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Comparison of Sedentary Estimates between activPAL and Hip- and Wrist-worn ActiGraph

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Abstract

Purpose—Sedentary behavior is an emerging independent health risk factor. The accuracy of measuring sedentary time using accelerometers may depend on the wear location. This study in older adults evaluated the accuracy of various hip- and wrist-worn ActiGraph accelerometer cutoff points to define sedentary time using the activPAL as the reference method.

Methods—Data from 62 adults (mean age 78.4 years) of the Aging Research Evaluating Accelerometry (AREA) study were used. Participants simultaneously wore an activPAL accelerometer on the thigh and ActiGraph accelerometers on the hip, dominant, and nondominant wrist for 7 days in a free-living environment. Using the activPAL as the reference criteria, we compared classification of sedentary time to hip-worn and wrist-worn ActiGraph accelerometers over a range of cut-off points for both 60-second and 15-second epochs.

Results—The optimal cut-off point for the hip vertical axis was <22 counts per minute (cpm) with an area under the curve (AUC) of 0.85; the optimal hip vector magnitude cut-off point was <174 cpm with an AUC of 0.89. For the dominant wrist, the optimal vector magnitude cut-off point to define sedentary time was <2303 cpm (AUC: 0.86) and for the nondominant wrist <1853 cpm (AUC: 0.86). The optimal 15s cutoff points results in lower agreements compared with activPAL.

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Conflict of Interest

The authors have no conflict of interest

Conclusions—Hip- and wrist-worn ActiGraph data may be used to define sedentary time with a moderate to high accuracy when compared to activPAL. The observed optimal cut-off point for hip vertical axis <22 cpm is substantially lower than the standard <100 cpm. It is unknown how these optimal cut-off points perform in different populations. Results on an individual basis should therefore be interpreted with caution.

Keywords

accelerometry; sitting; sedentary behavior; validation studies; sensitivity and specificity; older adults

INTRODUCTION

There is a growing interest in sedentary behavior as an independent risk factor for health (5, 6). Objective measures, such as accelerometers, are frequently used to estimate sedentary time in population based research. Accelerometers worn at the thigh such as the activPAL can distinguish postures and are the most accurate to assess time spent sitting or lying down (12). Two other common locations for placement of accelerometers are at the hip and wrist.

Accelerometers worn at the hip, including the ActiGraph, are widely used to classify activity by intensity using cut-off points (2, 7, 14, 18, 20, 23). There are commonly used cut-off points to define sedentary time from a hip-worn accelerometer (1, 14, 15). In addition, earlier accelerometers only had the capability to collect movement along the vertical axis, leading to cut-off points being primarily developed for the vertical axis only. While recent models can collect triaxial accelerometry data, it is unclear how triaxial cut-off points based on a vector of magnitude compare to uniaxial vectors when classifying sedentary time.

Wrist accelerometers have been increasingly used in research settings to study sleep patterns as well as to increase adherence to wear protocols (21). However, the accuracy of estimating sedentary time using a wrist-worn accelerometer compared to a thigh-worn device remains unclear. Currently, there is no established cut-off point to determine sedentary behavior using ActiGraph wrist accelerometers.

Validation studies to determine the accuracy of commonly used cut-off points for the hip in older adults are scarce (1). Further, the accuracy of accelerometry data collected on the wrist to assess sedentary time in older adults has not been examined. There are several large ongoing studies in older adults that included accelerometry (24) so methodical research in this age groups are urgently needed to correctly classify sedentary behavior and physical activity. The aim of the current study was to compare the sedentary time estimates from activPAL and hip- and wrist-worn ActiGraph accelerometers across various cut-off points among older, free-living adults.

METHODS

Study Population

The Aging Research Evaluating Accelerometry (AREA) study, part of the Developmental Epidemiologic Cohort Study (DECOS) conducted at the University of Pittsburgh

(2012-2013) is a methodological study designed to examine the impact of accelerometer wear location on physical activity and sedentary behavior assessment among 81 older adults. During the 7-day free-living component of the AREA study, participants simultaneously wore up to 5 monitors: an ActiGraph worn on the left and right wrist, a hip-worn ActiGraph, an activPAL worn on the upper thigh, and a Sensewear on the left triceps. The study was approved by the Institutional Review Board of the University of Pittsburgh and National Institute on Aging; all participants provided written informed consent.

For the current study, we examined accelerometer data from the thigh-worn activPAL as well as hip- and wrist-worn ActiGraphs. Of the 89 total participants, 68 were eligible as the activPAL was added to the protocol in the second wave of the study. We then excluded those with missing data or device failures for any of the 4 accelerometers ($N = 5$). One participant was excluded for insufficient wear time (described below), resulting in a final analysis sample of 62 participants.

Accelerometer Measures

Two brands of accelerometers were employed (activPAL and ActiGraph) over a total of 4 wear locations (thigh, hip, and each wrist). The activPAL3 physical activity monitor (PAL Technologies Limited, Glasgow, Scotland, UK) is a thigh-worn triaxial accelerometer with the capability of determining posture based on acceleration information. The ActiGraph GT3X+ (ActiGraph Inc, Pensacola, FL, USA) is a triaxial accelerometer that was worn on the right hip and each wrist. Accelerometer data were collected at 20 Hz for activPAL and 80 Hz for ActiGraph and then aggregated to 15- and 60-second epochs for analyses.

Participants were instructed to wear the wrist- and thigh-worn accelerometers continuously for a period of 7 full days. Accelerometers were permitted to be removed at night to increase comfort. Hip and wrist accelerometer data, using all three axes, were screened for periods of wear ("wear time") using methods described by Choi et al (3). Briefly, non-wear time was defined as 90 consecutive minutes of zero counts, with an allowance of 2-minutes of nonzero counts provided there were 30-minute consecutive zero count windows up and downstream. A valid wear day consisted of at least 10 hours of wear time. Participants were required to have at least 1 valid day to be included in the sample (4.8% had 2 or 3 valid days; 3.2% had 4 days; 11.3% had 5 days; 16.1% had 6 days; and 64.5% had 7 or 8 valid days.). In order to compare accelerometer data across wear locations, we limited the data from all devices to times when the two wrist, hip and thigh-worn devices were worn.

As sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤ 1.5 METs while in a sitting or reclining posture (19), the activPAL sedentary status was used as the reference criteria (8, 12). ActivPAL sedentary time was the sum of the number of minutes where the participant was classified as sitting or lying down.

Sedentary time was evaluated by the ActiGraph accelerometer based on the time when the monitor registered counts per minute (cpm) less than a specific cut-off point. Two previously established cut-off points for the hip accelerometer were used: <100 cpm in the vertical axis (15, 23) and <200 cpm in the vector magnitude (1). The vector magnitude derived from the ActiLife software was calculated as the square root of the sum of the squares of the three

axes. As there is debate if these cut-off points are appropriate for all individuals, particularly among older individuals, we also calculated the sedentary time based on a priori cut-off points for the hip using both the vertical axis and the vector magnitude. The hip cut-off points included <25 cpm to <300 cpm by 25 cpm intervals (<25, <50, ..., <300). As there are no established ActiGraph wrist cut-off points for sedentary behavior in adults, we calculated sedentary time based on a priori cut-off points using the vector magnitude. The wrist vector magnitude cut-off points included <750 cpm to <3500 cpm by 250 cpm intervals.

Statistical Analyses

We described the distribution of counts per minute for the 4 ActiGraph accelerometer measures (hip vertical axis, hip vector magnitude, dominant wrist vector magnitude, and nondominant wrist vector magnitude) during the 4 classifications of time by activPAL: total, sedentary, standing, and stepping.

To determine the AREA optimal cut-off points, we modeled ActiGraph counts as a continuous variable to predict activPAL sedentary status for each minute of valid data onto a receiver operating curve (ROC). The optimal cut-off point was defined as the threshold that maximized the sum of the sensitivity and specificity (9, 16). The area under the curve (AUC) was used to describe the fit of the model; an AUC of 1 represents perfect accuracy. This was performed for the hip vertical axis, hip VM, dominant wrist VM, and nondominant wrist VM. Optimal cut-off points were determined for both 60-second and 15-second epochs. For each optimal cut-off point as well as the accepted standard cut-off points (hip vertical <100 cpm and hip VM <200 cpm)(1, 15, 23), we also calculated the mean difference in daily sedentary wear time (minutes per day) between the ActiGraph and the activPAL. Bland-Altman plots were created to further examine AREA optimal cut-off points compared to activPAL sedentary time.

To examine the variability in classification agreement of sedentary time over a range of cut-off points, we calculated the sensitivity, specificity, and Kappa statistic between the activPAL and the ActiGraph. For each epoch of valid wear time, we compared the classification of that minute as sedentary or not sedentary according to activPAL and ActiGraph, using the activPAL as the 'gold standard'. The sensitivity represents the probability of each epoch being classified as sedentary by ActiGraph given that it is sedentary according to activPAL. The specificity represents the probability of each epoch not being sedentary according to ActiGraph given that it is not sedentary according to activPAL. While the AUC describes the model fit of the continuous ActiGraph counts to predict activPAL sedentary time, it is difficult to compare specific cut-off points using AUC as the only metric. To better describe the classification accuracy and compare cut-off points, we calculated the kappa statistic, which evaluates for every epoch, how well the dichotomized continuous counts into ActiGraph sedentary or not is classified compared to activPAL. We used the guidelines of Landis and Koch to evaluate the strength of the Kappa statistic: kappa less than 0.40 indicates "poor" agreement, values between 0.40 and 0.75 indicate "moderate" agreement, and values greater than 0.75 indicate "excellent" agreement (13). This was performed for each cut-off point for the hip and wrist accelerometers.

To further describe potential misclassification of ActiGraph sedentary time, means of sedentary time for both optimal and standard cut-off points during each activPAL status (sitting, standing, stepping, and transitions) were calculated. In secondary analyses, we included standing time while not stepping as part of the activPAL sedentary definition. ActivPAL sedentary + standing time was the sum of the number of minutes where the participant was classified as sitting, lying down, or standing, but not stepping/walking (12). Minute-level and day-level analyses were repeated using this as the standard. Statistical analyses were conducted in SAS v9.3 and R v3.1.3. This study utilized the high-performance computational capabilities of the Helix and Biowulf Systems at the National Institute of Health, Bethesda, MD (<http://helix.nih.gov>).

RESULTS

We analyzed data from 62 participants (26 men) with a mean age of 78.4 (SD = 5.7, range = 70 to 92) years. Eleven percent of participants used a cane to walk and 59 participants (95.2%) were right-handed. Participants wore the monitors (based in hip wear time) on average 929 minutes (~15.5 hours) per day. Table 1 shows the distribution of hip and wrist worn cpm during activPAL sedentary, standing, and stepping time. During activPAL sedentary minutes (N = 222 080 across 62 participants), the median cpm for the hip-worn ActiGraph was 0 cpm in vertical axis as well as in the vector magnitude. The median wrist-worn cpm was 622 for the dominant wrist and 428 for the nondominant wrist. From the 95th percentile, we observed that the ActiGraph registered counts above the standard cut-off points for sedentary behavior at least 5% of the time during which the activPAL classified the individual as sedentary. The distribution of counts per 15-second epoch is displayed in Supplemental Table 1 (see Table, Supplemental Digital Content 1, Distribution of ActiGraph hip and wrist counts per 15 seconds by activPAL status, AREA 2012-2013).

Figure 1 is a panel of four ROCs predicting sedentary behavior from ActiGraph 60-second counts against the criterion measure of the activPAL, one for each of four ActiGraph measures: the hip vertical axis, hip VM, dominant wrist, and nondominant wrist. The AREA optimal cutoff point for the hip vertical axis was <22 cpm with an AUC of 0.85. The sensitivity, specificity, and Kappa statistic at this cut-off point were 84.5%, 74.1%, and 0.59, respectively (Table 2). For the hip VM, the optimal cut-off point was <174 cpm (AUC: 0.89, Figure 1). At this cut-off point, the sensitivity, specificity, and Kappa were 87.1%, 80.3%, and 0.67 (Table 2).

The classification of sedentary time using wrist cut-off points was similar to the hip cut-off points. The optimal dominant wrist cut-off point was <2303 cpm (AUC: 0.86, Figure 1). The sensitivity, specificity, and Kappa at this value were 80.5%, 77.9%, and 0.58 (Table 2). For the nondominant wrist, the optimal cut-off point was <1853 cpm (AUC: 0.86, Figure 1). The sensitivity, specificity, and Kappa for this cut-off point were 81.5%, 76.6%, and 0.57 (Table 2). To examine the variability of these classification measures across various cut-off points, the sensitivity and specificity, along with the Kappa statistic, are listed for each cut-off point in Supplemental Table 2 (see Table, Supplemental Digital Content 2, Classification of activPAL sedentary behavior by various ActiGraph hip and wrist cut-off points, AREA 2012-2013). When defining sedentary time using the standard hip ActiGraph cut-off point of

<100 vertical cpm, the Kappa was slightly lower than the AREA optimal cut-off point (0.55 vs 0.59). However, the Kappa for the <200 VM cpm cut-off point was very similar to the AREA optimal cut-off point (0.68 vs 0.67). The further from these cut-off points one moves, the less accurate we are able to classify sedentary time. For example at <300 hip vertical cpm, the Kappa was 0.37. However, there was a large range where the Kappa remained the same or similar for both the hip and wrist cut-off points. For example, for the nondominant wrist the AREA optimal cut-off point (<1853 cpm) had a Kappa of 0.57. Cut-off points ranging from <1750 to <2500 had Kappa ranging from 0.57 to 0.58.

For the 15-second epoch analyses, the classification accuracy of sedentary time was slightly lower when compared to the 60-second epoch analyses. The AREA optimal cut-off point for the hip vertical axis was <1 cp15s (count per 15 seconds) with an AUC of 0.75 (Figure 2). The optimal cut-off points for the hip vector magnitude, dominant wrist, and nondominant wrist were <20 cp15s (AUC = 0.83), <517 cp15s (AUC = 0.81), and <376 cp15s (AUC = 0.81). The sensitivity, specificity, and Kappa for each 15-second cut-off points are listed in Table 2.

Mean differences (95% confidence intervals (95% CI)) in daily sedentary time based on various ActiGraph cut-off points for the hip and wrist compared to activPAL sedentary time are shown in Table 2. On average, for 60-second epochs, participants had 566.1 (SD = 149.5) minutes per day of sedentary time according to the activPAL (Table 2). The daily sedentary time did not substantially differ between the AREA optimal ActiGraph hip cut-off points and activPAL sedentary status. The Bland-Altman plots presented in figure 3 show of the difference between ActiGraph sedentary time cut-off points and activPAL sedentary time for the AREA optimal hip and wrist cut-off points. The ActiGraph hip vertical cut-off point of <22 cpm overestimated sedentary time by 5.0 (95% CI: - 29.5, 19.5) minutes per day. The ActiGraph hip VM cut-off point of <174 cpm underestimated daily sedentary time by 2.5 (-20.4, 25.5) minutes per day. The optimal wrist cut-off points underestimated daily sedentary time compared to activPAL (dominant wrist: 30.2 (10.7, 49.6) minutes per day; nondominant wrist: 22.6 (0.5, 44.6) minutes per day). Using the standard hip cut-off point of <100 vertical cpm resulted in an overestimation of daily sedentary time of 114.3 (-140.5, -88.1) minutes per day. The standard hip VM cut-off point of <200 cpm did not substantially overestimate sedentary time compared to the activPAL (9.9 (-32.8, 13.0) minutes per day).

The ActiGraph 15-second hip vertical cut-off point of <1 cp15s overestimated daily sedentary time by 53.4 (95%CI: -76.4, -30.4) minutes per day. The corresponding vector magnitude cut-off point of <20 cp15s underestimated sedentary time by 12.8 (-8.8, 34.4) minutes per day. The dominant and nondominant wrist optimal cut-off points performed similarly underestimating sedentary time by 64.7 minutes.

Table 3 describes the misclassification of ActiGraph sedentary time by activPAL status. For all cut-off points, the majority of ActiGraph sedentary time occurs during activPAL sitting or lying. However, there is a substantial amount of ActiGraph sedentary time that occurs when the activPAL registers standing. For the standard 60-second hip vertical cut-off point of <100 cpm, on average, 11.7% (79.4 (SD = 45.4) minutes) of daily sedentary time is while

standing. Similar trends are observed for optimal 60-second cut-off points. For 15-second cut-off points, the amount of time spent standing is greater compared to 60-second cut-off points. Very little sedentary time using either 60-second or 15-second epoch occurred while stepping. Classifying sedentary time using a 15-second epoch reduced the amount of time spent in transitional statuses between sitting, standing, and stepping, compared to 60-second epochs.

In secondary analyses, adding standing without stepping time to the definition of sedentary behavior increased the overall agreement slightly between activPAL and ActiGraph across all wear locations (see Table, Supplemental Digital Content 3, Sedentary minutes per day by activPAL and various ActiGraph cut-off points, AREA 2012-2013; see Figure, Supplemental Digital Content 4, ActiGraph sedentary time cut-off points that maximize sensitivity and specificity from ROC curves using ActivPAL sedentary + standing status as the criterion measure). The hip vertical axis AREA optimal cut-off point was <33 cpm (AUC: 0.92), while the hip vector magnitude optimal cut-off point was <307 cpm (AUC: 0.94). The AREA optimal cutoff point for the dominant wrist was <2511 cpm (AUC: 0.87) and <2080 cpm (AUC: 0.87) for the nondominant wrist. The daily mean differences in sedentary time between activPAL, when including standing time, and ActiGraph are shown in Supplementary Table 3 (see Table, Supplemental Digital Content 3, Sedentary minutes per day by activPAL and various ActiGraph cut-off points, AREA 2012-2013).

DISCUSSION

This study in older adults evaluated the accuracy of various hip- and wrist-worn ActiGraph accelerometer cut-off points to define sedentary time as compared to the activPAL as the reference method. The AREA optimal cut-off point to define sedentary time for the hip vertical axis was <22 cpm and the AREA optimal VM cut-off point was <174 cpm, both with AUC >0.85. For the wrist, the AREA optimal VM cut-off points were <2303 cpm for dominant wrist and <1853 cpm for the nondominant wrist (AUC = 0.86). The optimal cut-off points from the 15-second epoch analyses resulted in less accurate estimates of sedentary time compared to the 60-second epoch analyses.

Given the increased interest in sedentary time as an independent risk factor for health it is important to measure sedentary time as accurately as possible. Objective measures such as accelerometers could monitor daily activity levels, including sedentary time, although its accuracy to measure sedentary time correctly may depend on its wear location. The activPAL, worn at the upper thigh, was developed to differentiate among postures and classifies a person's activity into time sitting, standing, and stepping. Compared to direct observation both in a laboratory setting (8) and in free-living individuals (12), the activPAL has shown to be an accurate and precise monitor for measuring sedentary time.

Many previous studies have used a hip-worn ActiGraph monitor and the most used cut-off point to define sedentary time is <100 cpm (15, 23); this cut-off point is substantially higher than the AREA optimal <22 cpm. Using the standard cut-off point of <100 cpm resulted in an overestimation of sedentary time by almost 2 hours compared to activPAL, whereas the AREA optimal hip 60-second epoch cut-off points did not show a significant difference in

daily sedentary time. In the current study, the AREA optimal cut-off point using the hip VM had slightly higher sensitivity, specificity, and Kappa compared to using the vertical axis alone. However, the mean difference in daily sedentary time was similar. A recent study in older adults that also explored different ActiGraph hip cut-off points to define sedentary time compared to activPAL shows similar optimal cut-off points (<25 V cpm and <200 VM cpm) (1). The optimal 15-second epoch cut-off points resulted in less accurate estimates of sedentary time compared to the 60-second epoch cut-off points. Use of the 15-second epoch cut-off points resulted in greater overestimation of sedentary time for the hip vertical axis and a greater underestimation of sedentary time for the hip VM and wrist than using the 60-second epoch cut-off points. More research is needed to corroborate these findings.

An increasing number of studies implement the wrist as the wear location for accelerometers as this is thought to increase total wear time and compliance. However, to what extent a wrist-worn accelerometer could accurately estimate sedentary time in older adults is unknown. Our study shows even though the agreement is slightly lower than for the hip VM, data from a wrist-worn accelerometer could be used to estimate sedentary time in older adults. Wrist accelerometers appeared to underestimate daily sedentary time by about 25 minutes compared to the activPAL. Furthermore, the AREA optimal wrist cut-off points for each wrist performed similarly in these data. Several studies in children and adolescents aimed to estimate sedentary behavior from ActiGraph wrist accelerometer data (4, 10, 11). However, currently, there are no accepted cut-off points to determine sedentary behavior for the ActiGraph wrist for adult populations.

Considerations when Using Cut-off points

Cut-off points based on counts over a specified interval provide a quick and easy way to determine the intensity of the observed movement. Previous studies have employed them to characterize sedentary behavior, light-intensity physical activity, and moderate-to-vigorous intensity physical activity in a wide range of populations (2, 7, 14, 18, 20, 23). However, this classification of sedentary behavior and physical activity requires balancing the ease of use and efficiency with the inherent limitations and challenges. Some of these challenges include: 1) generalizability, 2) 'one' optimal cut-off point, and 3) reducing the information provided by accelerometers. Cut-off points are generally developed in laboratory-based settings with scripted activities to derive a translation from energy expenditure to counts per minute. These studies are often conducted among younger, healthy adults using a treadmill-based protocol. The adaptability of cut-off points created in these settings has been questioned when they are ported to different populations and a free-living environment. Another important challenge is that the optimal cut-off point, may in fact be a range of cut-off points. In our data, we calculated the AREA optimal cut-off point, however the surrounding cut-off points do not appear very different from the optimal cut-off point.

Thirdly, accelerometers provide much more than an aggregate of volume over time. Accelerometers can provide axis-specific information, such as orientation and posture. Cut-off points that are based on counts to define sedentary time from a hip-worn or wrist-worn accelerometer cannot be used to determine posture. Therefore, sitting time may not be distinguished from standing time if the cpm is similar. Standing time may be misclassified as

sitting time and therefore resulting in misclassification of light-intensity physical activity. In our study the standard hip cut-off point of <100 vertical cpm resulted indeed in a substantial overestimation of sitting time and therefore underestimation of light-intensity physical activity. In our study we also compared various ActiGraph cut-off points to activPAL sitting + standing time (supplemental data). A slightly higher agreement was found when using hip cut-off points when standing was included in the activPAL sedentary definition. The standard cut-off point of <100 vertical cpm estimated similar amounts of sedentary+sitting time to the activPAL, compared to the nearly 2 hours overestimation when using sitting alone. However, the AREA optimal did not perform better in terms of daily sedentary time by adding standing time.

Future methods such as machine learning approaches might be able to use more of the accelerometer data to provide a more accurate depiction of the movement. A recent study using a machine learning approach for wrist accelerometer data in children and adolescent shows high recognition rates for sitting time in lab-based study (22). The use of this method should be investigated in free living and in other age groups. Another recent study shows that the wrist-worn GENEActiv, using a different methodology, the Sedentary Sphere concept, was able to determine posture with a more than 80% agreement compared to activPAL (17). Furthermore, in this study we did not make use of the axis data other than to calculate the vector of magnitude. It is possible that a more complex equation that accounts for position of the wrist relative to the ground might improve the estimate of sedentary time in wrist worn accelerometers. However, as of yet, this data has not been used in that way.

Strengths and Limitations

Our study has important strengths. First, this is a large study in older adults where participants wore 4 accelerometers simultaneously for multiple days. Second, the derived cut-off points for sedentary time were based on free-living accelerometer data which has an advantage over a lab-based study in which activities may not reflect activities in daily living. Third, this study examined both 60-second and 15-second epochs to define sedentary behavior. Restricting to 60-second epochs requires that the entire minute consist of the same activPAL status (sitting vs standing), resulting in discarding the minutes where individuals transitioned from sitting to standing or vice versa. Some limitations also need to be considered. First, no true gold standard for sedentary time has been used although the activPAL, shown to be an accurate measure of sedentary times, was used as a reference method in our study (8, 12). Second, AREA participants were very compliant with a complex study protocol, free of major health and frailty issues, and mostly White, which may limit generalizability to other populations.

Conclusions

Although the hip and wrist worn ActiGraph data may be used to define sedentary time with moderate to high agreement, a significant amount of time spent standing is misclassified as sedentary time. Using 60-second epoch data is preferred over 15-second epoch data with respect to optimal cut-off points to define sedentary time. The observed optimal cut-off point for hip vertical axis <22 cpm is substantially lower than the standard <100 cpm. It is

unknown how these optimal cut-off points perform in different populations. Results on an individual basis should therefore be interpreted with caution.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

ActiGraph sedentary time cut-off points from 60-second epoch data that maximize sensitivity and specificity from ROC curves using ActivPAL sedentary status as the criterion measure: A) hip vertical axis; B), hip vector magnitude; C) dominant wrist vector magnitude; D) nondominant wrist vector magnitude, AREA 2012-2013

Figure 2.

ActiGraph sedentary time cut-off points from 15-second epoch data that maximize sensitivity and specificity from ROC curves using ActivPAL sedentary status as the criterion measure: A) hip vertical axis; B), hip vector magnitude; C) dominant wrist vector magnitude; D) nondominant wrist vector magnitude, AREA 2012-2013

Figure 3.

Bland-Altman plots of the difference between ActiGraph sedentary time cut-off points and activPAL sedentary time for A) AREA hip vertical axis optimal cut-off point; B) AREA hip vector magnitude optimal cut-off point; C) dominant wrist vector magnitude optimal cut-off point; D) nondominant wrist vector magnitude optimal cut-off point.

Horizontal dotted lines are drawn at the mean difference, and at the limits of agreement.

Table 1
Distribution of ActiGraph hip and wrist counts per minute by activPAL status, AREA 2012-2013.

activPAL Status	N	Minutes	5th Pctl	25th Pctl	Median	75th Pctl	95th Pctl	Maximum
Total Time								
ActiGraph hip: vertical axis	364	938	0	0	0	118	876	9276
ActiGraph hip: vector magnitude	364	938	0	0	50	613	2161	14 697
ActiGraph dominant wrist	364	938	0	238	1652	4084	7414	43 406
ActiGraph nondominant wrist	364	938	0	136	1238	3441	6653	41 347
Sedentary Time								
ActiGraph hip: vertical axis	222	080	0	0	0	0	135	9276
ActiGraph hip: vector magnitude	222	080	0	0	0	54	469	14 697
ActiGraph dominant wrist	222	080	0	15	622	1851	4512	27 105
ActiGraph nondominant wrist	222	080	0	5	427	1417	3836	26 423
Standing Time								
ActiGraph hip: vertical axis	37	192	0	0	0	42	333	4480
ActiGraph hip: vector magnitude	37	192	0	10	124	378	1054	7821
ActiGraph dominant wrist	37	192	0	960	2927	5080	8123	43 164
ActiGraph nondominant wrist	37	192	0	638	2198	4136	6942	39 380
Stepping Time								
ActiGraph hip: vertical axis	4776		327	1303	2112	3278	5785	9187
ActiGraph hip: vector magnitude	4776		1155	2581	3355	4507	7129	12 673
ActiGraph dominant wrist	4776		1368	3526	5170	7391	21 599	43 406
ActiGraph nondominant wrist	4776		1174	3258	5017	7011	19 608	41 347

ActiGraph wrist counts are derived from the vector magnitude. Values are counts per minute, unless otherwise specified.

Table 2
Classification of activPAL sedentary time by various ActiGraph hip and wrist cut-off point, AREA 2012-2013

	Sensitivity	Specificity	Kappa	Mean (SD) Sedentary Time	Mean Difference (95% CI) ^a
60-Second Analyses					
activPAL Sedentary Time				566.1 (149.5)	Reference
Standard ActiGraph cut-off point ^b					
Hip: Vertical Axis <100 cpm	93.6	58.1	0.55	680.4 (150.8)	-114.3 (-140.5, -88.1)
Hip: Vector Magnitude <200 cpm	88.4	78.9	0.68	575.9 (145.4)	-9.9 (-32.8, 13.0)
AREA Optimum ActiGraph cut-off point ^c					
Hip: Vertical Axis <22 cpm	84.5	74.1	0.59	571.1 (146.4)	-5.0 (-29.5, 19.5)
Hip: Vector Magnitude <174 cpm	87.1	80.3	0.67	563.6 (145.2)	2.5 (-20.4, 25.5)
Dominant Wrist <2303 cpm	80.5	77.9	0.58	535.9 (145.7)	30.2 (10.7, 49.6)
Nondominant Wrist <1853 cpm	81.5	76.6	0.57	543.5 (145.5)	22.6 (0.5, 44.6)
15-Second Analyses					
activPAL Sedentary Time				597.8 (149.9)	Reference
AREA Optimum ActiGraph cut-off point ^c					
Hip: Vertical Axis <1 cp15s	87.4	60.7	0.50	651.2 (144.0)	-53.4 (-76.4, -30.4)
Hip: Vector Magnitude <20 cp15s	83.4	73.0	0.56	585.0 (142.7)	12.8 (-8.8, 34.4)
Dominant Wrist <517 cp15s	75.1	74.6	0.48	533.1 (140.0)	64.7 (45.7, 83.7)
Nondominant Wrist <376 cp15s	75.2	74.1	0.47	533.2 (136.5)	64.7 (44.3, 85.0)

Abbreviations: SD, standard deviation; 95% CI, 95% confidence interval; cpm, counts per minute. Wrist cut-off points were derived using the vector magnitude.

^aMean difference was calculated as activPAL - ActiGraph.

^bStandard cut-off points for the hip were from Matthews et al and Aguilar-Farias et al. (1, 15) There are no current sedentary cut-off point for the ActiGraph wrist.

^cAREA optimum cut-off points were derived from receiver operating curve (ROC) to maximize the sum of sensitivity and specificity. Values are minutes per day, unless otherwise specified.

Table 3

ActiGraph sedentary time by activPAL Status, AREA 2012-2013.

	ActiGraph Sedentary	Sitting	Mix of Sitting and Standing	Standing	activPAL Mix of Standing and Stepping	Stepping	Mix of Sitting, Standing, Stepping
1-Minute Analyses							
Standard ActiGraph cut-off points ^a							
Hip: Vertical Axis <100 cpm	680.4 (150.8)	528.9 (151.1)	11.5 (6.6)	79.4 (45.4)	48.8 (25.3)	0.3 (1.3)	11.3 (6.7)
Hip: Vector Magnitude <200 cpm	575.9 (145.4)	499.5 (150.4)	6.2 (4.7)	56.4 (38.5)	10.1 (6.7)	0.2 (0.7)	3.5 (2.3)
AREA Optimum AG cut-off point ^b							
Hip: Vertical Axis <22 cpm	571.1 (146.4)	477.1 (149.0)	5.8 (4.5)	64.4 (40.5)	19.6 (10.9)	0.2 (1.0)	3.8 (2.5)
Hip: Vector Magnitude <174 cpm	563.6 (145.2)	491.9 (150.1)	5.6 (4.3)	53.6 (37.4)	8.9 (6.0)	0.2 (0.7)	3.3 (2.2)
Dominant Wrist <2303 cpm	535.9 (145.7)	455.1 (149.5)	7.5 (4.5)	39.8 (28.7)	23.4 (13.8)	1.2 (2.3)	8.8 (4.6)
Nondominant Wrist <1853 cpm	543.5 (145.5)	458.5 (144.7)	7.1 (4.4)	42.6 (29.0)	25.3 (20.8)	1.1 (2.2)	8.8 (9.7)
15-Second Analyses							
AREA Optimum ActiGraph cut-off point ^b							
Hip: Vertical Axis <22 cpm	651.2 (144.0)	521.2 (148.2)	3.8 (1.8)	105.5 (51.3)	16.9 (7.6)	1.0 (1.8)	2.6 (1.6)
Hip: Vector Magnitude <174 cpm	585.0 (142.7)	496.5 (148.5)	2.8 (1.4)	75.1 (42.2)	8.2 (4.4)	0.6 (1.1)	1.8 (1.1)
Dominant Wrist <2303 cpm	533.1 (140.0)	448.5 (145.4)	2.6 (1.3)	61.0 (33.4)	15.3 (8.1)	4.0 (3.3)	1.7 (0.9)
Nondominant Wrist <1853 cpm	533.2 (136.5)	447.3 (140.3)	2.4 (1.3)	63.7 (32.8)	14.8 (10.3)	3.2 (3.3)	1.6 (1.4)

Abbreviations: SD, standard deviation; 95% CI, 95% confidence interval; cpm, counts per minute. Wrist cut-off points were derived using the vector magnitude.

^aStandard cut-off points for the hip were from Matthews et al and Aguilar-Farias et al. (1, 15) There are no current sedentary cut-off point for the ActiGraph wrist.^bAREA optimum cut-off points were derived from receiver operating curve (ROC) to maximize the sum of sensitivity and specificity. Values are minutes per day, unless otherwise specified.