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Day-level sedentary pattern estimates derived from hip-worn accelerometer cut-points in 8-
12 year olds: Do they reflect postural transitions?

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Disclosure of interest

The husband of JS is the Director of a company which manufactures ‘sit-stand’ desks (Sit Less Pty Ltd) specifically designed for use in a range of settings including primary and secondary schools. The remainder of the authors report no conflicts of interest.
Abstract

Improving sedentary measurement is critical to understanding sedentary-health associations in youth. This study assessed agreement between the thigh-worn activPAL and commonly-used hip-worn ActiGraph accelerometer methods for assessing sedentary patterns in children. Both devices were worn by 8-12 year olds (N=195) for 4.6±1.9 days. Two ActiGraph cut-points were applied to two epoch durations: ≤25 counts (c)/15s, ≤75c/15s, ≤100c/60s, and ≤300c/60s. Bias, mean absolute deviation (MAD), and intraclass correlation coefficients (ICCs) tested agreement between devices for total sedentary time and 11 sedentary pattern variables (usual bout duration, sedentary time accumulated in various bout durations, breaks/day, break rate, and alpha). For most sedentary pattern variables, ActiGraph 25c/15s, 75c/15s, and 100c/60s had poor ICCs, with bias and MAD >20%. ActiGraph 300c/60s had better agreement than the other cut-points, but all ICCs were <0.587. ActiGraph underestimated sedentary time in longer bouts and usual bout duration, and overestimated sedentary time in shorter bouts, breaks/day, and alpha. For total sedentary time, ActiGraph 25c/15s, 300c/60s, and 75c/15s had good/fair ICCs, with bias and MAD <20%. Sedentary patterns derived from two commonly used ActiGraph cut-points did not appear to reflect postural changes. These differences between measurement devices should be considered when interpreting findings from sedentary pattern studies.

Keywords: accelerometry, children, sitting, validity
Introduction

A commonly used definition of sedentary behavior is any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (i.e., low movement) in a seated, reclined, or lying position (i.e., posture) (Sedentary Behaviour Research Network, 2012; Mark S. Tremblay et al., 2017). Total sedentary time, most frequently objectively assessed using hip-worn accelerometer cut-point methods, has been associated with unfavorable metabolic and cardiovascular health risk factors in children, though findings have been somewhat inconsistent (M. S. Tremblay et al., 2011; van Ekris et al., 2016). There is also evidence to suggest that sedentary patterns, which refer to the manner in which sedentary time is accumulated throughout the day or week while awake, such as the timing, duration, and frequency of sedentary bouts and breaks (Mark S. Tremblay et al., 2017), may be important to health (Bellettiere et al., 2017; Carson, Stone, & Faulkner, 2014; Cliff et al., 2016; Keith M. Diaz et al., 2017; Diaz, Howard, Hutto, & et al., 2017; Saunders et al., 2013). Many different variables have been used to represent sedentary patterns (S. F. Chastin & Granat, 2010; Sebastien FM Chastin et al., 2015). Commonly used variables include prolonged sedentary time accumulated in bouts lasting ≥10 or ≥30 minutes and breaks from sedentary time, the latter of which reflects how often sedentary time is broken up by standing/moving and is also referred to as sit-to-stand transitions (Altenburg & Chinapaw, 2015). Although each variable is distinct, there is overlap among some variables (e.g., breaks from sedentary time is often negatively correlated with time spent in bouts lasting ≥30 minutes) and all are generally used to indicate whether sedentary time is accumulated in prolonged bouts.

Hip-worn accelerometers are a widely used and accepted method for assessing physical activity in children (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013; Matthews, Hagströmer,
Pober, & Bowles, 2012). Although they are typically used to capture activity intensity, they are increasingly being used to assess children’s total sedentary time and sedentary patterns (Cliff et al., 2016; van Ekris et al., 2016). While such methods have been shown to have acceptable validity for assessing youth’s total volume of sedentary time, three recent studies, including one in youth, have shown that the widely used 100 counts per minute hip-worn accelerometer cut-point substantially overestimates breaks from sedentary time as compared to direct observation (Lyden, Keadle, Staudenmayer, & Freedson, 2014; Mitchell, Borner, Finch, Kerr, & Carlson, 2017) and activPAL (Barreira, Zderic, Schuna, Hamilton, & Tudor-Locke, 2015; Mitchell et al., 2017). A limitation of these aforementioned studies is that only total sedentary time and breaks from sedentary time have been investigated. Other sedentary pattern-related variables that are commonly investigated, such as time spent in prolonged bouts of sedentary time, have not been addressed in measurement comparison studies, despite potentially important health implications such as associations between greater prolonged sedentary bouts and elevated cardiometabolic risk markers (Belletièr et al., 2017; Carson et al., 2014; Cliff et al., 2016).

The activPAL, a thigh-worn accelerometer that functions as an inclinometer, has become the preferred tool for sedentary assessment in children because of its ability to discern sitting from standing (Aminian & Hinckson, 2012; Ridley, Ridgers, & Salmon, 2016). However, hip-worn accelerometer cut-points are still widely used for assessing sedentary patterns. A next step in sedentary pattern assessment research is to identify whether estimates of multiple sedentary pattern variables derived from commonly used hip-worn accelerometer cut-points adhere to the commonly-used sedentary definition by investigating agreement with activPAL. The most commonly used cut-point in children is 100 counts per minute applied to 15 second epochs (Cain et al., 2013; Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, &
Pfeiffer, 2011), but some studies have used higher cut-points such as 300 counts per minute
(Ridley et al., 2016). Understanding agreement between these hip-accelerometer cut-points and
activPAL for assessing sedentary patterns is critical to informing the selection and interpretation
of measurement methods. It is also essential for informing the specific activities that should be
targeted in health promotion interventions for children, including standing, standing and moving,
and frequency of breaks. Discrepancies between measurement methods could also be a potential
cause of the lack of consensus in findings on sedentary patterns and health in youth (Cliff et al.,
2016).

The present study assessed agreement between activPAL and the widely used 100 counts
per minute hip-worn ActiGraph cut-point, as well as a 300 counts per minute cut-point, for
deriving multiple day-level sedentary pattern variables in children. Many variables have been
used to represent sedentary patterns and there is currently a lack of consensus on which are most
important to health. Thus, we investigated commonly used sedentary pattern variables such as
time spent in sedentary bouts of various durations, usual bout duration which reflects the bout
duration in minutes at which 50% of sedentary time was accumulated, alpha which indicates the
relative proportion of longer to shorter bouts, and break rate which reflects the number of breaks
per hour of sedentary time.

Methods

Participants

Data were drawn from the Winter, 2012 assessment in the Patterns of Habitual Activity
across Seasons (PHASE) Study (N.D. Ridgers, Salmon, & Timperio, 2015). Primary schools
located within 40km of the Melbourne Central Business District, Australia, and with enrolments
of >200 pupils, were stratified into tertiles of socioeconomic status (SES) using the Socio-
Economic Index for Areas (Australian Bureau of Statistics, 2011). Schools within each SES strata were randomly selected and invited to participate. Principals from nine schools (five high, three mid, and one low SES) provided written informed consent to participate in the study. All 1270 children in Years 4 and 5 (aged 8-12 years) received an invitation to participate. Informed written parental consent for at least one component of the study was received for 326 children (25.7%). Approvals for the study were granted by the Deakin University Human Ethics Advisory Group (Health), Department of Education and Early Childhood Development, and Catholic Education Office (Melbourne).

**Measures**

**Activity data collection:** Children were asked to simultaneously wear a hip-mounted ActiGraph (GT3X+; Pensacola, FL, USA) and thigh-mounted activPAL (PAL Technologies Ltd, Glasgow, UK) for eight consecutive days during waking hours, except during water-based activities. The ActiGraph collected data at 30 hrz and activPAL at 20 hrz. Instructions concerning the correct wear and care of the monitors were provided. The activPAL was enclosed in a small pocket on an adjustable elasticized belt and secured at the mid-anterior position on the child’s thigh. A minimum sitting/upright period of 10-seconds was used to define a new posture, a commonly used setting and the default setting from the manufacturer (Edwardson et al., 2017). This threshold was chosen over a shorter threshold to minimize error in the activPAL and restrict the detection of multiple rapid transitions by the activPAL, because only 1 transition per every 2 epochs was possible for the ActiGraph based on the definitions provided below. Only days with ≥10 hours of valid wear time based on the ActiGraph were included in the analyses (Mattocks et al., 2008). Data collected prior to 6:00 (6am) and after 23:00 (11pm) were removed.
Non-wear time, defined as ≥60 consecutive minutes of zero counts on the vertical axis, was determined from the ActiGraph. These data were removed and corresponding data from the activPAL also removed. More specifically, data from the two devices were merged based on their time stamp and times without data from both devices were removed. This approach, which has been previously used (Kerr et al., 2018), was used to infer activPAL non-wear time based on the ActiGraph data, because there is currently no consensus on identifying non-wear from activPAL data. This was done so that daily wear time would be the same between devices. We also employed the following procedure to account for times when the ActiGraph but not activPAL may have been worn. In such circumstances, the activPAL would likely register substantially long periods of sitting due to non-wear, hence days when participants had an activPAL-derived usual bout duration (defined in the following section) >4 standard deviations from the mean were removed, following data processing. This resulted in removal of 10 participant-days with usual bout durations between 65.7 and 143.7 minutes/day, suggesting potential non-wear. Usual bout durations for all remaining participant-days were ≤55.3 minutes/day.

Data processing: activPAL uses a proprietary algorithm to derive whether each second consisted primarily of sitting/lying or standing/walking. A break in sitting/lying, referred to as a break in sedentary time in this study, was defined as any time a standing/walking second was preceded by a sitting/lying second. No tolerance was allowed, but a new posture was only registered if the posture was engaged in for ≥10 seconds as per the initialization setting mentioned previously.

The ActiGraph data were processed using the low frequency extension filter (ActiGraph, 2014) and the vertical axis data were converted to 15- and 60-second epochs, taking a sum of
counts, as is done by the ActiLife software (ActiGraph, 2012), to allow the application of four
previously established cut-points that have acceptable validity for assessing total daily sedentary
time but have yet to be tested with regards to assessing sedentary patterns: ≤25 counts per 15-
second epoch (ActiGraph 25c/15s) and ≤100 counts per 60-second epoch (ActiGraph 100c/60s)
(Trost et al., 2011); and ≤75 counts per 15-second epoch (ActiGraph 75c/15s) and ≤300 counts
per 60-second epoch (AG 300c/60s) (Ridley et al., 2016). The ≤100 counts/minute cut-point and
15-second epoch duration (Evenson et al., 2008; Trost et al., 2011) were chosen because they
reflect common practice (Cain et al., 2013). The 60-second epoch duration also reflects common
practice in both youth (Cain et al., 2013) and adults (Freedson et al., 1997; Matthews et al.,
2008). The ≤300 counts per minute cut-point was chosen because it has been preferred in some
studies and may result in reduced overestimation of breaks in sedentary time (Ridley et al.,
2016). Each epoch was classified as a sedentary epoch when the count value was within the
aforementioned thresholds, or a non-sedentary epoch when the count value exceeded the
aforementioned thresholds. Similar to what was done for the activPAL, a break in sedentary time
from the ActiGraph was defined as any time a non-sedentary epoch was preceded by a sedentary
epoch (no tolerance).

The second- (for activPAL) and epoch- (for ActiGraph) level data were processed to
create 12 day-level sedentary variables for each of the aforementioned five cut-points: 1) total
volume of sedentary time; 2) usual bout duration, which represents the bout duration in minutes
at which 50% of sedentary time was accumulated; greater values equating to more prolonged
sedentary time (Sebastien FM Chastin et al., 2015); 3) sedentary time accumulated in bouts
lasting 0-4.99, 4) 5-9.99, 5) 10-19.99, 6) 20-29.99, 7) ≥10 minutes, 8) ≥20 minutes, and 9) ≥30
minutes; 10) number of breaks/day; 11) break rate, number of breaks divided by total sedentary
time in hours; and 12) alpha, which is unitless and represents the relative proportion of longer to shorter sedentary bouts; greater alpha values mean that sedentary time was accumulated via a proportionally greater amount of short bouts (S. F. Chastin & Granat, 2010). No tolerance was allowed for any of the bouts.

**Participant characteristics:** Participant age and sex were assessed by questionnaire. Body mass index (BMI) was calculated using objective height and weight measures, as kg·m⁻², and converted to age- and sex-normed percentiles.

**Statistical Analyses**

The agreement between each activPAL and the corresponding ActiGraph variable was assessed by calculating mean differences, (i.e., bias; predicted – criterion), %bias (bias / criterion * 100), mean absolute deviation (MAD; | predicted – criterion |), %MAD (MAD / criterion * 100), and intraclass correlation coefficients (ICCs) (Shrout & Fleiss, 1979). We did not conduct significance tests for bias estimates because of the large sample size and so interpretations could be focused on effect sizes. Thresholds for interpreting bias vary by the inferences that will be drawn from the measure, with thresholds used in population health research often ranging between ≤5% and ≤15% (Dixon et al., 2018). For the present study, we selected a less stringent threshold of ≤|20%| to be acceptable for group/sample-level agreement to minimize the likelihood of falsely inferring unacceptable agreement between measures. P values were not used to interpret bias because they are subject to sample size and in the present study were likely to be significant even when the bias was small. MAD indicates the variance (i.e., across days) in the bias, and a MAD that is substantially larger than the bias is generally indicative of poorer individual/day-level validity. Thus, both bias and MAD values should ideally be <|20%| of the criterion mean. Criteria for interpreting ICCs were: poor (≤0.40), fair (0.41-0.60), good (0.61-0.80), and excellent (0.81-1.0) (Cicchetti, 1994). Central tendency measures (means, standard
deviations, and ranges) were used to summarize the results across the sedentary pattern variables for each ActiGraph cut-point. Agreement plots were created for the 60-second epoch ActiGraph measures, selected because it was the better performing epoch duration for sedentary pattern variables, with a reference line denoting perfect agreement (Y = X) to help visualize overall agreement and consistency of bias across the continuum of each sedentary pattern variable. Statistical analyses were performed in SPSS v23 (IBM Corp., 2015) and R (R Core Team, 2017).

Results

One hundred ninety-five participants wore both devices simultaneously for ≥1 valid day. Participants had a mean age of 10.5 (SD = 0.7) years, 48.7% were girls, 28.6% were overweight or obese, and mean BMI percentile was 60.2 (28.1). Mean wear time was 4.6 (SD = 1.9) days and 777.7 (SD = 91.4) minutes/day.

Total Sedentary Time

The agreement metrics for the 15-second epoch variables are presented in Table 1, and for the 60-second epoch variables in Table 2. For total sedentary time, ICCs were good and %bias and %MAD were <|20%| for ActiGraph 25c/15s and ActiGraph 300c/60s. The ICC for ActiGraph 75c/15s was fair and %bias and %MAD were <|20%|. The ICC for ActiGraph 100c/60s was poor and %bias and %MAD were >|20%|. The agreement plots (ActiGraph 100c/60s and ActiGraph 300c/60s; Figures 1 and 2) appeared to show a somewhat consistent magnitude and pattern of bias, as indicated by the distance from the line of perfect agreement, across the continuum of values of total sedentary time, indicating that bias was similar across days with low and high sedentary time.

Sedentary Pattern Variables
For ActiGraph 25c/15s, each sedentary pattern variable had a poor ICC, %bias >|20%|, and %MAD >20%, with the exception of time in bouts lasting 5-10 minutes. Similarly, each sedentary pattern variable for ActiGraph 75c/15s had a poor ICC, %bias >|20%|, and %MAD >20%, with the exception of time in bouts lasting 10-20 minutes. Each sedentary pattern variable for ActiGraph 100c/60s had a poor ICC, %bias >|20%|, and %MAD >20%, with the exception of time in bouts lasting 5-10 minutes and number of breaks per day.

ActiGraph 300c/60s showed better agreement with activPAL than the other three hip-accelerometer cut-points. Of the 11 sedentary pattern variables, agreement was best for time in bouts lasting ≥10 minutes, number of breaks per day, and break rate. The next best agreement values were for time in bouts lasting 10-20, ≥20, and ≥30 minutes. Time in bouts lasting 0-5 minutes, 5-10 minutes, and 20-30 minutes, and usual bout duration and alpha had poor ICCs, %bias >|20%|, and %MAD >20%, with the exception of time in bouts lasting 20-30 minutes.

The direction of the biases were that each of the four ActiGraph cut-points underestimated time in bouts lasting 20-30, ≥10, ≥20, and ≥30 minutes and usual bout duration, and overestimated time in bouts lasting 0-5 minutes and number of breaks/day, break rate, and alpha, with the exception of ActiGraph 300c/60s which underestimated break rate by 0.4%. Time in bouts lasting 5-10 minutes was overestimated by each cut-point except ActiGraph 25c/60s. Time in bouts lasting 10-20 minutes was underestimated by each cut-point except ActiGraph 300c/60s.

In the agreement plots (ActiGraph 100c/60s and ActiGraph 300c/60s; Figures 1 and 2), bias appeared to increase somewhat as the criterion values for usual bout duration, time in prolonged bouts (≥10, ≥20, and ≥30 minutes), and break rate became larger. The agreement plot and ICC for alpha indicated almost no correlation between the measurement methods.
Discussion

The novel contribution of the present study was the finding that the commonly used 100 counts per minute cut-point applied to the hip-worn ActiGraph accelerometer, whether using 60-second or 15-second epochs, had poor validity for assessing sedentary pattern variables in children as compared to the posture-based measure provided by activPAL. A cut-point of 300 counts per 60-second epoch had better validity, but was still less than ideal. In agreement with previous studies, this study showed that hip-accelerometer cut-point methods can have acceptable validity for assessing total daily volume of sedentary time (N. D. Ridgers et al., 2012; Ridley et al., 2016; Trost et al., 2011). While previous studies have shown that hip-accelerometer cut-point methods do not accurately capture breaks in sedentary time, also known as sit/stand transitions (Barreira et al., 2015; Lyden et al., 2014; Mitchell et al., 2017), the present study provides a more complete comparison of a range of sedentary pattern variables between activPAL and hip-accelerometer cut-points. Future research is needed to identify whether such misclassification could result in spurious associations or missed/underestimated associations between sedentary patterns and health in children. Thus, caution should be used when using hip-accelerometer cut-point derived sedentary pattern variables in children, particularly those derived using the common 25 counts per 15-seconds cut-point, to test associations between sedentary time and health, evaluate sedentary time interventions, and recommend specific sedentary intervention strategies such as how often to break up sedentary time.

Agreement between the devices for the sedentary pattern variables was better for the hip-accelerometer cut-point of ≥300 counts per 60-second epoch than the other cut-points investigated. However, no sedentary pattern variable derived using this cut-point had a good or excellent ICC. Bias values for 6 of the 11 pattern variables were >20%, and all pattern variables
had a MAD >20%. The sedentary pattern variables with the strongest validity, assessed with this
cut-point, were number of breaks, break rate, and time in bouts lasting ≥10 minutes. Time spent
in bouts lasting ≥30 minutes, which has been commonly used in hip-accelerometer studies,(Cliff
et al., 2016) had poor validity even with the ≥300 counts per 60-seconds cut-point. Usual bout
duration and alpha also had poor validity when assessed by the hip-accelerometer cut-points, but
are becoming more commonly used metrics to capture prolonged versus interrupted sedentary
patterns (S. F. Chastin & Granat, 2010; Sebastien FM Chastin et al., 2015). The poor agreement
does not appear to be due to a low prevalence of prolonged bouts (e.g., ≥30 minutes), because
participants spent a fair amount of time, a mean of 123.3 minutes/day, in bouts lasting ≥30
minutes according to the activPAL. It is likely that a higher cut-point would reduce the false
positive rate (i.e., saying a break has occurred when it has not) but potentially at the expense of
sensitivity. It is possible that more contemporary approaches, such as using machine learning
(Lyden et al., 2014), may have greater promise for improving validity of sedentary pattern
assessments from hip-accelerometers than traditional cut-point methods.

All of the hip-accelerometer cut-points tested overestimated breaks in sedentary time and
time spent in short bouts of sedentary time lasting 0-5 minutes, and underestimated time spent in
longer bouts. Underestimation was greater for time spent in longer than shorter bouts, for
example time in bouts lasting ≥30 minutes was underestimated by 31.6% for ActiGraph 300c/60s
and time spent in bouts lasting ≥10 minutes was underestimated by 10.3% for ActiGraph
300c/60s. This shows the profound impact that a “false break”, which is break in sedentary time
due to the count value exceeding the specified cut-point, can have on estimates of prolonged
sedentary time and estimates of validity. Such false breaks are also likely the reason the hip-
accelerometer cut-points had stronger validity for assessing total sedentary time than sedentary
patterns. Whereas a few epochs misclassified as breaks can break a prolonged (e.g., 30-minute) bout into many shorter (e.g., 10-minute) bouts, this misclassification would have minimal impact on estimates of total sedentary time. Fidgeting while seated could be one explanation for false breaks in ActiGraph-derived sedentary time. Allowing for a forgiveness/tolerance, for example requiring more than one epoch to be above the accelerometer count cut-point to define a break in sedentary time, may reduce overestimation of breaks. However, similar to using a higher cut-point, this may also lead to missing true breaks in sedentary time. There is currently no consensus on whether tolerance should be allowed. Indeed, previous research has suggested better construct/predictive validity and associations with health for hip-accelerometer assessed time spent in prolonged bouts of sedentary time when no tolerance was used, as compared to a 30-second and 60-second tolerance (Altenburg et al., 2015).

Although misclassification of breaks may reduce a prolonged bout into many shorter bouts, in agreement with previous studies, this appeared to have minimal impact on estimates of total sedentary time based on acceptable estimates of validity for total daily volume of sedentary time (N. D. Ridgers et al., 2012; Ridley et al., 2016; Trost et al., 2011). The most commonly used youth cut-point of 25 counts per 15-seconds showed good agreement with activPAL-assessed total sedentary time, in agreement with previous studies (Evenson et al., 2008; Trost et al., 2011). The 300 counts per 60-seconds had the strongest agreement of the cut-points tested, for both total sedentary time and the sedentary pattern variables, but was only slightly better than the 25 counts per 15-seconds cut-point. Thus, the 300 counts per 60-seconds and 25 counts per 15-seconds cut-points appear to provide acceptable estimates of total volume of sedentary time.

If acceptable methods are developed for estimating sedentary patterns, it may be that different
cut-points and/or approaches are needed for estimating total sedentary time versus sedentary patterns.

The present study is among the first to show that using shorter epoch lengths (15 seconds) with hip-accelerometer cut-points leads to substantially greater overestimation of breaks in sedentary time, as compared to using 60-second epochs. This suggests that, while shorter epochs are generally preferred over 60-second epochs for capturing the spontaneous nature of children’s total time in physical activity (Baquet, Stratton, Van Praagh, & Berthoin, 2007; Trost et al., 2011), they may not be preferred for assessing sedentary patterns. This is not surprising because shorter epochs increase sensitivity to detect movement, which may result in misclassification of subtle movements while sitting as false breaks.

Taken together, the findings from the present study suggest that the activities measured by hip-accelerometer cut-points may not reflect sit/stand transitions, which are the postural changes that are key to defining sedentary patterns (Sedentary Behaviour Research Network, 2012; Mark S. Tremblay et al., 2017). Researchers should be careful to use terminology that distinguishes the activities measured by each method, such as referring to activPAL-derived variables as representing sitting or sedentary time and hip-accelerometer cut-point derived variables as representing stationary time (Mark S. Tremblay et al., 2017). Relatedly, breaks assessed from hip-accelerometer cut-point methods could be clarified as reflecting changes in movement rather than breaks in sedentary or sitting time, as is often used. Further research should compare associations with health outcomes between methods to improve understanding of the role of sedentary patterns on health, specifically the role of breaks from sitting (i.e., from activPAL) vs. breaks from low movement (i.e., from hip-accelerometer cut-points), as the two do
not appear to be highly correlated. Researchers should also be cautious when comparing results from studies using different devices or cut-points to assess sedentary patterns.

**Strengths, limitations, and future directions**

The present study was among the first to investigate agreement between the thigh-worn activPAL posture-based monitor and both the most commonly used, and an increased, hip-worn accelerometer cut-point for assessing a range of sedentary pattern variables in children. Importantly, these data were collected during free-living activities so that a variety of common, non-contrived activities were captured. The data from each device were processed based on the same wear times so that the times captured were the same between devices. Participants did not log the times the devices were taken off and put back on, but this may have improved our ability to filter out non-wear time. Since some participants only wore the devices for one or two valid days, their sedentary pattern estimates may not be representative of their typical activities. However, this is unlikely to have impacted the agreement between devices as individual days were matched between devices, which is a study strength. Whist the focus of the present study was on investigating the validity of the most commonly used ActiGraph methods for estimating sedentary patterns, other methods exist. It is possible that other cut-points, including those applied to the vector magnitude output (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014), combined with tolerances such as a tolerance of up to 1 non-sedentary epoch between two sedentary epochs, could lead to more valid estimates of sedentary patterns from the ActiGraph. Applying the inclinometer function to thigh-worn ActiGraph data (Steeves et al., 2015) and applying machine learning algorithms (Kerr et al., 2018; Lyden et al., 2014) also have promise for creating valid estimates of sedentary patterns. Thus, future research is needed to optimize parameters and methods applied to ActiGraph data for improving validity of sedentary pattern estimates, with consideration of how moderate-to-vigorous physical activity estimates are
impacted. The minimum sitting/upright period of 10-seconds applied to the activPAL could have led to failure to detect rapid (i.e., <10-second) transitions. If rapid transitions were common in the dataset, this could have led to overestimation of biases for breaks in sedentary time and potentially prolonged sedentary time. More work is needed to create consensus on the definition of a break in sedentary time. Finally, whilst activPAL is generally considered an acceptable measure of posture, it is not perfect and can misclassify posture. For example, activPAL could have misclassified unconventional sitting postures, such as propping on the edge of a chair, or kneeling on a chair, which are often observed in children, as standing or sit-to-stand transitions (Alghaeed et al., 2013; Davies, Reilly, & Paton, 2012; Ridley et al., 2016). Thus, future research should replicate this study using direct observation as the criterion.

Conclusions

While generally providing acceptable estimates of total volume of sedentary time as compared to activPAL, the 100-counts and an increased 300-counts hip-worn accelerometer cut-points appear to have limited validity for capturing sedentary patterns and the postural components of sedentary time, such as transitions between sitting and standing, in children. Compared to the activPAL, breaks in and short bouts of sedentary time were substantially overestimated, and prolonged sedentary time variables were underestimated using these ActiGraph cut-points. Better consideration of the differences between these measurement devices would support an improved understanding of the impacts of sedentary patterns on health, such as the relative role of posture versus low movement. Given that hip-worn accelerometers are and will likely continue to be commonly used in research investigating the activity spectrum, a priority of future research should be to develop new optimization/computational methods for
processing data to derive valid estimates of posture-based sedentary patterns in children outside of artificial laboratory settings.
<table>
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<th>activPAL Mean (SD)</th>
<th>ActiGraph 25c/15s Mean (SD)</th>
<th>ActiGraph comparison method</th>
<th>ActiGraph 75c/15s Mean (SD)</th>
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<tbody>
<tr>
<td></td>
<td>bias</td>
<td>%bias</td>
<td>MAD</td>
</tr>
<tr>
<td>Total sedentary time (minutes/day)</td>
<td>457.7 (106.6)</td>
<td>433.7 (90.9)</td>
<td>-24.0</td>
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<td>Usual bout duration (minutes/day)</td>
<td>14.9 (7.2)</td>
<td>2.9 (1.4)</td>
<td>-12.0</td>
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<td>Time in bouts lasting 0-5 minutes (minutes/day)</td>
<td>86.9 (32.1)</td>
<td>278.8 (53.3)</td>
<td>191.9</td>
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<tr>
<td>Time in bouts lasting 5-10 minutes (minutes/day)</td>
<td>76.9 (30.3)</td>
<td>73.7 (34.9)</td>
<td>-3.2</td>
</tr>
<tr>
<td>Time in bouts lasting 10-20 minutes (minutes/day)</td>
<td>104.8 (44.8)</td>
<td>47.5 (36.1)</td>
<td>-57.3</td>
</tr>
<tr>
<td>Time in bouts lasting 20-30 minutes (minutes/day)</td>
<td>66.5 (42.2)</td>
<td>13.4 (20.7)</td>
<td>-53.1</td>
</tr>
<tr>
<td>Time in bouts lasting ≥10 minutes (minutes/day)</td>
<td>293.9 (111.0)</td>
<td>81.1 (62.0)</td>
<td>-212.8</td>
</tr>
<tr>
<td>Time in bouts lasting ≥20 minutes (minutes/day)</td>
<td>189.3 (107.8)</td>
<td>33.6 (43.3)</td>
<td>-155.7</td>
</tr>
<tr>
<td>Time in bouts lasting ≥30 minutes (minutes/day)</td>
<td>123.3 (98.9)</td>
<td>20.1 (34.3)</td>
<td>-103.2</td>
</tr>
<tr>
<td>Number of breaks per day</td>
<td>82.8 (25.6)</td>
<td>336.5 (61.4)</td>
<td>253.8</td>
</tr>
<tr>
<td>Break rate (breaks/hour of sedentary time)</td>
<td>11.4 (4.2)</td>
<td>48.3 (12.2)</td>
<td>37.0</td>
</tr>
<tr>
<td>Alpha (unitless)</td>
<td>1.40 (0.07)</td>
<td>2.05 (0.17)</td>
<td>0.65</td>
</tr>
</tbody>
</table>

ICC = intraclass correlation coefficient; MAD = mean absolute error; SD = standard deviation.
Table 2. Mean differences in sedentary pattern variables between activPAL and the 60-second epoch ActiGraph processing methods (N = 902 days from 195 children)

<table>
<thead>
<tr>
<th>activPAL Mean (SD)</th>
<th>ActiGraph 100c/60s</th>
<th>ActiGraph 300c/60s</th>
<th>Actigraph comparison method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sedentary time (minutes/day)</td>
<td>457.7 (106.6)</td>
<td>346.9 (91.4)</td>
<td>110.8</td>
</tr>
<tr>
<td>Usual bout duration (minutes/day)</td>
<td>14.9 (7.2)</td>
<td>6.4 (2.9)</td>
<td>-8.5</td>
</tr>
<tr>
<td>Time in bouts lasting 0-5 minutes (minutes/day)</td>
<td>86.9 (32.1)</td>
<td>125.2 (28.5)</td>
<td>38.3</td>
</tr>
<tr>
<td>Time in bouts lasting 5-10 minutes (minutes/day)</td>
<td>76.9 (30.3)</td>
<td>83.2 (31.5)</td>
<td>6.3</td>
</tr>
<tr>
<td>Time in bouts lasting 10-20 minutes (minutes/day)</td>
<td>104.8 (44.8)</td>
<td>74.4 (40.0)</td>
<td>-30.4</td>
</tr>
<tr>
<td>Time in bouts lasting 20-30 minutes (minutes/day)</td>
<td>66.5 (42.2)</td>
<td>29.4 (30.4)</td>
<td>-37.1</td>
</tr>
<tr>
<td>Time in bouts lasting ≥10 minutes (minutes/day)</td>
<td>293.9 (111.0)</td>
<td>138.5 (78.6)</td>
<td>-155.4</td>
</tr>
<tr>
<td>Time in bouts lasting ≥20 minutes (minutes/day)</td>
<td>189.3 (107.8)</td>
<td>64.1 (60.1)</td>
<td>-125.2</td>
</tr>
<tr>
<td>Time in bouts lasting ≥30 minutes (minutes/day)</td>
<td>123.3 (98.9)</td>
<td>34.7 (46.2)</td>
<td>-88.6</td>
</tr>
<tr>
<td>Number of breaks per day</td>
<td>82.8 (25.6)</td>
<td>89.9 (17.2)</td>
<td>7.1</td>
</tr>
<tr>
<td>Break rate (breaks/hour of sedentary time)</td>
<td>11.4 (4.2)</td>
<td>16.3 (4.1)</td>
<td>5.0</td>
</tr>
<tr>
<td>Alpha (unitless)</td>
<td>1.40 (0.07)</td>
<td>2.23 (0.26)</td>
<td>0.83</td>
</tr>
</tbody>
</table>

ICC = intraclass correlation coefficient; MAD = mean absolute error; SD = standard deviation
Figure 1a. Agreement plots for sedentary pattern variables between activPAL and ActiGraph 100 counts per 60-seconds cut-point (N = 899 days from 195 children)
Figure 1b. Agreement plots for sedentary pattern variables between activPAL and ActiGraph 100 counts per 60-seconds cut-point (N = 899 days from 195 children)
Figure 2a. Agreement plots for sedentary pattern variables between activPAL and ActiGraph 300 counts per 60-seconds cut-point (N = 899 days from 195 children)
Figure 2b. Agreement plots for sedentary pattern variables between activPAL and ActiGraph 300 counts per 60-seconds cut-point (N = 899 days from 195 children)
References


