was highest for test condition 3, where no significant difference was observed. In addition, 100% agreement was observed for cut-point classification by VAC from the criterion measure (waist) and the clipped attachment method. That is, in the each condition, all four monitors produce an activity count within the same intensity range, moderate intensity (CPM of 2020-5999) for condition 1 and 2 and vigorous intensity (CPM >5999) for condition 3 (data

Table 1: Mean (SD) step and VACs per minute differences across various accelerometer attachment methodologies

Test condition	Steps				Vertical axis counts/Min			
	Over belt (criterion)	Under belt	Clipped to belt	Clipped to cloths	Over belt (criterion)	Under belt	Clipped to belt	Clipped to cloths
Condition 1 (3 mph - Jeans)	111.9 (5.4)	112.0 (5.4)	111.9 (5.4)	112.0 (5.4)	3492.9 (497.3)	3353.1 (496.5)*	3101.5 (486.9)*	3003.2 (586.2)*
Condition 2 (3 mph - shorts)	112.2 (4.7)	112.1 (4.7)	112.1 (4.7)	112.0 (4.8)	3584.6 (459.3)	3542.2 (442.7)	3326.4 (461.1)	3358.4 (414.2)*
Condition 3 (6 mph - shorts)	158.6 (4.8)	158.8 (4.8)	158.5 (4.9)	158.6 (5.0)	10734.8 (1779.1)	10745.1 (1784.1)	10810.6 (1684.3)	10479.9 (1749.9)

*Significant differences from criterion measure at $P<0.05$. Values shown are mean (SD) and reference trial 1 of each test condition. Data for steps shown in steps/minute and vertical axis shown in counts/minute. Condition 1 reflects 3 mph wearing self-selected blue jeans. Condition 2 reflects 3 mph wearing self-selected athletic shorts. Condition 3 reflects 6 mph wearing self-selected athletic shorts. For condition 1 the "clipped to cloths" method was clipped to the participant's self-selected belt worn with the jeans, where condition 2 and 3 were clipped to the waistband. VAC: Vertical axis counts

Table 2: Associations of step and vertical axis CPM across various accelerometer attachment methodologies

Trial	Steps					Vertical axis counts/Min				
	P value	Agreement %	Spearman's rho	Spearman's rho average	ICC	*P* value	Agreement %	Spearman's rho	Spearman's rho average	ICC
Condition 1 (3 mph - jeans)										
1	0.528	80-100	0.997-1.00	0.998	1.00	<0.001*	90-100	0.867-0.927	0.935	0.937
2	0.214	80-90	0.988-1.00	0.994	0.999	0.637	90-100	0.503-0.927	0.692	0.897
3	0.078	90	0.994-1.00	0.997	1.00	0.568	90-100	0.564-0.867	0.686	0.923
4	0.615	90	0.939-1.00	0.972	0.994	0.267	90-100	0.745-0.891	0.848	0.941
Condition 2 (3 mph - shorts)										
1	0.366	90-100	0.985-0.997	0.990	0.999	0.042*	90-100	0.498-0.952	0.760	0.933
2	1.00	80-90	0.997-1.00	0.998	1.00	0.108	90-100	0.818-0.952	0.876	0.977
3	0.645	90	0.997-1.00	0.998	1.00	0.312	90-100	0.745-0.939	0.840	0.962
4	0.205	90	0.969-0.997	0.983	0.999	0.517	90-100	0.709-0.976	0.856	0.961
Condition 3 (6 mph - shorts)										
1	0.160	100	0.994-.997	0.997	1.00	0.227	90-100	0.952-0.988	0.970	0.988
2	0.955	80-100	0.975-.994	0.987	0.999	0.814	90-100	0.527-0.988	0.783	0.972
3	0.447	90	0.997-1.00	0.998	0.999	0.359	90-100	0.794-0.939	0.890	0.985
4	0.242	88.89	1.000	1.00	1.00	0.200	88.89-100	0.550-0.817	0.733	0.919

Trial 1: Accelerometers attached in different methods. Trial 2: All accelerometers threaded over the main support structure of the clip. Trial 3: All accelerometers clipped to the elastic belt. Trial 4: All accelerometers clipped to the self-selected belt for trial 1 and waistband for Trials 2 and 3.
P values reflect results of repeated measures ANOVA for differences in vertical axis count and Step counts between monitors used in each trial, with (*) representing significant differences between attachment methods. "Agreement %" shows the range of agreement of between monitor comparisons resulting from Bland–Altman plots. Range is provided for Spearman's rho correlations with the average correlation also represented. "ICC" reflects the intraclass correlation (absolute agreement) of monitors used for Trials 1, 2, and 3. ICC: Intraclass correlation coefficients, CPM: Counts per minute

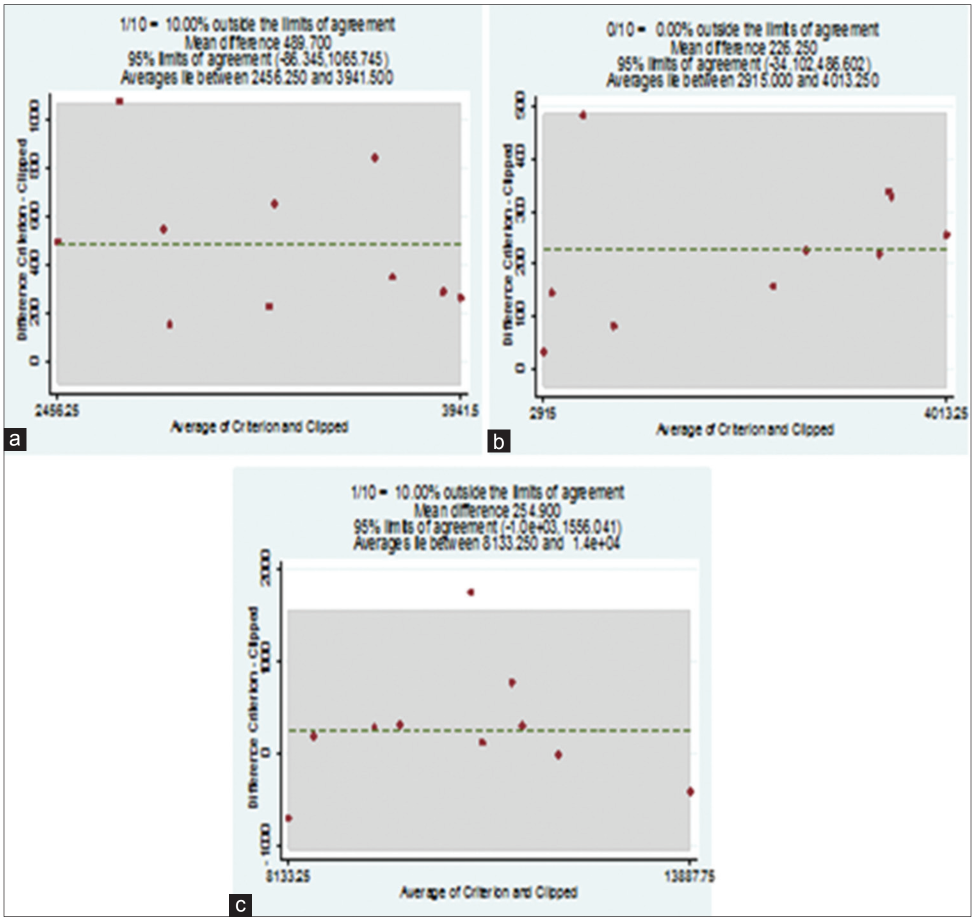

Figure 2: Bland–Altman plots reflect a comparison between the criterion methods of attachment (threaded over the main support structure of the clip) and clipped to the self-selected belt (condition 1) or waistband (condition 2 and 3). Test conditions 1, 2, and 3, respectively, are shown in a, b, and c

not shown in tabular format). As with the analysis of step counts, trial 2-4 of each condition produced confidence in the reliability of the accelerometers, showing no significant differences when all accelerometers where attached in the same method (all $P > 0.05$).

DISCUSSION

The main finding of this study was that the way in which the accelerometer clip was threaded over the belt or clipped to it did not matter with regard to accelerometer-derived steps. Similarly, clipping the monitor cradle over the shorts or jean's waistband produced similar steps to when the accelerometer was worn on the elastic belt. Collectively, these findings suggest that accelerometer attachment methodology of the belt and clip does not differentially influence accelerometer-derived steps. This was not the case, however, with accelerometer-derived activity counts in the vertical axis as significant differences were seen between attachment style to the elastic belt and between the elastic belt and clipped to the shorts and jeans. Notably, however, an agreement was very high, rendering a need for caution when interpreting the statistical significance repeated measures ANOVA tests.

At walking speeds (3 mph) for conditions 1 and 2 of the experiment, significant differences were observed between VAC produced in accelerometers clipped to the jeans or shorts and those worn in the traditional manor. However, significance testing alone is an inappropriate stand-alone measure of the efficacy or comparability of clothing clipped accelerometry as our findings show a high degree of agreement between the methods of attachment as well as high degree of correlation between counts produced. Although significant differences were observed for VAC, these differences were relatively small as displayed in Table 1. Further, these significant differences in VAC did not change the classification status for a single participant as based on the Troiano 2020 cut-point for moderate-vigorous PA and 5999 for vigorous PA [11]. That is, for all trials, the CPM across the four monitors classified the trial in the same respective intensity. For example, for the 3 mph trials, all four monitors produced a CPM between 2020 and 5999, and thus, classified the trial as a moderate-intensity.

Regarding the different methods of attaching the accelerometer to the elastic belt, walking speed appears to provide the variability in counts evidenced in condition 1 where each method was found to significantly differ from the criterion method [Table 1]. However, these findings were not corroborated in condition 2 which was also a walking trial. Speculatively, this suggests that perhaps the blue jeans worn in condition 1 were constrictive enough to alter the gait pattern when compared to condition 2 where the individual wore athletic shorts. These findings may highlight the need to ensure uniform attachment when applying traditional elastic belt methodology in future studies.

Traditional accelerometer placement calls for the belt worn device to be placed on the iliac crest at the midaxillary line. Many individuals do not wear their pants at this level on the hip resulting in a displacement of several inches below that of the iliac crest, which may explain the statistical difference in counts produce when comparing the traditional placement (criterion method) to the clothing clipped method. The lower correlations observed in intermonitor reliability may be explained, in part, by deviation from the midaxillary line as each of the four accelerometers were attached in the same manor.

CONCLUSION

Manufacturer recommendations of wear for the GT9X are that the device be worn at the wrist, clipped to the elastic belt or the subjects own belt and on the waistband of clothing [18]. The previous research has examined alternate attachment sites for the use of accelerometry, with some examples including the wrist, low back, and even worn as a necklace [13,19,20]. To our knowledge, this is the first study to evaluate VAC and step differences when considering how the belt is threaded through the clip and whether the clip is attached to the accelerometer elastic belt, self-selected "free-living" belt, or over the waistband. The findings concerning both metrics, step counts and VAC, are encouraging as the ability to clip the device onto participants clothing (i.e., waistband of the shorts/belt of pants) may substantially reduce participant burden by removing the cumbersome elastic belt that is typically employed. These findings may potentially increase the compliance in future studies choosing step counts as the metric of interest, while also allowing comparison to the previous studies utilizing traditional attachment protocols.

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Source of Support: Nil, Conflict of Interest: None declared.