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Original Research

Pocket carried and waist-mounted accelerometry

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ABSTRACT

Purpose: Evaluate differences in counts/minutes, physical activity intensity estimates, and perceived protocol compliance between wearing an accelerometer in the traditional waist attachment site versus worn in the thigh pocket. **Methods:** About 10 participants wore 2 accelerometers concurrently while engaging in 3 treadmill-based laboratory test conditions, including a 4.8 km/h athletic short, 4.8 km/h blue jeans, and 9.6 km/h athletic shorts and one free-living test condition. Accelerometer 1 was attached in the traditional method (belt-worn at the waist), while accelerometer 2 was placed in the front thigh pocket. Questionnaire reported compliance beliefs pertaining to a 7-day wear time protocol were also obtained. **Results:** All participants self-reported that the pocket option would increase the convenience of study compliance. In laboratory testing, small mean differences were observed for condition 1, 2, and 3, respectively. Larger incongruity in central tendency was identified for vector magnitude and step counts for all laboratory-based testing. High agreement was observed for all Bland-Altman analyses. Of practical importance, free-living assessment provided high agreement (≥90%) and correlation ($r \geq 0.758$) between monitors at the two locations, with estimates of time spent in moderate-to-vigorous intensity activity ($r = 0.962$). **Conclusion:** Results from free-living evaluation are promising. Due to the mixed findings across the evaluated metrics for laboratory tests, future research is needed to determine the suitability of utilizing the pocket as a potential site for accelerometer monitoring.

KEY WORDS: Actigraph, non-compliance, objective monitoring, physical activity, triaxial accelerometer

INTRODUCTION

In recent years, accelerometer use has increased dramatically and has considerably benefited our ability to objectively assess the free-living (non-laboratory based) physical activity behavior of individuals [1]. Accelerometers are ambulatory monitoring devices which provide several advantages over the use of similar devices such as pedometers, specifically, the ability to assess frequency, intensity, and duration of physical activity. Studies, such as the National Health and Nutrition Examination Survey (NHANES), conducted by the Center for Disease Control and Prevention, utilize accelerometer measured physical activity levels in their nationally representative sample [2].

Among others, a cited problem with accelerometer use is issues with protocol compliance among study participants [3,4]. In the 2003-2004 and 2005-2006 NHANES cycles, only about 25% of participants provide complete data for the 7-day study period [1]. This is problematic in that important differences in health status have been identified between individuals who provide complete data and those who do not. That is, individuals providing incomplete, often referred to as invalid data, are more likely to have unfavorable health conditions (i.e., cardiovascular disease, diabetes, and obesity) than their counterparts [3]. Typically, study protocols require participants to produce at least 10 h/day of wear time for 4 days over a 7 day monitoring period [5], and those who fail to meet this expectation are deemed to provide invalid data. It is common practice to remove invalid data from analysis which, given the previously mentioned nature of individuals producing invalid data, may potentially bias findings regarding relationships between physical activity and various health conditions, as well as reduce the sample size, potentially influence statistical power.

In practice, common placement of an accelerometer is the midaxillary line of the iliac crest, as energy expenditure is proportional to movement at the center of mass [6]. This location is often referenced in research by the terms hip or waist [7]. Placing the device at this location often requires that participants wear a cumbersome elastic belt. Inconvenience, discomfort and forgetfulness have been cited by participants as reasons for noncompliance to accelerometer-based study protocols [1,8]. To address forgetfulness, 24 h wear time protocols have been suggested and show promise [9] and may allow researchers the additional opportunity to study sleep behavior among their study participants. Recent studies have investigated the feasibility of wearing these devices in alternate locations on the body such as the wrist [10] and at the chest [11], with such methods shown to increase compliance when compared to traditional waist-mounted methodology among a child population [12]. Although wrist-worn methodology presents improvements in protocol compliance, data produced by this method does not compare well with that derived at the waist [10], and additionally, may present issues with reliability [7].

An unexplored methodology for accelerometer use is the ability of an individual to carry these devices in their pocket, specifically, the front pocket over the thigh. In theory, this methodology could greatly increase the likelihood of protocol compliance due to reasons referenced above. It is plausible to suspect this method may have the potential to produce valid and reliable data. The activPAL (PAL Technologies Ltd, Glasgow, UK) accelerometer manufacturers specify their monitor be warn at the midline of the anterior thigh affixed by self-adherent elastic wrap. In addition, the user manual for the Actigraph GT3X-BT (Actigraph LLC, Pensacola, FL) states that this model can be worn at the thigh.

It is important that research continues to investigate and establish the reliability and validity of innovative ways to increase the ease of compliance with accelerometer protocols. Thus, the aim of the current study was to test the efficacy for physical activity assessment via an accelerometer carried in the thigh pocket, i.e., examine differences in activity counts when comparing waist-mounted versus pocket worn accelerometry. A secondary aim was to assess whether participants believe a pocket protocol would increase their likelihood of compliance during a traditional 7-day assessment period.

METHODS

Participants

All study procedures were reviewed and approved by the authors' institutional review board. Participants of the current study (n = 10) were males of at least 18 years of age. All participants were either students or University employees. Participants were provided with informed consent and completed the Physical Activity Readiness Questionnaire before engagement in any test procedures.

Accelerometers

In this study, we used the Actigraph GT9X Link (Actigraph LLC, Pensacola, FL) accelerometer as it is Actigraph's most recent offering and a model commonly represented in current literature. The GT9X is a triaxial accelerometer with a programmable liquid crystal display and Bluetooth capabilities. This model offers attachment capabilities at the waist, wrist, and the ability to clip the device to the waistband of an individual's clothing. In this study, participants wore 2 monitors simultaneously in each test condition. Accelerometers were initialized and data were downloaded in 1 s epochs using ActiLife version 6 (Actigraph, Pensacola, FL). Accelerometer 1 was placed in the traditional method of attachment at the waist where the device is worn on an elastic belt resting at the midaxillary line of the iliac crest. All elastic belts utilized were the product of the accelerometer manufacturer. Accelerometer 2 was placed in the participant's front thigh pocket. Pocket carried accelerometers were unrestricted and held in place only by gravity and constriction placed on the accelerometer by the individual's garment. Before testing, 3 measures of the individual's pocket were recorded in attempts to control for differences in clothing choice. The first was pocket length as measured from top to bottom and the second was a width measurement from side to side. These measurements were made with the garment turned inside out and lying flat on a table. The third measurement provided an estimate of constriction placed on the accelerometer by the garment. With the participant wearing the clothing (jeans or athletic shorts) a researcher pulled the fabric away from the thigh at the midpoint of the pocket, until no slack remained, then measured the distance from that point to the thigh.

Procedures

The study protocol consisted of three laboratory based test conditions along with one free-living test condition which occurred once the participant left the laboratory. Specifically, condition 1 required the participant to walk in a pair of self-selected blue jeans at a speed of 3 mph (4.8 km/h). In condition 2, the participant walked at 3 mph (4.8 km/h) in self-selected athletic shorts. Condition 3, again in athletic shorts, the participant jogged at 6 mph (9.6 km/h). Finally, condition 4 was a free living comparison of the waist and pocket carry methodology. For standardization purposes, the free-living assessment was executed with all participants wearing the athletic shorts. During each test condition, the participant wore 2 accelerometers concurrently, one at the waist attached to the manufacturer provided elastic belt (criterion measure) and the other carried in the thigh pocket. Both accelerometers were worn on the right side of the body for each participant regardless of leg dominance, as past study suggests leg dominance does not change accelerometer data [13]. Each laboratory condition (1-3) was a treadmill protocol lasting 3 minutes, with conditions reflecting different speeds and clothing combinations. The 3 min time period began 10 s after the treadmill reached the designated speed to allow the participant time to assume their normal gate pattern. Total physical activity time for laboratory-based testing was approximately $9^1/_2$ min with the entire participant visit lasting <30 min. Because accelerometers are primarily used to study physical activity 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 in a free-living environment. Condition 4 allowed the individual to participate in their normal daily activities in the free-living setting. On completion of laboratory test conditions (1-3), participants were asked to wear the 2 accelerometers during all waking hours for the remainder of their day, while allowing for removal of the device for showering or swimming.

In addition to the accelerometer derived data, participants were asked to complete a short 5-item questionnaire assessing their compliance beliefs pertaining to traditional 7-day wear time protocols. Before testing procedures, participants were fitted with an accelerometer in the traditional manner (belt worn at the midaxillary line of the iliac crest) and asked to answer questions 1 and 2. The following completion of questions 1 and 2 [Table 1], a second accelerometer was placed into the participant's thigh pocket, and the remaining questions were answered.

Analysis

All analyses were conducted using SPSS version 22 (SPSS Inc., Chicago, IL) and Stata version 12.0 (College Station, TX). For all significance testing, an alpha level of 0.05 was set a-priori. Accelerometer metrics chosen for analysis were vector magnitude, vertical axis counts, and step counts for data produced during lab testing. For the two accelerometers used during each treadmill test condition, the three previously mentioned accelerometer metrics represent the average counts per minute produced during each 3-min test condition. For the free-living assessment, total wear time, time and percentage of wear time spent in differing intensity levels were also evaluated between the two monitors worn using thresholds established by Freedson *et al*. 1998, and Matthew 2005 [14-16]. For each metric analyzed, paired samples *t*-test were used to examine mean differences between the hip and pocket placed monitors. In addition, Bland–Altman plots were constructed to examine limits of agreement between the two monitor placements. Pearson's product moment correlation coefficient identified the relative relationship between activity counts produced at each of the two wear locations. Finally, descriptive statistics were reported for demographics and questionnaire items.

RESULTS

The median age of participants in this study was 27.0 years (median = 27.0, range = 22.0-33.0) with the majority of individuals identifying as non-Hispanic whites, at 90% of the sample. Participants were highly educated with 90% reporting having a graduate degree. Median body mass index (BMI) score was 26.4 kg/m^2 with a range of 23.4-30.9 kg/m^2. Three participants were classified as normal weight followed by 6 classified as overweight and one participant identified as obese based on BMI thresholds set by the World Health Organization. Furthermore, waist circumference median value was 87.4 cm (median = 87.4, range = 77.6-98.0) and median leg length was 84.4 cm (median = 84.4, range = 78.0-98.3). These data, as well as, descriptive statistics on participant pocket dimensions can be seen in Table 2.

As seen in Table 1, the majority of participants (60%) reported that compliance with a 7-day monitoring period would be an inconvenience when the accelerometer is worn at the hip in the traditional belt-mounted manner. When asked to rate confidence in their ability to adhere to study protocols on a scale of 1-10, while wearing the device at the hip, the mean response was 7.5 (median = 7.5, range = 4.0-10.0). As hypothesized, the option to carry an accelerometer in the thigh pocket increased participant confidence in their ability to comply with study protocols (median = 10.0, range = 8.0-10.0). 90% identified increased confidence in wearing the device for 7 days with 100% citing the pocket option would increase the convenience of wearing the device for 7 days.

Large differences were observed between data produced at the pocket when compared to those at the hip for vector magnitude and step count metrics in all laboratory test conditions. The pocket carried monitors consistently produced a higher overall vector magnitude and lower step count estimate than monitors worn in the traditional manner on the hip, Table 3. Interestingly, differences in central tendency were much smaller for vertical axis counts. Irrespective of test condition or accelerometer metric, Bland–Altman plots indicated <10% of the observations were outside the limits of agreement. However, as depicted in Figure 1, there was evidence of fixed bias (mean difference, shown by the dotted line not being on zero), heterogeneous bias (shown by the fan shape of the dots, becoming wider at higher levels of counts) and proportional bias (shown by the downward slope of the differences).

For the free-living assessment, and for condition 4 of the experiment, wear time estimates were virtually identical with a significant correlation of $r = 0.983$ between the hip and pocket carried monitors. All free-living metrics examined produced a high degree of correlation ($r \geq 0.758$), all of which were statistically significant, and agreement of at least 90% between monitors placed in the thigh pocket and those worn at the hip. Notably, moderate-to-vigorous intensity activity estimates were indistinguishable between placement sites ($R^2 = 0.926$), Figure 2. In addition, with the exception of time spent in moderate, vigorous and percentage of vigorous, all comparisons produced correlations >0.90, Table 3.

DISCUSSION

Vertical axis counts appeared to provide the most comparable data with all test conditions producing smaller central tendency differences between waist-mounted and pocket worn

Table 1: Qualitative perceptions of monitor compliance at difference sites

Q1	How confident are you in your ability to wear the device, during all waking hours and during all daily activities while utilizing the traditional method of wear for a period of 1-week?	7.5 (4.0-10.0)
Q2	Would it be an inconvenience to wear the accelerometer for a period of 2-week, while wearing the monitor at the waist (on a belt) for a minimum of 10 h/day?	60%
Q3	If you could place the device in your front thigh pocket would that increase the convenience of wearing the device for a period of 1-week, including wearing the monitor for at least 10 h/day?	100%
Q4	Would the option of carrying this device in your pocket increase your confidence in your ability to wear this device for a period of 1-week?	90%
Q5	Given the ability to choose the traditional method of wear or the pocket carry method, how confident are you that you could wear the device, during all waking hours and during all daily activities, for a period of 1-week?	10.0 (8.0-10.0)

Questions 1 and 5 present median and range for answers scored on a 10-point Likert scale. Questions 2-4 reflect the percentage of participants who answered yes

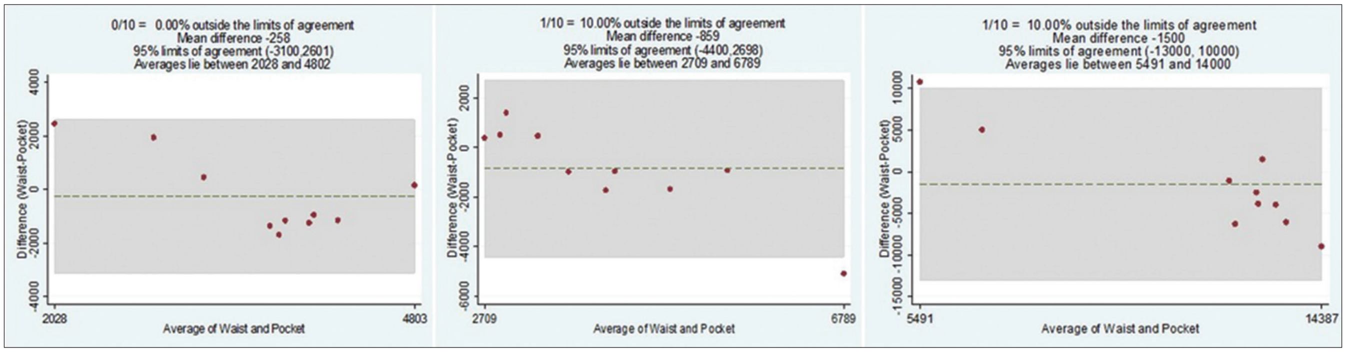

Figure 1: Bland–Altman plots reflect comparison between vertical axis counts produced at the criterion placement method (belt mounted at the midaxillary line of the iliac crest) and the experimental pocket placement. Test conditions 1, 2, and 3 are shown in Figures 1a-c, respectively

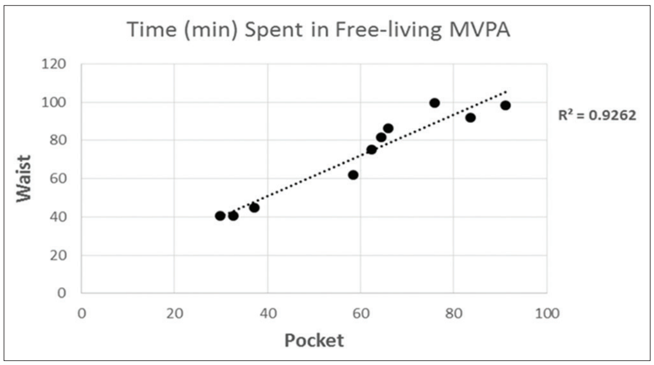

Figure 2: Reflects the high degree of correlation in time (minutes) spent in moderate-to-vigorous physical activity recorded between the waist mounted and pocket carried accelerometer. As seen in tabular form, results were similar for all free-living metrics

Table 2: Characteristics of the study variables

Participant characteristics (*n*=10)	Median (range)
Age (year)	27.0 (22.0-33.0)
BMI (kg/m^2)	26.4 (23.4-30.9)
Leg length (cm)	84.4 (78.0-98.3)
Waist circumference (cm)	87.4 (77.6-98.0)
Ethnicity (%)	
Non-Hispanic white	90
Other/multi-racial	10
Education (%)	
Some college	10
Master's degree or higher	90
Pocket dimensions (Jeans)	Median (range)
Width (cm)	17.7 (15.5-22.5)
Length (cm)	25.2 (16.5-29.0)
Depth (cm)	5.6 (1.75-7.75)
Athletic shorts	
Width (cm)	15.0 (12.5-19.5)
Length (cm)	29.5 (26.0-36.0)
Depth (cm)	13.0 (7.5-18.0)

Descriptive statistics presented for participant characteristics.
BMI: Body mass index

accelerometers. In addition, for condition 1, all observations were found to lie within the 95% limits of agreement, Figure 1. In the free-living test condition, extremely high correlations were observed for all metrics examined, Table 3. This is of consequence as the free-living metric estimates produced were the product of the vertical axis. It is possible the discrepancy between laboratory and free-living findings is the result of dissimilarity between activities performed during the free-living condition and the treadmill walking and jogging performed in the laboratory. Evidence of comparable vertical axis data from the thigh pocket is promising as many existing cut points have been produced based on this axis as earlier accelerometers were primarily uniaxial [14,17]. Furthermore, research suggests that vector magnitude holds no superiority over use of the vertical axis when estimating energy expenditure [18]. Future research should attempt to further investigate vertical axis counts produced at the thigh pocket among larger and more diverse sample to further validate this as a potential mechanism through which 7-day protocol compliance is increased.

Problems with study protocol compliance have been identified in the previous literature [1] resulting in incomplete and traditionally unused data. In addition, problematic implications pertaining to the exclusion of this invalid data from analytics have been presented [3] which have the potential to underestimate, ultimately biasing, the relationship between physical activity and health outcomes. For these reasons, it is important to continue to refine methodology that increases participant compliance and reduces the production of invalid data. Encouragingly, all participants in this study reported that thigh pocket placement of the accelerometer would reduce the inconvenience of study participation, however, laboratory testing produced incomparable data between wear sites for step counts and vector magnitude, with the vertical axis producing more plausible evidence for comparability. Further, results for vertical axis counts were promising as particularly high correlations were observed in the free-living condition, Table 3. In laboratory testing, the pocket placed accelerometer produced consistently higher vector magnitude values and lower step counts, Figure 3. The disagreement for laboratory comparisons made for vector magnitudes and steps appear to be magnified with increasing speeds.

Incongruent laboratory-based data produced between attachment methods in this study may be due to the insecure nature of body contact with the device when placing the accelerometer in the front thigh pocket. A more secure contact to the thigh could have been accomplished through adhesive tape or securing the elastic belt to the thigh; such methods have been utilized in past accelerometer studies [19,20].

Table 3: Median accelerometer metrics across the test conditions

Laboratory testing	Condition	Median waist counts (range)	Median pocket counts (range)	Agreement (%)	Pearson's r	R^2
Vector magnitude	1 (4.8 km/h jeans)	4095.03 (3349.8-7386.2)	6746.11 (3785.7-7804.0)	90	−0.312	0.097
	2 (4.8 km/h shorts)	4291.93 (3263.3-6943.8)	7364.72 (4092.8-9722.5)	100	0.580	0.336
	3 (9.6 km/h shorts)	11537.94 (9534.2-17986.3)	22147.26 (14293.7-27838.8)	90	−0.085	0.007
Vertical axis	1 (4.8 km/h jeans)	3592.16 (3015.0-4878.3)	4376.50 (806.0-4789.0)	100	0.087	0.007
	2 (4.8 km/h shorts)	3603.16 (2899.6-5009.6)	3710.5 (2255.0-5932.0)	90	0.592	0.350
	3 (9.6 km/h shorts)	10822.00 (9330.6-12337.3)	14546.81 (4362.0-18873.0)	90	0.121	0.014
Steps	1 (4.8 km/h jeans)	109.33 (55.0-120.6)	63.16 (49.3-110.3)	90	−0.009	0.000
	2 (4.8 km/h shorts)	109.00 (55.0-117.0)	74.50 (57.0-112.0)	90	−0.027	0.000
	3 (9.6 km/h shorts)	154.83 (120.3-162.3)	100.00 (76.3-153.3)	90	−0.077	0.005

Free living	Median waist min/% (range)	Median pocket min/% (range)	Agreement (%)	Pearson's r	R^2
Wear time (min)	518.90 (377.2-694.4)	506.82 (377.3-730.6)	100	0.983*	0.966
Sedentary (min)	543.35 (350.1-803.2)	524.16 (326.4-783.5)	90	0.984*	0.968
Sedentary (%)	84.26 (76.3-90.3)	82.70 (69.9-89.2)	90	0.962*	0.925
Light (min)	42.43 (20.0-64.1)	43.60 (18.3-77.6)	90	0.964*	0.929
Light (%)	6.55 (2.95-11.5)	7.34 (3.3-14.2)	90	0.920*	0.846
Moderate (min)	52.15 (24.7-73.0)	56.79 (33.7-74.3)	90	0.885*	0.783
Moderate (%)	6.56 (5.0-13.4)	7.91 (4.4-12.7)	90	0.909*	0.826
Vigorous (min)	11.41 (4.9-25.2)	22.33 (3.2-34.1)	100	0.758*	0.574
Vigorous (%)	1.66 (0.9-4.9)	2.71 (0.7-7.5)	90	0.817*	0.667
MVPA (min)	63.41 (29.8-98.3)	78.47 (40.5-99.6)	90	0.962*	0.926
MVPA (%)	8.05 (5.9-18.4)	9.85 (7.1-20.3)	100	0.963*	0.927

Comparison between accelerometer data produced at the waist to that produced the thigh pocket. *Indicates significance at the 0.05 level. Agreement is from the Bland–Altman plot. MVPA: Moderate-to-vigorous physical activity

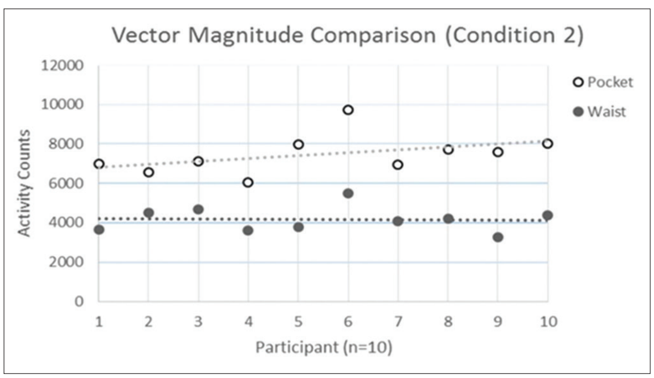

Figure 3: Illustration of the overestimation of pocket produced vector magnitude counts consistently observed during laboratory test conditions. As seen in tabular format, results were similar for all test conditions for vector magnitude as well as step count comparisons

Nevertheless, these methods would likely do little to reduce the inconvenience of 7-day free-living protocol compliance which was the primary concern of the current study. Likewise, deviation away from the body may explain equivalent counts produced only in the vertical axis in that the monitor deviating from the body during ambulatory movement could inflate overall vector magnitude values [18]. Our results seem to support this outcome as vector magnitude was consistently higher in pocket carried accelerometers, Figure 3, while vertical axis counts remained statistically equivalent to the hip placed monitors.

The strengths of this study lie in its novel approach to addressing a pressing concern in physical activity assessment research utilizing accelerometers, that being non-compliance with a traditional 7-day monitoring protocol. Thus far, no study has tested the efficacy of pocket carried accelerometers. In addition, this study used laboratory-based and free-living testing conditions, which similar conceptual studies have neglected to do. Limitations of our study are a small sample size composed of only male participants. Future studies are needed that employ a larger sample size, particularly samples that are sufficiently powered to evaluate non-inferiority. Given the nature of clothing style differences combined with anatomical differences by sex, our findings may not translate to the female population, which should be of interest for future studies. However, since this study is "proof of concept" in nature, it seems appropriate to establish its plausibility among a small sample before application to a larger more diverse group. In addition, we utilized the traditional hip placement of the device as our criterion measure for comparison. Future study should examine this pocket placement in relation to a marker of energy expenditure such as indirect calorimetry or doubly labeled water.

CONCLUSION

This study examined the efficacy of carrying a triaxial accelerometer in the thigh pocket as a means of reducing inconvenience associated with a traditional 7-day data collection protocol. All participants reported that the pocket placement would increase the convenience of wearing the accelerometer. Only vertical axis counts were shown to be somewhat comparable to the traditional wear site as low-to-moderate correlations were observed in the laboratory tests and high correlations were observed in free-living testing, Table 3. Notably, however, there was evidence of bias observed in the Bland–Altman plots, suggesting that comparability of data between these two methods may be questionable. Further, very strong correlations were observed during the free-living comparison. Further study seems warranted to establish this pocket methodology as a potential option for assessment of free-living physical activity.

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