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Using Activity Monitors to Measure Sit-to-Stand Transitions in Overweight/Obese Youth

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Abstract

Introduction—Reducing sedentary behavior has emerged as an important health intervention strategy. Although hip-worn, and more recently wrist-worn, accelerometers are commonly used for measuring physical activity and sedentary behavior, they may not provide accurate measures of postural changes. The current study examined the validity of commonly used hip- and wrist-worn accelerometer cut points and the thigh-worn activPAL activity monitor for measuring sit-to-stand transitions as compared to direct observation in youth with overweight and obesity.

Methods—Nine children wore three activity monitors while being directly observed. The monitors included a hip- and wrist-worn ActiGraph and thigh-worn activPAL. The hip-worn ActiGraph was processed with the normal and low frequency filters and the inclinometer function. Cut points of 25 counts per 15-second epoch for the hip, and 105 counts per 15-second epoch for the wrist were applied to the vertical axis to identify sit-to-stand transitions. Epoch-level absolute agreement, Bland-Altman plots, mixed-effects linear regression, and Intraclass Correlation Coefficients (ICCs) were investigated.

Results—The hip and wrist accelerometer cut points and hip inclinometer function overestimated the number of hourly sit-to-stand transitions by approximately triple as compared to direct observation. ICCs between the ActiGraph methods and direct observation were all <0.12. Sit-to-stand transitions assessed from ActivPAL were within 17% of direct observation; ICC was 0.26.

Conclusion—Despite the common use of the 100 count hip-worn accelerometer cut point for assessing sedentary time, these processing decisions should be used with caution for assessing sit-to-stand transitions. Future research should investigate other processing methods for ActiGraph data, and studies investigating postural changes should consider including devices such as activPALs.

Keywords

sedentary behavior; breaks; ActiGraph; activPAL; agreement

Introduction

Sedentary behavior, which is defined as any waking activity with a sitting or reclining posture that results in energy expenditure below 1.5 METS (25, 32), has recently emerged as a public health priority due to the myriad of physical and mental health outcomes associated with too much sitting, even after adjusting for the amount of physical activity (e.g., 10, 24, 30, 34). Measures of sedentary behavior that are reliable, valid, and feasible for use in large studies are essential for drawing accurate conclusions about the prevalence, influences, and health outcomes of sedentary behavior, in addition to evaluating interventions.

Much of the research on the associations among sedentary behavior and health outcomes in youth has been conducted using indirect (parent-, teacher-, or self-report) measures of time spent watching TV (34). These studies have shown that watching more than two hours of TV per day is associated with lower fitness, self-esteem, academic achievement, and pro-social behavior, and higher body mass index (BMI; 34). Indirect measures are feasible for use in large-scale studies; however, they are prone to biased estimates because individuals can over- or under-report sedentary behavior. Further, indirect measures provide information on total sedentary time, but few provide information about the pattern of accumulation of sedentary behavior.

Alternatively, direct measures, such as accelerometers, are often used to measure sedentary behavior in youth. Although findings have been somewhat inconsistent in youth, some evidence suggests that accelerometer-measured sedentary time is important to youth's health, particularly body composition (34). An advantage of using accelerometers to measure sedentary behavior is that they provide information on the way in which youth accumulate sedentary time (e.g., 15, 31), which research has shown to also be associated with health outcomes. For example, recent research has shown that more breaks in sitting time, also referred to as sit-to-stand transitions, are associated with lower adiposity, fasting glucose levels, and cardio-metabolic risk in youth (6, 31). However, these and other studies have employed accelerometer cut points to measure sit-to-stand transitions and sedentary bout patterns with little evidence of the validity of these methods for measuring sedentary metrics other than total sedentary time.

Only four studies were identified that investigated the validity of hip-worn accelerometers for measuring sit-to-stand transitions, and all were in adults. Each of these studies found that hip-worn accelerometers substantially overestimated the number of sit-to-stand transitions as compared to activPAL (4, 16) or direct observation (20, 23). Few studies were identified that investigated the validity of the thigh-worn activPAL for measuring sit-to-stand transitions. These studies found that the activPAL provided valid estimates of transitions, but were limited to adults (12, 20) or prescribed activities (non free-living; 2, 12). To date, no identified studies have examined the validity of hip- or wrist-worn accelerometers or thigh-worn activPALs for measuring sit-to-stand transitions in free-living youth or in overweight/

obese samples. Therefore, the current study advances the literature by examining the validity of accelerometers and activity monitors for measuring sit-to-stand transitions in a youth sample with overweight/obesity. Assessing validity in youth with overweight/obesity is particularly important because they are common targets of sedentary interventions (3), and sedentary interventions may be a more acceptable starting point in this population and a catalyst for physical activity.

A primary aim of the current study was to examine criterion validity of commonly used cut points applied to hip- and wrist-worn accelerometer data for measuring sit-to-stand transitions in youth with overweight or obesity. The normal and low frequency filter of the hip-worn ActiGraph were investigated. Additionally, because of the evolving methodology for accelerometer data collection and processing (18, 22, 36), the current study also aimed to fill a gap in the literature by examining the validity of the inclinometer function of the hip-worn accelerometer for measuring sit-to-stand transitions. Criterion validity of the thigh-worn activPAL for measuring sit-to-stand transitions was also investigated, given that previous studies were limited to adults. Direct observation, the gold standard for assessing changes in posture (4, 17), was used as the criterion measure.

Methods

Participants and Procedures

Participants included nine youth with obesity (BMI 95th percentile; ages 10-17) who were engaged in a behavioral weight-management program. Parents provided written informed consent, and children provided written assent. Children were enrolled in the study for the duration of an evening weight-management group session (approximately two hours). The first hour of the weight-management session included group exercise activities and active games, and the second hour was spent in a classroom. The group leader was asked to incorporate sit-to-stand transitions during both hours of the session to prevent the youth from sitting or standing for the entire data collection period.

All participants wore three non-invasive physical activity measurement devices (i.e., one hip-worn ActiGraph, one wrist-worn ActiGraph, and one thigh-worn activPAL), and trained research staff coded direct observations of their postures. The same computer clock was used to initialize activity devices within 1-hour prior to data collection and to time-synchronize the direct observations. The procedures were approved by the local IRB.

Measures

ActiGraph—Participants wore two GT3X model ActiGraph accelerometers (ActiGraph, Pensacola, FL) for the duration of data collection. One ActiGraph was worn on the right hip, affixed with a belt, and the other ActiGraph was worn on the non-dominant wrist, affixed with a watch-like strap. Raw acceleration in g-force was recorded at 30 hrz for each of the three axes (vertical, medio-lateral, and antero-posterior). Using the ActiLife software, raw accelerometer files were converted into 1-second files denoting the counts recorded per every 1 second for the vertical axis. When downloading the hip-worn ActiGraph, the inclinometer feature was selected, which employs an algorithm from the manufacturer to

infer the posture of the participant (i.e., standing, lying, sitting, or not being worn). Additionally, the hip-worn ActiGraph was downloaded in regular frequency and low frequency (LF). The regular frequency algorithm raises the lower end of the frequency bandwidth to exclude “acceleration noise,” whereas the LF option is used to increase sensitivity in populations with slow or light movement by extending the bandwidth (1).

activPAL—Participants wore one activPAL Micro accelerometer (PAL Technologies, LTC) for the duration of data collection. The activPAL has good criterion validity for assessing posture (i.e., sitting, standing, lying) as compared to direct observation (2, 9, 20) in adult and non-free living samples. All participants wore the activPAL on the right thigh, affixed with adhesive tape (Tagaderm, similar to a bandage). The event files produced from the activPAL software were used to create second-level files denoting, for each second, whether the participant was sitting, standing, standing and walking, in a sit-to-stand transition, or in a stand-to-sit transition. The minimum sitting/upright time to define a new posture was 1 second.

Direct observations (criterion)—Research staff coded youth participant postures using in-person direct observations facilitated by a multifunctional digital stopwatch and a synced excel tracking form (XNOTE Stopwatch; available at xnotestopwatch.com). Activity codes were continuously assigned to youth participants while they were wearing the devices and in view of the coders. Activity was coded according to the following definitions: Standing (upright position in which a majority of one's weight is supported by one or both feet); Sitting (a position in which one's weight is supported by one's buttocks rather than one's feet and in which one's back is upright); Lying (in a horizontal position on a supporting surface; includes push-up position); and Out of scene. Sit-to-stand transitions were inferred when the participant went from sitting to standing. Similar to activPAL, the minimum sitting/upright time to define a new posture was 1 second.

Demographics—Participant sex and age were gathered by self-report during study consenting procedures.

Data Processing and Analyses

Second-level data from each device and direct observation were merged using the synchronized time stamps. A sum aggregation was used to convert the vertical axis counts from the ActiGraphs to 15-second intervals (i.e., epochs) in SPSS v23. A 15-second epoch was chosen because youth studies commonly use epochs of 5-30 seconds, as opposed to adult studies which often use 60-second epochs (5, 36). A cut point of 25 counts per 15-second epoch was applied to the hip-worn accelerometer data to represent the commonly used 100 counts per minute cut point. (e.g., 4, 20, 27, 28, 35). For the wrist-worn ActiGraph, a cut point of 105 counts per 15-second epoch was derived from a previous study that showed good validity of a similar cut point applied to 5-second epochs for assessing total sedentary time (8). For the hip- and wrist-worn accelerometers, a sit-to-stand transition was defined as a non-sedentary epoch preceded by a sedentary epoch, based on the aforementioned cut points. For the direct observation and activPAL data, each 15-second epoch was considered to be a sit-to-stand transition epoch if at least one sit-to-stand

transition occurred during the 15 seconds. For the epoch-level analyses, a ± 1 epoch window was employed such that devices would be considered in agreement with direct observation if off by no more than ± 1 epoch. Next, 2×2 confusion matrices were used to visually display false positives, false negatives, true positives, and true negatives with regards to sit-to-stand transitions. These values were then used to calculate accuracy, sensitivity, specificity, positive predictive value, and negative predictive value for the test devices compared to the direct observation criterion measure.

Because aggregated metrics are commonly used in public health studies (13, 14, 30, 31), the data were also aggregated to the hour level to derive the number of sit-to-stand transitions during the hour. This aggregation step was conducted using the 1-second files for the direct observation and activPAL data, and the 15-second epoch-level file for the ActiGraph data. Hours with <15 minutes of data were excluded from hour-level analyses. Mixed-effects linear regression, adjusted for nesting of hours within participants, was used to compare the mean differences in the number of sit-to-stand transitions between the test measures and direct observations, as were root-mean-square errors. Further, Intraclass Correlation Coefficients (ICCs) were calculated from the covariance estimates of these same models to examine correlations between measures. Finally, Bland-Altman plots were used to graphically examine the hour-level agreement between the test methods and direct observation, and 95% confidence intervals were calculated, as described by Carstensen et al. (7), to account for the nested data structure.

Results

Epoch-level analyses

The accuracy, specificity, and negative predictive value of the ActiGraph Hip, ActiGraph Hip-LF, and ActiGraph Wrist were over 85% compared to direct observation (see Table 1). Given that a large majority of epochs were not sit-to-stand transitions, these test measures had high true negative rates (i.e., correctly indicating that the participants not engaged in a sit-to-stand transition). However, sensitivity and positive predictive values were low (<48% and <11%, respectively), meaning that the ActiGraph Hip, ActiGraph Hip-LF, and ActiGraph Wrist were prone to false positives (i.e., indicating that a sit-to-stand transition occurred when it did not) and to a lesser extent false negatives (i.e., missing a sit-to-stand transition that occurred). A similar pattern was observed with the ActiGraph Inclinometer, although worse agreement was observed for this test device. The ActiGraph Inclinometer had a very high false positive rate.

Compared to direct observation, the activPAL had accuracy, specificity, and negative predictive values over 96%; the sensitivity and positive predictive values were lower (52.94% and 44.12%, respectively), indicating that the activPAL was somewhat prone to false positives and to a lesser extent false negatives. Of the 57 false positives, close examination of the data revealed that 87.7% were while the participant was actually sitting, 87.7% were resolved by the activPAL within a mean of 60 seconds (SD = 117), and the remaining 12.3% were resolved because the participant changed posture (e.g., stood up) within of mean of 98 seconds (SD = 112) from the false sit-to-stand transition.

Hour-level analyses

All ActiGraph test measures overestimated the number of sit-to-stand transitions (see Table 2). The ActiGraph Hip, ActiGraph Hip-LF, and ActiGraph Wrist indicated 190-202% more sit-to-stand transitions than indicated by direct observation. The ActiGraph Inclinometer indicated 258-282% more sit-to-stand transitions than indicated by direct observation. ICCs between the ActiGraph methods and direct observation were all <0.12 . The activPAL slightly overestimated sit-to-stand transitions compared to direct observation (6.84 vs. 5.84 transitions per hour; 17% difference). The activPAL showed a modest correlation with direct observation ($ICC = 0.26$).

The Bland-Altman plots in Figure 1 show a slight pattern of greater overestimation as the number of sit-to-stand transitions increases for the ActiGraph HIP and ActiGraph Hip-LF, and a more substantial pattern of greater overestimation as the number of sit-to-stand transitions for the ActiGraph Wrist, and especially the ActiGraph Inclinometer. The 95% limits of agreement were generally large, indicating a wide range of error. ActivPAL, on the other hand, showed a much smaller mean difference and limits of agreement, and showed fairly consistent bias as the number of sit-to-stand transitions increased.

Discussion

The primary aims of the current study were to examine the validity of hip- and wrist-accelerometer cut points and the thigh-worn activPAL for measuring sit-to-stand transitions in youth as compared to direct observation. Few studies have investigated accelerometers for assessing sit-to-stand transitions (4, 12, 16, 20, 23), and limitations of these studies were that all were in adults. The current study extended the previous literature by examining both epoch-level and hour-level validity of these measures in youth with overweight and obesity, a population frequently targeted for intervention (3). Overall, findings show that the commonly used hip- and wrist-worn accelerometer cut points do not have strong validity for measuring sit-stand transitions. ActivPAL, on the other hand, showed good validity for assessing sit-to-stand transitions, and this is in agreement with adult studies (12, 20).

As compared to direct observation, the ActiGraph Hip, Hip-LF, and Wrist overestimated sit-to-stand transitions by about triple the transitions, highlighting the limitation of accelerometer cut point methods for measuring the core behavior (sit-to-stand transitions) that comprises bout pattern calculations such as minutes in prolonged sedentary bouts. The ActiGraph Inclinometer function on the hip accelerometer did not perform more favorably than the other ActiGraph methods. These findings are similar to those in adult samples that showed poor validity for using accelerometer cut points to assess sit-to-stand transitions (4, 16, 20, 23).

Several studies have shown that hip-worn accelerometer cut points are acceptable for assessing total sedentary time in youth (e.g., 19, 26, 27). However, present findings suggest using caution when considering using accelerometer cut points for assessing sit-to-stand transitions and sedentary bout patterns. The lack of validity for the hip- and wrist-accelerometer cut points for assessing sit-to-stand transitions has several implications. Evidence is accumulating on the deleterious effects of few sit-to-stand transitions in youth

(6, 31). However, a majority of this evidence was derived from accelerometer cut points. More valid measures of sit-to-stand transitions (e.g., activPAL or other methods of processing hip-worn accelerometer data) would likely result in reduced measurement error, more power for detecting true associations, and a better understanding of how and why sedentary behavior has negative health implications.

Although the activPAL slightly overestimated sit-to-stand transitions, the magnitude of the differences was small. These differences were slightly greater than those observed in previously published studies (2, 12, 20), and close examination of the present data revealed that the disagreement primarily occurred during the first half of the data collection (i.e., physical activity sessions) and not during the classroom activity. Thus, it appears that mis-estimation of sit-to-stand transitions is more frequent during activity sessions, which are more common in youth than adults. Most of the false transitions were caught (i.e., the correct posture was detected) by the activPAL algorithms within 1.5 minutes. Furthermore, slight overestimation of sit-to-stand transitions during physical activity is not likely to impact estimates of prolonged sitting (e.g., usual bout duration, minutes in 30+ minute bouts) at the day- and participant-level, which are commonly investigated (e.g., 14, 15, 30, 31).

Other methods have evidence of validity or show promise for assessing sit-to-stand transitions. For example, wearing the ActiGraph on the thigh, similar to how the activPAL is worn, has evidence of validity for assessing posture (33), and consumer devices such as the LUMO back have evidence of validity for assessing total sedentary time (29). Other methods for processing accelerometer data, such as machine learning techniques that utilize the triaxial information from the accelerometer, have good evidence of validity for assessing energy expenditure and sedentary time, show promise for improving assessment of sit-to-stand transitions (21), and should be a priority of future research. Different methods, or even devices, may need to be used to validly assess different activities (e.g., physical activity vs. sedentary time vs. sit-to-stand transitions), although to minimize participant and researcher burden it would be valuable to use only one device. It is possible that other accelerometer cut points have better validity for assessing sit-to-stand transitions. However, some studies have suggested using higher cut points (17), whereas others suggest lower cut points (13), so there is no consensus. Changing the cut point is likely to trade off false positives for false negatives, so substantial improvement to overall validity is not likely to be observed simply from changing the cut point.

The strengths of this study include being among the first to investigate the validity of hip- and wrist-worn accelerometer cut points and of the activPAL activity monitor for assessing sit-to-stand transitions in free-living youth, examining both epoch- and hour-level metrics and using direct observation as the gold standard comparison measure. A limitation of the study is the small sample size and short period of observation per participant (i.e., 2 hours), so findings may not generalize to other samples or populations. Additionally, youth participants engaged in exercise for a portion of their time in the study. Although the exercises included typical activities that youth engage in on a regular basis (e.g., jumping, getting on floor and up again), these activities may have inflated the bias across measures. It is likely that agreement would have been higher if these activities were excluded, but this

would limit external validity. Also, given evidence suggesting that weight status may affect the accuracy of accelerometry in adults (11), the current results may not be generalizable to normal weight youth. Although sedentary behavior is highly prevalent in free-living samples, the low frequency of sit-to-stand transitions in the present free-living sample made for a more robust test of negative predictive values (because there were so many non-transitions) and less robust test of positive predictive values. Thus, both negative and positive predictive values should be interpreted with caution, and all analyses should be taken into account when drawing conclusions.

Consistent with previous evidence in adults, there is little evidence to suggest that accelerometer cut point methods have acceptable validity for assessing sit-to-stand transitions in youth. These findings are not surprising because the hip and wrist are not ideal placements for capturing posture, and similar acceleration counts can result from body movements occurring while sitting or standing. ActivPAL, on the other hand, has evidence of validity for assessing sit-to-stand transitions. Despite the common use of hip- and wrist-worn accelerometer cut point methods to assess sit-to-stand transitions and sedentary patterns, these methods should be used with caution. Use of these methods could lead to mis-estimation of associations between sedentary patterns and health. Future research should investigate other processing methods for hip- and wrist-worn accelerometer data and correction factors, and studies investigating sedentary patterns and health should consider including activPAL when possible.

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Figure 1.

Bland Altman plots for hour-level agreement between ActiGraph/activPAL methods and direct observations

Note. Lines are at zero, mean difference, 95% limits of agreement, and best fit.

Table 1
Epoch-level agreement for measuring sit-to-stand transitions in youth with overweight and obesity

	Direct Observation	
ActiGraph Hip	Yes	No
Yes	28 (1.1%)	251 (10.0%)
No	57 (2.3%)	2178 (86.6%)
	Accuracy = 87.75%, Sensitivity = 32.94%, Specificity = 89.67%, PPV = 10.04%, NPV = 97.45%	
ActiGraph Hip-LF	Yes	No
Yes	24 (1.0%)	241 (9.6%)
No	61 (2.4%)	2188 (87.0%)
	Accuracy = 87.99%, Sensitivity = 28.24%, Specificity = 90.08%, PPV = 9.06%, NPV = 97.29%	
ActiGraph Inclinometer	Yes	No
Yes	52 (2.1%)	1121 (44.6%)
No	33 (1.3%)	1308 (52.0%)
	Accuracy = 54.10%, Sensitivity = 61.18%, Specificity = 53.85%, PPV = 4.43%, NPV = 97.54%	
ActiGraph Wrist	Yes	No
Yes	192 (1.3%)	1863 (12.9%)
No	213 (1.5%)	12212 (84.3%)
	Accuracy = 85.66%, Sensitivity = 47.41%, Specificity = 86.76%, PPV = 9.34%, NPV = 98.29%	
activPAL	Yes	No
Yes	45 (1.8%)	57 (2.3%)
No	40 (1.6%)	2372 (94.4%)
	Accuracy = 96.14%, Sensitivity = 52.94%, Specificity = 97.65%, PPV = 44.12%, NPV = 98.34%	

Note. LF = Low frequency filter; PPV = Positive predictive value; NPV = Negative predictive value.

Hour-level agreement for measuring sit-to-stand transitions in youth with overweight and obesity (N = 16 hours from 9 participants)**Table 2**

	Estimated Mean (SE) Number of Sit-to-Stand Transitions per Hour		Mean Difference (SE) Number of Sit-to-Stand Transitions per Hour			ICC
	Test Method	Direct Observation	ActiGraph Method – Direct Observation	p	RMSE	
ActiGraph Hip vs. Direct Observation	17.26 (1.77)	5.70 (1.77)	11.56 (2.47)	<.001	6.98	0.01
ActiGraph Hip-LF vs. Direct Observation	16.51 (1.85)	5.70 (1.85)	10.81 (2.57)	<.001	7.26	0.02
ActiGraph Inclinometer vs. Direct Observation ^a	4.30 (.21)	1.47 (.21)	282.62% (26.37%)	<.001	0.75	0.12
ActiGraph Wrist vs. Direct Observation	17.00 (2.38)	5.70 (2.38)	11.30 (3.37)	.002	9.53	0
activPAL vs. Direct Observation	6.84 (1.82)	5.84 (1.82)	1.00 (2.00)	.622	5.66	0.26

Note.

^aThe sit-to-stand transition variable was non-normally distributed for the ActiGraph Inclinometer, so the dependent variable in this model was natural log transformed; the mean difference can be interpreted as the percent difference between the ActiGraph Inclinometer and activPAL.

LF = low frequency filter; SE = standard error; RMSE = Root-mean-square error; ICC = Intraclass Correlation Coefficient.