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Issues related to measuring and interpreting objectively measured sedentary behavior data

Running head: Interpreting sedentary behavior data

ABSTRACT

The use of objective measures of sedentary behavior has increased over the past decade. However, as is the case for objectively measured physical activity, methodological decision before and after data collection are likely to influence the outcomes. The aim of this paper is to review the evidence on different methodological decisions made by researchers when examining sedentary behavior. The different issues researchers may encounter when measuring sedentary behavior have been divided into: 1) activity monitor placement; 2) epochs, cut points and non-wear time definitions; 3) criteria for sedentary behavior bouts and breaks; and 4) combining motion and posture data. This paper recommends that 1) activity monitors should be placed on the thigh and combined with a data reduction approach that estimates inclination, especially in children and adults; and 2) researchers should clearly report their data processing decisions to enhance the ability to evaluate and compare studies in the future. However, the paper also highlights a dearth of methodological evidence to inform the use of objective measures of sedentary behavior. Based on the gaps in the literature, research recommendations, which require addressing to develop a best practice protocol when measuring sedentary behavior objectively, have been made.

Key words**:** accelerometry; sitting; methodology;

INTRODUCTION

The use of objective measures of physical activity have been well established and it has been widely reported that the interpretation of data depends on several methodological decisions made before and after data collection (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013; Cliff, Reilly, & Okely, 2009; Ridgers & Fairclough, 2011). More recently, researchers have started to focus on objectively measured sedentary behavior (Atkin et al., 2013a; Healy et al., 2008; Mitchell, Pate, Beets, & Nader, 2012a; Mitchell et al., 2012b). Accelerometry has increased our understanding of levels of sedentary behavior over the life span (Matthews et al., 2008) and the association with health outcomes (Cliff et al., 2013; Healy et al., 2008; Mitchell et al., 2012a). However, similar to physical activity, reported levels of objectively sedentary behavior as well as the association between sedentary behavior and health outcomes are likely to be affected by methodological decisions made before and after data collection (Chinapaw, Altenburg, & Brug, 2015; Chinapaw et al., 2014). Methodological approaches in studies assessing sedentary behavior have varied and include different types of accelerometers (i.e. posture based compared to motion based), cut points and non-wear time definitions (Basterfield et al., 2011; Chastin, Ferriolli, Stephens, Fearon, & Greig, 2012; Healy et al., 2008; Kwon, Burns, Levy, & Janz, 2012). Several issues also arise when examining patterns of sedentary behavior, such as breaks in sedentary time or continuous bouts of sedentary behavior which might also influence health outcomes (Altenburg et al., 2015; Cliff et al., 2014; Dunstan et al., 2012; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Saunders et al., 2013). For example, what is the minimum duration of a break in sedentary behavior before it becomes beneficial for health or how do different definitions of breaks or bouts influence health outcomes? This paper reviews the evidence evaluating different methodologies when measuring sedentary behavior objectively. In addition, it will identify gaps in the literature and provide recommendations for future research.

METHODOLOGICAL DECISIONS WHEN MEASURING SEDENTARY BEHAVIOR

Activity Monitor Placement

Until recently, the primary option for the objective measurement of habitual sedentary behavior was using hip-worn accelerometers (e.g. ActiGraph, Actical). However, it has been indicated that hip-mounted accelerometers and cut point data reduction approaches have difficulties distinguishing sitting from standing still (Dowd, Harrington, & Donnelly, 2012). For example, Dowd et al. (2012) reported that the Actigraph classified 100% of the time standing still as sitting in a laboratory-based study among 15-18 year olds. This becomes an issue when assessing sedentary behavior, defined as any waking activity characterized by an energy expenditure ≤ 1.5 metabolic equivalents and a sitting or reclining posture (Sedentary Behaviour Research Network, 2012), because the lack of movement during standing still is misinterpreted as sedentary behavior when using waist-mounted accelerometers and a cut point-based data reduction.

To overcome the limitations of hip-mounted accelerometers, the use of posture-based devices, such as the *activ*PAL (PAL Technologies Ltd., Glasgow, UK) which is currently the most commonly used posture-based monitor, has increased in studies examining free-living sedentary behavior (Chastin et al., 2012; Salmon et al., 2011). The *activ*PAL uses the inclination of the thigh to predict time spent lying, sitting, standing, and stepping. Using the *activ*PAL software, time stamped event files can be created which makes it possible to count the number of breaks from sitting to an upright position, to count the number of bouts of sitting, and to calculate average durations of breaks and bouts. In addition, the *activ*PAL software can generate a 15 second epoch file in which the number of transitions from a sitting to upright position are calculated based on a predefined minimal break length (i.e. if this is set to 10 seconds and the break in sitting is only 5 seconds this will not be counted as a break). The *activ*PAL appears to be an accurate tool to examine sedentary behavior (i.e. sedentary behavior defined by posture). Kozey-Keadle et al. (2011) compared estimates of sitting time defined using several different ActiGraph cut points and the *activ*PAL with direct observation defined sitting time among adults. Participants (office workers) were observed for 6 hours on two working days. During the second day they were encouraged to break up their sitting more often. The results of this study showed that the *activ*PAL provided the most accurate estimates of sitting time (79.5% ± 13.8%) among adults compared to direct observation (83.7% ± 11.2%). In addition, the *activ*PAL was the only monitor sensitive enough to detect changes in sitting time (Kozey-Keadle et al., 2011). This finding was confirmed by a study by Lyden et al. (2012) which reported the *activ*PAL was able to detect changes in total sitting time during a sedentary behavior intervention. However, the recent ActiGraph models (GT3X and up) also provide the possibility of classifying posture through the use of equations that estimate inclination from raw triaxial data. A recent study in adults reported excellent accuracy for both the *activ*PAL and ActiGraph GT3X+ (attached to the thigh) when classifying sitting, standing and stepping (the majority of the activities were correctly classified more than 90% of the time for both monitors) during a laboratory based protocol (Steeves et al., 2015). In addition, the ActiGraph (attached to the thigh) provided similar estimates of sitting time compared to the *activ*PAL (64% versus 62%) under free-living conditions (Steeves et al., 2015). Carr and Mahar (2011) reported that the hip-based ActiGraph correctly classified 90% of time spent sedentary (sedentary was defined as sitting and standing still) when using ≤150 counts per minute. However, the ActiGraph inclinometer function was less accurate in determining posture, classifying less than 70% of the time correctly as sitting, standing or walking) (Carr & Mahar, 2011). This may indicate that, unlike for measurement of physical activity, where motion-sensors might potentially be placed on a number of body segments such as the waist, wrist, ankle, upper-arm, or chest, the location of monitor placement is an important choice when measuring sedentary behavior and current evidence suggests that placement on the thigh combined with a data reduction approach that estimates inclination from triaxial data provides the most accurate assessments. This is because the thigh is the segment of the body that changes position when shifting from sitting to standing. Innovative pattern-recognition approaches might in the future offer alternative placement such as the wrist, by identifying the different wrist positions/movement patterns between typical sitting, standing and stepping activities, if such approaches can be disseminated in user-friendly software. Last, it has to be noted that the validity of thigh-based monitors when measuring physical activity is relatively unknown. To date, only two studies have developed a physical activity cut point for the *activ*PAL in preschool-aged children and adolescents (Dowd et al., 2012; Janssen et al., 2014b). While the cross-validation of their developed cut-points showed promising results (sensitivity and specificity > 90%), these results are based on their specific laboratory protocols and the validity of the developed cut points should also be cross-validated in free-living conditions. In addition, to our knowledge, no study has examined the validity of a thigh-based ActiGraph for measuring physical activity, and this evidence would be useful for many studies aiming to accurately assess both sedentary behavior and physical activity.

In children and adolescents several studies have also examined the concurrent validity of hip-based accelerometers and devices aiming to measure posture when examining sedentary behavior (De Decker et al., 2013; Dowd et al., 2012; Ridgers et al., 2012). In school-aged children, good agreement between the ≤100 counts per minute ActiGraph cut point and *activ*PAL defined sitting time was reported at the group level (mean difference -5.2 minutes on a school day), however wide limits of agreement (-77.6 to 67.1) were reported indicating a greater degree of under- and overestimation of sitting time at the individual level (Ridgers et al., 2012). This may affect the ability of the ActiGraph ≤100 counts per minute cut point to detect intervention effects. This finding was also confirmed in two studies among preschool-aged children (Martin et al., 2011; Van Cauwenberghe, Wooller, Mackay, Cardon, & Oliver, 2012). Dowd et al. (2012) was the only study which examined the accuracy of the ActiGraph ≤100 counts per minute cut point and *activ*PAL monitor using a criterion method among adolescent girls. This study reported 99.1% agreement between *activ*PAL and direct observation, whereas agreement between the ActiGraph ≤100 counts per minute cut point and direct observation was 66.7% when assessing sitting, standing, and slow walking. The lower level of agreement for the ActiGraph was mainly due to the inability of the ActiGraph to detect the difference between sitting and standing still when using a ≤ 100 count per minute cut point (Dowd et al., 2012). To add to this evidence, we conducted secondary analyses on 36 preschool-aged children testing the ability of the most accurate ActiGraph and Actical sedentary behavior cut points for classifying standing as a non-sedentary activity. Participants followed a 150-minute activity protocol within a room calorimeter. The protocol involved child-appropriate sedentary behaviors, light intensity physical activities and moderate-to-vigorous intensity physical activities (Janssen et al., 2013a). ActiGraph, Actical, and *activ*PAL data were used as 15-second epochs. Sedentary behavior was defined using a cut point of ≤ 25 counts per 15 seconds for the ActiGraph (Janssen et al., 2013b). For the Actical, sedentary behavior was classified using a cut point of ≤ 6 counts per 15 seconds (Janssen et al., 2015). Standing still was calculated by summing up all epochs classified by the *activ*PAL as 15 seconds of standing (excluding stepping). Results showed that *activ*PAL classified 26.7 (± 10.0) minutes as standing still during the duration of the activity protocol. Of these 17.7 (± 7.5) minutes and 17.3 (± 7.4) minutes were misclassified as sedentary using the ≤ 25 counts per 15 seconds cut point for the ActiGraph and the ≤6 counts per 15 seconds cut point for the Actical (both $p < .05$ compared to the *activ*PAL), respectively. These results indicate that using hip-based accelerometers and cut points may lead to an overestimation of sedentary behavior in young children due to the inclusion of standing. This is in line with previous studies reporting hip-based monitors overestimate time spent sedentary in adolescents and adults (Dowd et al., 2012; Lyden et al., 2012).

One issue to take into account when using the *activ*PAL is the effect of 'other' postures (e.g. kneeling, crawling) on estimated time spent sedentary. Aminian and Hinckson (2012) conducted a study among 9 to 10 year old children who followed a structured activity protocol including sitting, standing, and walking activities. They reported perfect correlations between direct observation and the *activ*PAL in time spent sitting, standing, and walking ($r = 1.00$) and near perfect correlation between direct observation and the *activ*PAL in posture transitions ($r = .99$). However, this study excluded postures such as squatting, crawling, and kneeling. These postures appear to affect the accuracy of the *activ*PAL as has been shown in studies among preschool-aged children. Several studies examined the accuracy of the *activ*PAL using a criterion measure in preschool-aged children (Davies, Reilly, & Paton, 2012b; De Decker et al., 2013; Janssen et al., 2014a). Two studies reported sensitivity and specificity was > 80% (Davies et al., 2012a; Janssen et al., 2014a) for classifying sitting behavior whereas another study reported a sensitivity and specificity of 53.8% and 67.5%, respectively (De Decker et al., 2013). The main difference between these studies was the time spent in 'other' postures. The accuracy of the *activ*PAL in young children might be lower due to the greater amount of 'other' postures (e.g. kneeling on one knee, crawling, or hanging over the edge of a chair while leaning on a table) young children engage in compared to adults. It has been shown that more time in 'other' postures results in an increase in time spent sitting as estimated by the *activ*PAL (Janssen et al., 2014a). While 'other' postures are most likely to occur among younger children it is possible that certain adult populations, e.g. preschool teachers, engage in more 'other' postures compared to adults who are employed in desk-based professions. Therefore, when using the *activ*PAL the amount of 'other' positions a population is likely to engage in needs to be taken into consideration. Also, the practical utility of the thigh-mounted *activ*PAL might be slightly lower compared to the ActiGraph placed on the waist, especially in young children (De Decker et al., 2013). Therefore, when measuring sedentary behavior in adults, adolescents, and children, a posture-based monitor, such as the *activ*PAL, might be the method of choice whereas in preschool-aged children the accuracy might be slightly lower than that found in older age-groups.

Last, it has been suggested that wrist worn accelerometers might increase compliance compared to hip worn accelerometers. Validation studies among adults and children developing sedentary behaviour cut points for the wrist worn GENEActiv accelerometer have reported sensitivity and specificity values > 95% (Esliger et al., 2011; Phillips, Parfitt, & Rowlands, 2013; Schaefer, Nigg, Hill, Brink, & Browning, 2014; Zhang, Rowlands, Murray, & Hurst, 2012). However, in a cross-validation study cut points developed by Esliger et al. (2011) resulted in a moderate classification accuracy of 69.7% (Welch et al., 2013). In addition, studies examining both accelerometers on the hip and wrist reported the accuracy of the wrist-worn devices was comparable or lower to the accuracy of hip worn devices when examining sedentary behavior (Esliger et al., 2011; Phillips et al., 2013; Welch et al., 2014; Welch et al., 2013; Zhang et al., 2012). The limited accuracy of both hip-based and wrist-based monitors might partly be due to the placement of the monitors but, perhaps, more so due to the use of cut point methodologies. Several studies have begun to investigate various machine leaning or pattern recognition approaches that have the potential to enhance the accuracy of estimates of sedentary behavior by making use of the high-frequency triaxial data now provided by most activity monitors (Hagenbuchner, Cliff, Trost, Van Tuc, & Peoples, 2014; Lyden, Keadle, Staudenmayer, & Freedson, 2014; Rowlands et al., 2014; Trost, Zheng, & Wong, 2014). Nevertheless, most studies developing and testing pattern recognition approaches have been laboratory-based and more research studies are needed to examine the accuracy of the developed algorithms before implementation in field-based studies is appropriate. Also, to improve consistency and comparability between studies it will be important to make these techniques and programs available to the wider research community.

Epochs and Cut Points

As previously mentioned, when using motion based monitors most researchers continue to use epoch–based data instead of raw acceleration data due to the limited availability of accurate, user-friendly approaches for the latter. Two studies in preschool-aged children and 7-16 year old children have shown the effect of different epoch settings on estimated time spent sedentary, with larger epochs resulting in lower estimates of sedentary time compared to shorter epochs (Colley, Harvey, Grattan, & Adamo, 2014; Edwardson & Gorely, 2010). However, these studies did not have a criterion measure and it remains unclear which epoch length provides the most accurate estimate of time spent sedentary. We used ActiGraph accelerometer data from 37 preschool-aged children participating in the aforementioned laboratory study to examine differences in estimated time spent in sedentary behaviors using direct observation (second-by-second) and ActiGraph cut points of ≤ 25 counts per 15 seconds and ≤ 100 counts per 60 seconds for 15-second and 60-second epochs, respectively. The results showed that 15-second epochs resulted in significantly higher estimates of sedentary behavior compared to 60-second epochs (67.9 (± 13.3) minutes versus 51.6 (± 14.9) minutes for 15-second and 60-seconds epochs, respectively; $p < .05$). In addition, compared to second-by-second direct observation (sedentary time 57.7 ± 11.2 minutes), using a 15-second epoch resulted in an overestimation of sedentary time (+ 10.2 ± 15.2 minutes; $p = .001$) whereas a 60-second epoch resulted in a slight underestimation of sedentary time (-6.1 ± 16.2 minutes; $p = .089$). These results are counter-intuitive given young children’s intermittent behavioral patterns (shorter epochs should better capture the quick changes in patterns compared to longer epochs). However, young children are unlikely to sit still for the entire time they sit and their fidgeting behavior may explain part of the overestimation of sedentary time when using shorter epochs. They may fidget for 15 seconds to 30 seconds after which they sit still again, which may result in some epochs being classified as non-sedentary when using 15-second epochs. When using 60-second epochs on the other hand, their sporadic physical activity behavior could result in sedentary behavior being under-estimated, as it is likely that children participate in short 30-second bursts of physical activity which will increase the counts over 100 counts per minute and consequently classify a 60 second epoch as non-sedentary.

The reported results are based on a study using a laboratory-based protocol, which may have influenced the results as the protocol was structured and less sporadic compared to children's free-living activities. Also, this intermittent pattern is less likely to appear in older age groups and it is therefore recommended to collect data using the shortest epochs available as these can be transformed to larger epochs during data processing. The epoch length that should be used in the different age groups remains uncertain and further research in free-living circumstances using criterion measures of sedentary behavior, e.g. direct observation, should be used to test the accuracy of different epochs in different age groups.

When using data from traditional activity monitors that is typically collected or converted into epochs, researchers often use cut points to classify an epoch as sedentary or non-sedentary (i.e. physical activity). The cut point methodology is mainly used when data is collected by motion based monitors, such as the ActiGraph and Actical, and not when using posture based monitors such as the *activ*PAL. It has been shown that different cut points result in significantly different estimates of sedentary behavior (Colley et al., 2014; Edwardson & Gorely, 2010). In addition, when examining the association between sedentary behavior and health outcomes the results are also influenced by the chosen cut point (Atkin et al., 2013b). Nevertheless, the evidence on the comparative validity of sedentary behavior cut points among adults is limited. Oliver et al. (2010) compared several Actical cut points ranging from 0 counts per 15 seconds to ≤100 counts per 15 seconds among adults in free-living conditions. Their findings showed the use of ≤5 counts per 15 seconds resulted in the most accurate estimation of sedentary time compared to the *activ*PAL (sensitivity and specificity 94.4% and 53.7%, respectively). For the ActiGraph, three studies among adults examined the accuracy of several cut points using a criterion method. Carr and Mahar (2011) used a laboratory based protocol and classified activities as sedentary based on the physical activity compendium (Ainsworth et al., 2011), whereas Kozey-Keadle et al. (2011) used direct observation in free-living circumstances with lying and sitting being classified as sedentary. Both studies recommended using a cut point of ≤ 150 counts per minute when estimating sedentary time among adults. Carr and Mahar (2011) reported an accuracy of 90.1% when classifying sedentary behavior, whereas Kozey-Keadle et al. (2011) reported using ≤ 150 counts per minute resulted in the lowest bias (1.8%). In addition, Crouter et al. (2013) compared the accuracy of the ≤ 50 and ≤ 100 counts per minute cut point and reported the ≤ 50 counts per minute resulted in the most accurate estimates of sedentary time against indirect calorimetry (mean difference -1.8% versus 9.9% for ≤ 50 and ≤ 100 counts per minute, respectively). These results are different to the most commonly used cut point of ≤ 100 counts per minute. Whether a difference of 50 counts per minute would result in biologically meaningful differences in estimates of sedentary time is uncertain.

In children three studies examined the accuracy of several ActiGraph cut points simultaneously using calorimetry and direct observation as criteria methods. In toddlers, preschool-aged children, and school-aged children the ActiGraph ≤ 100 counts per minute cut point appeared most accurate when estimating time spent in sedentary behaviors (Janssen et al., 2012; Trost, Fees, Haar, Murray, & Crowe, 2012; Trost, Loprinzi, Moore, & Pfeiffer, 2011). For the Actical, only one study examined the accuracy of several sedentary behavior cut points in preschool-aged children and found that a cut point of ≤ 6 counts per 15 seconds provided the most accurate estimates (Janssen et al., 2015).

Non-wear Time Definitions

Another methodological decision researchers have to consider is defining non-wear time. Non-wear time is often identified using a predefined number of consecutive zeros. However, sitting often results in zero counts and, especially in older children and adults, is likely to appear in bouts. Therefore, the length of consecutive zeros may influence estimates of time spent sedentary. Several studies have investigated the effect of different non-wear criteria on wear time and sedentary time (Atkin et al., 2013b; Chinapaw et al., 2014). These studies showed that increasing the predetermined number of consecutive zeros resulted in higher estimates of total wear time and sedentary behavior. However, thus far only a few studies used a reference method (i.e. self-reported non-wear time using an activity diary) to establish the most accurate approach to exclude non-wear time. Winkler et al. (2012) used three algorithms based on 60 minutes of consecutive zeros which differed in the amount of movement tolerated in these 60 minutes (i.e. ≤ 100 counts per minute on two 1 minute occasions; ≤ 50 counts per minute on two 1 minute occasions and no interruption at all). The algorithm with a limited amount of tolerance for movement (≤ 50 counts per minute on two 1 minute occasions) provided the best accuracy. In addition, Oliver et al. (2011) compared non-wear criteria ranging from 20 to 180 minutes of consecutive zeroes and reported that the criterion of 60 minutes of consecutive zeros was most accurate. However, Choi et al. (2011, 2012) reported that in youth, adults, and older adults, a time window of 90 minutes of consecutive zeros while allowing 2 minutes of interruptions resulted in the most accurate estimates of non-wear time compared to a 60 minute time window (Choi, Liu, Matthews, & Buchowski, 2011; Choi, Ward, Schnelle, & Buchowski, 2012). Nevertheless, in a study among obese and overweight adults a time window of 20 minutes of consecutive zeros was most accurate (Berendsen et al., 2014). This indicates non-wear time may be population specific. In addition, it is possible that the most accurate length of non-wear time criterion is age-dependent. Studies suggest that young children spent significantly less time sitting and engage in shorter bouts of sitting compared to older children and adults (Carson, Cliff, Janssen, & Okely, 2013; Kwon et al., 2012; Mitchell et al., 2012b; Ortega et al., 2013; Trang et al., 2013). Therefore, longitudinal studies using very stringent criteria (i.e. 10 minutes of consecutive zeros) may underestimate sedentary behavior in an older age-group, whereas using less stringent rules (i.e. 60 minutes of consecutive zeros) at a younger age may potentially lead to an overestimation of sitting time. More research is needed to examine the most accurate criteria to define non-wear time as well as examining how different non-wear criteria influence changes in sedentary time when compared to a criterion measure.

Criteria for Sedentary Behavior Bouts and Breaks

In addition to total volume of sedentary behavior, it has been suggested that the way in which sedentary behavior is accumulated might also influence health outcomes (Cliff et al., 2014; Dunstan et al., 2012; Fröberg & Raustorp, 2014; Healy et al., 2008; Healy et al., 2011; Saunders et al., 2013). This has led to an increased focus on patterns of sedentary behavior or the fragmentation of sedentary behavior. However, the definition of breaks in sedentary behavior and the length of bouts of sedentary behavior differ between studies. Bouts of sedentary behavior range from 5 minutes to 120 minutes, with and without allowed interruptions (Carson et al., 2013; Carson & Janssen, 2011; Cliff et al., 2014; Healy et al., 2011; Kwon et al., 2012; Saunders et al., 2013). In addition, definitions of a break in sedentary behavior differ both in the duration of a break and the amount of sedentary behavior that has to precede the break (Carson et al., 2013; Colley et al., 2013; Healy et al., 2008; Saunders et al., 2013). To date, it is unknown when a sedentary bout becomes detrimental for health, nor is it clear how long a break needs to last to ameliorate this effect, or if there is an interaction between the two (i.e. will a longer bout of sitting require a longer break in sitting time?). Studies examining different sedentary behavior bout lengths have reported mixed results. Some reported associations with several health outcomes (Carson, Stone, & Faulkner, 2014; Cliff et al., 2014; Colley et al., 2013; Healy et al., 2008; Healy et al., 2011), whereas others found no association between health and sedentary behavior fragmentation (Carson & Janssen, 2011; Denton et al., 2013; Kwon, Burns, Levy, & Janz, 2013; Oliver et al., 2013). Consequently, it remains unknown what the definition of a break or bout should be. However, a recent study by Kim et al. (2015) examined the association between health and sedentary behavior bouts and breaks using several different criteria. The results showed that bouts <5minutes were associated with reduced cardiovascular risk factors whereas bouts > 10 minutes were associated with increased risk factors. The authors suggested defining a sedentary bout of > 10 minutes might be needed to capture the impact of prolonged sedentary behavior on health. However, more research needs to be conducted to confirm this threshold. In addition, recent studies have started to use a new metric, the fragmentation index. The fragmentation index summarizes the pattern of accumulation in one single metric, taking out the effect of total sedentary time (Chastin & Granat, 2010; Chastin et al., 2012). To show how different definitions of fragmentation can influence study outcomes, we conducted secondary analyses on accelerometer data of 100 adolescents who were part of the Gateshead Millennium Study (Parkinson et al., 2011). Sedentary behavior was defined as ≤ 25 counts per 15 seconds. In addition, four consecutive 15 second epochs had to remain ≤ 25 counts per 15 seconds to be defined as a bout of sedentary behavior. Fragmentation was examined using bouts per day, bouts per hour and the fragmentation index (bouts per hour of sedentary behavior). Rank order correlations showed a significant correlation between bouts per day and bouts per hour, and bouts per hour and bouts per hour spent sedentary ($p < .01$ for both). However, the correlation between bouts per hour and bouts per hour spent sedentary was only week (r = .343), whereas there was a very weak non-significant correlation between bouts per day and bouts per sedentary hour (r = .112). These results indicate that rank orders change when using different definitions of fragmentation. This is important to know as the use of different constructs of fragmentation can influence results reported on the associations between fragmentation of sitting time and health outcomes.

Combining Motion Data and Posture Data

Last, with the inclusion of an inclinometer function in the ActiGraph and with the *activ*PAL providing counts per epoch, the question arises 'is it possible to combine these measures?'. If it is possible this may be an improvement in practicality as it would provide the opportunity to measure sedentary behavior and physical activity at the same time. As previously mentioned, the accuracy of the ActiGraph inclinometer to measure posture when positioned at the waist appears to be limited. Therefore, placing the monitor on the thigh may be recommended to gain accurate measures of sedentary behavior. However, it is unknown how this will affect the accuracy of physical activity intensity estimates. To date only two studies have developed a physical activity intensity cut point for the *activ*PAL. Both studies used the acceleration data of the *activ*PAL to estimate physical activity intensity cut points. The acceleration data is averaged in counts per 15-second epochs by the *activ*PAL software and the authors used this data to develop physical activity cut points, using a similar approach to that used to develop cut points for motion-based monitors such as the ActiGraph or Actical. Both reported good sensitivity and specificity for the developed cut points in preschool-aged children (Janssen et al., 2014b) and adolescents (Dowd et al., 2012). However, studies cross-validating these cut points are required to examine the accuracy of these moderate-to-vigorous intensity physical activity cut points under free-living conditions.

RECOMMENDATIONS

Research Recommendations

Currently there is a dearth of information on the appropriate methodological approach when measuring sedentary behavior objectively. Future research is recommended to examine:

- The feasibility and practical utility of the use of thigh based monitors in young children;
- The most accurate criteria to define non-wear time;
- The effect of different definitions of sitting fragmentation on health outcomes;
- The validity of pattern recognition approaches in free-living conditions in all age groups;

Practical Recommendations

Given the limited amount of methodological evidence to inform the application of objective measures of sedentary behavior it is difficult to make recommendations for practice. However, based on the limited evidence available it is recommended that:

- Activity monitors are placed on the thigh and are combined with a data reduction approach that estimates inclination, especially in children and adults;
- Researchers clearly report their data processing decisions to enhance the ability to evaluate and compare studies in the future.

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