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Evaluating the Responsiveness of Accelerometry to Detect Change in Physical Activity

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Abstract

The responsiveness to change of the Actical and ActiGraph accelerometers was assessed in children and adolescents. Participants (n=208) aged 6–16 years completed two simulated free-living protocols, one with primarily light-to-moderate physical activities (PA) and one with mostly moderate-to-vigorous PA. Time in sedentary, light, moderate, and vigorous PA was estimated using 8 previously developed cut-points (4 for Actical and 4 for ActiGraph) and 15-s and 30-s epochs. Accelerometer responsiveness for detecting differences in PA between protocols was assessed using standardized response means (SRM). SRM values ≥0.8 represented high responsiveness to change. Both accelerometers showed high responsiveness for all PA intensities (SRMs = 1.2–4.7 for Actical and 1.1–3.3 for ActiGraph). All cut-points and epoch lengths yielded high responsiveness, and choice of cut-points and epoch length had little effect on responsiveness. Thus, both the Actical and ActiGraph can detect change in PA in a simulated free-living setting, irrespective of cut-point selection or epoch length.

Keywords

children; accelerometer; sensitivity; ActiGraph; Actical

INTRODUCTION

Physical activity (PA) is associated with many health benefits in children and adolescents, including improvements in bone health, neuromuscular strength, cholesterol profile, glucose tolerance, and self-esteem (Boreham & Riddoch, 2001; Sothern, Loftin, Suskind, Udall, & Blecker, 1999). As a result, researchers and professional organizations recommend

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conducting interventions to increase PA in children and adolescents (Ressel, 2003). To determine the effectiveness of these interventions at increasing PA, the accurate assessment of PA is essential.

Accelerometry has become popular for assessing PA in youth due to its many advantages over other PA measurement methods (e.g., objective measurement with low participant and researcher burden) (Welk, 2002). Accelerometers are generally worn on the hip and measure accelerations of the body in one or more planes of movement. These movements are translated into "activity counts," which are reflective of PA level. Counts are summed in time intervals, or epochs, to characterize the frequency, duration and intensity of PA (Bonomi, Goris, Yin, & Westerterp, 2009). Recent technological improvements, such as improved battery life and memory capacity, as well as reductions in cost allow for use of accelerometers in large studies and interventions (Corder, Ekelund, Steele, Wareham, & Brage, 2008; Godfrey, Conway, Meagher, & Olaighlin, 2008).

There are many different accelerometers used to measure PA; two commonly used accelerometers are the Actical (Philips Respironics, Bend, OR) and ActiGraph (ActiGraph, LLC, Pensacola, FL). The Actical is an "omnidirectional" accelerometer that primarily assesses movement in the vertical plane, and the ActiGraph GT1M is a uniaxial accelerometer that assesses accelerations in the vertical plane. The Actical and ActiGraph have both been tested in a variety of settings and populations and were found to be reliable and valid for estimating PA in children and adolescents (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Freedson, Pober, & Janz, 2005; Puyau, Adolph, Vohra, & Butte, 2002). Additionally, these accelerometers have both seen extensive use in surveillance and intervention studies in youth (Colley et al., 2013; Kriemler et al, 2011). Although the ActiGraph GT1M has been superseded by the GT3X and GT3X+ models, it has been shown that counts recorded by the GT1M, GT3X, and GT3X+ are equivalent, and that cut-points developed for the vertical axis from earlier ActiGraph models can be applied to data collected by the GT3X and GT3X+ in adults and children (Robusto & Trost, 2012; Sasaki, John, & Freedson, 2011).

Despite previous validation of the Actical and ActiGraph, there is another measurement property, responsiveness to change, which is often overlooked in validation studies. Responsiveness to change, defined as the ability to detect meaningful change over time (Cohen, 1977), is also recognized as a vital property of any measurement tool, but to date there is limited knowledge regarding the responsiveness of the Actical or ActiGraph GT1M to detect changes in PA that may occur with lifestyle modification. It is often assumed that validated PA measurement instruments will be responsive to detecting changes in PA, but this is not necessarily the case. For example, the ActiGraph has been validated for measurement of time spent in sedentary behaviors (Hart, Ainsworth, & Tudor-Locke, 2011), but two studies have found that the ActiGraph is not responsive to detecting changes in sedentary behavior (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011; Lyden, Kozey Keadle, Staudenmayer, & Freedson, 2012).

Additionally, several lifestyle intervention studies using multiple validated PA measurement tools have found conflicting results regarding the effectiveness of the intervention for increasing PA. Caballero et al. found higher self-reported levels of PA in the intervention group relative to the control group, but ActiGraph accelerometers revealed no group differences (Caballero et al., 2003). Similarly, Haerens et al. found higher levels of PA in the intervention group relative to the control group when assessed with ActiGaphs, but self-report questionnaires found no group differences (Haerens, De Bourdeaudhuij, Maes, Cardon, & Deforche, 2007). One possible explanation of this discrepancy is that self-report methods in children (especially younger children) may have questionable accuracy due to cognitive limitations of children (Sirard & Pate, 2001). However, it is also possible that either of the assessment methods (or both) failed to detect change in PA. Although accelerometry has been found to be a valid and reliable method for estimating PA, it is possible that accelerometers may not be able to detect relatively small changes in total PA levels.

In addition, cut-point choice for PA intensities (sedentary, light, moderate, and vigorous) and epoch length have been shown to influence PA measurement when using accelerometers (McClain, Abraham, Brusseau, & Tudor-Locke, 2008; Ressel, 2003). Along with these differences in accuracy is the possibility that choice of cut-points and/or epochs may affect the responsiveness to change of accelerometers. However, we are unaware of any previous research evaluating whether cut-point choice or epoch length influences responsiveness to change.

In practice, an increase of only a few min/day or a small increase in the intensity of PA could provide health benefits (Steele, van Sluijs, Cassidy, Griffin, & Ekelund, 2009). A review by Kriemler et al. found that PA interventions induce only small changes in children's activity levels and time spent in moderate-to-vigorous PA (Kriemler, et al., 2011). Therefore, it is important to be able to detect relatively small (i.e., 5–10 min/hr) changes in PA that are likely to occur with interventions. To our knowledge, no study has induced different levels of PA in children and adolescents during free-play and assessed an accelerometer's ability to detect these changes. Evaluation of the responsiveness to change of accelerometers is necessary to ensure they are able to detect changes in PA that may occur with an intervention. Thus, the purposes of our study were 1) to assess the responsiveness of two commonly used accelerometers, the Actical and ActiGraph, to detect changes in PA in a field-based setting and 2) to determine if choice of epoch length or cut-points affected responsiveness to change.

METHOD

Participants

Participants were 6–16 year old children and adolescents (n= 208) recruited from the surrounding areas of East Lansing, MI and Corvallis, OR. Participants were recruited via email and flyers in local recreational facilities. The composition of the sample was 51% male and 78% Caucasian. Prior to data collection, written detail of the procedures and risks associated with the study were provided to all participants and their primary caregivers. Written informed consent was obtained from primary caregivers, and written assent was provided by each participant. The study design and procedures were approved by the Institutional Review Boards at Michigan State University and Oregon State University. Both sites participated in creating a procedures manual and training protocol. After training took place, site visits were conducted to assess protocol fidelity across sites.

Physical Activity Visits

Prior to PA assessment, height and weight were measured by trained data collectors according to standardized techniques described previously (Malina, 1995). Each measure was taken twice, and the readings were averaged. Height was measured to the nearest 0.1 cm, and weight was measured to the nearest 0.1 kg.

Each participant completed two visits to the laboratory (low- and high-intensity visits). Visits involved groups of 3–7 participants and were meant to simulate typical after-school programs. Both visits lasted approximately 90 min and included sedentary time (i.e., snack time, homework time) and activity time. During the sedentary time in both visits, participants were instructed to remain seated. The activity time during both visits was directed (some structured, some unstructured) to simulate a field-based setting where participants were free (within certain limits) to choose their activities. A summary of the visits can be found in Table 1, and a more detailed description of the visits follows.

The activity time in the low-intensity visit consisted of 40 min of primarily light- or moderate-intensity activities and 50 min of sedentary time, while the activity time in the high-intensity visit consisted of 60 min of predominantly moderate- or vigorous-intensity activities and 30 min of sedentary time. The activities performed during visits were age-appropriate activities and games. Thus, participants of similar ages were scheduled on the same days. Also, the visits were counter-balanced to avoid possible order effects.

Low-intensity visits started with a 15-min snack time, followed by 20 min of structured activity, 20 min of homework/rest, 20 min of unstructured activity, and 15 min of watching movies. Examples of structured activities performed in the low-intensity visits included bowling, a cooperative hula hoop game, and juggling. Examples of unstructured activities performed included a bean bag toss, catch, frisbee golf, and indoor tennis on a small court (with soft, foam balls).

High-intensity visits also began with a 15-min snack time. The snack was followed by 30 min of structured activity, 15 min of homework/rest, and 30 min of unstructured activity. Examples of structured activities in the high-intensity visits included an obstacle course, relay races, and shuttle runs. Examples of unstructured activities included jump rope, soccer, basketball, and tag.

Data Collection

In order to assess the utility of accelerometers for detecting change in PA, the two visits were deliberately constructed in the manner described above to elicit a higher volume of PA in the high-intensity visit compared to the low-intensity visit. In order to confirm that more PA was performed in the high-intensity visit, we used a slightly modified version of the Children's Activity Rating Scale (CARS) direct observation (DO) system was used to document time spent in sedentary, light-, moderate-, and vigorous-intensity activities (Puhl, Greaves, Hoyt, & Baranowski, 1990).

For both visits, DO was performed only during the structured and unstructured activity times. During the low-intensity visits, 40 min of observation was completed, with 4 different children observed (1 at a time) for 10 min each (2 during structured activities and 2 during unstructured activities). During the high-intensity visits, 60 min of observation was completed, with 6 different children observed for 10 min each (3 during structured activities and 3 during unstructured activities). The order of observation was randomized. If there were more than 4 participants in a low-intensity visit or 6 for a high-intensity visit, then 4 of the participants in the low-intensity visit and 6 in the high-intensity visit were chosen randomly for observation; therefore it is possible that some children were not observed in a visit if the group was large (>4 in a low-intensity visit or >6 in a high-intensity visit). If there were fewer than 4 participants in a low-intensity visit or fewer than 6 participants in a high-intensity visit, participants were chosen randomly to be observed more than once during the visit. During the snack, homework, and movie-watching portions of the visits, all participants remained seated for the duration of these activities; therefore, there was no need to perform direct observation during the sedentary parts of the visit. Data were summed for each visit to obtain the group's total time spent in each PA intensity (sedentary, light, moderate, or vigorous).

For both visits, participants each wore Actical and ActiGraph accelerometers on the right hip; placement order of the accelerometers on the belt was randomly assigned. Both accelerometers have been previously validated in children and correlate well with measured energy expenditure (Freedson, et al., 2005; Pfeiffer, McIver, Dowda, Almeida, & Pate, 2006). For the current study, data were recorded in the smallest epoch length possible for each accelerometer (15-s and 1-s epochs for the Actical and ActiGraph, respectively). Actical data were reintegrated into 30-s epochs, and ActiGraph data were reintegrated into 5-, 15-, and 30-s epochs to examine possible interactions of epoch length with accelerometer responsiveness. Reintegration of epochs was conducted using a customized macro program developed in Microsoft® Excel.

Data Reduction

Predictions of the numbers of min spent in sedentary (SED), light (LPA), moderate (MPA), vigorous (VPA), and moderate-to-vigorous (MVPA) PA from the accelerometers during the low-intensity and high-intensity visits were calculated for each participant according to multiple count cut-points and separately for 15- and 30-s epoch lengths (and 5-s epochs for the ActiGraph). For the Actical, previously validated cut-points of Puyau (Puyau, et al., 2002), Evenson (Evenson, et al., 2008), and both the single and multiple regression models from Heil (Heil, 2006) were compared. For the ActiGraph, previously validated cut-points of Freedson (Freedson, et al., 2005), Puyau (Puyau, et al., 2002), Treuth (Treuth et al., 2004), and Evenson (Evenson, et al., 2008) were compared.

A slightly modified version of the CARS served as the criterion measure (manipulation check) to confirm that the high-intensity visit involved more PA and less sedentary time than the low-intensity visit. According to the CARS protocol, PA was classified as 1 of 5 intensity levels (1 = lying, sitting; 2 = standing; 3 = walking slow/easy; 4 = walking moderate; 5 = running, strenuous activity). Trained observers recorded activity level continuously using a computerized DO software tool (BEST) following previously established coding rules (Puhl, et al., 1990). CARS has been previously validated with indirect calorimetry and correlates highly with accelerometer counts in children (Puhl, et al., 1990). The original CARS protocol allowed for a given activity intensity to be coded only once per min, and it does not weight activity classifications if more than 1 category was selected per min. Given the sporadic nature of children's activity (Bailey et al., 1995), we decided to modify the CARS protocol slightly to allow for coding of a given exercise intensity more than once per min. In addition, the BEST software tool allows for continuous recording of time-stamped data, allowing the exact timing and duration of each activity to be ascertained. Observers were instructed to record to wait 3 seconds before recording an activity; therefore, activities shorter than 3 seconds were not recorded. For the current study, inter-observer reliability for CARS was above r=0.8 at each of the data collection sites.

For our criterion measure of time spent in each PA intensity, DO data were translated to activity intensities. Activity levels 1 and 2 were classified as SED, 3 as LPA, 4 as MPA, and 5 as VPA. DO was not performed during rest, snack, or homework times. During these times, children were required to remain seated as they participated in activities such as homework or movie watching. Therefore, any time outside of activity times was assumed to be sedentary and coded as SED.

Statistical Analysis

Responsiveness to change was assessed using standardized response mean (SRM), which has been used in other studies to measure behavioral change (Meiorin et al., 2008; van der Zee, Kap, Rambaran Mishre, Schouten, & Post, 2011). SRM was calculated as the absolute mean change in PA divided by the standard deviation of individuals' change in score (Cohen, 1977; Meiorin, et al., 2008), as shown in equation (1):

$$SRM=\frac{|High\ intensity-Low\ intensity|}{SD\ of\,|High\ intensity-Low\ intensity|} \quad (1)$$

SRM absolute values of >0.2 and ≤0.5 were considered low, >0.5 and <0.8 were considered moderate, and ≥0.8 were considered high responsiveness scores (Cohen, 1977). SRMs were calculated separately for the Actical and ActiGraph accelerometers and for each PA intensity, each set of cut-points, and for multiple epoch lengths (15- and 30-s epochs for Actical; 5-, 15-, and 30-s epochs for ActiGraph). To compare SRM values among cut-points and epochs, 95% confidence intervals (CI) were calculated (Cohen, 1977). Paired t-tests were used to examine differences between the PA estimates for the high-intensity and low-intensity visits as detected by DO, which served as the manipulation check. Unit of analysis was visit. A p-value of p≤0.05 was used to determine statistical significance.

RESULTS

Descriptive statistics for the sample are displayed in Table 2. Approximately 26% of the participants in this study were classified as overweight/obese based on BMI percentiles (Kuczmarski et al., 2000). The number of min spent in each PA intensity level, as detected by DO, is shown in Table 3. SED during the high-intensity visit was 28.8 min lower than SED in the low-intensity visit. During the high-intensity visit, LPA, MPA, VPA, and MVPA were higher than in the low-intensity visit by 6.6, 8.9, 12.3, and 21.3 min, respectively. Differences in time in each PA intensity were statistically significant ($p < .0001$), indicating that the study design effectively induced more PA in the high-intensity visit compared to the low-intensity visit.

SRM values for the Actical and are shown in Table 4. For both the 15- and 30-s epochs, the SRM values were at or above 1.2 for all cut-points at all PA intensities, indicating high responsiveness to change for the Actical. Two types of comparisons were made: 1) comparison among cut-points for each epoch length and 2) comparisons between the 15- and 30-s epoch lengths for each set of cut-points. First, there were no differences in SED responsiveness among cut-points for either epoch. The Heil 2R cut-points had lower responsiveness for changes in LPA than the Puyau cut-points for the 15-s epoch and lower responsiveness than all other cut-points for the 30-s epoch. There were some significant differences in SRM for MPA and VPA among cut-points, but these diminished when examining SRM values for MVPA. The Heil 2R cut-points had a significantly lower SRM value than the other cut-points for MVPA for both epoch lengths. Second, there were no significant differences in SRM values for any of the PA intensities when comparing between the 15- and 30-s epochs.

SRM values for the ActiGraph are shown in Table 5. The SRM values were at or above 1.1 for all cut-points, at all PA intensities, and for all epochs, indicating high responsiveness to change in PA for the ActiGraph. As with the Actical, two types of comparisons were made for the ActiGraph: 1) comparison among cut-points for each epoch length and 2) comparisons among the 5-, 15-, and 30-s epoch lengths for each set of cut-points. First, no significant differences were observed for responsiveness to changes in SED. The Puyau cut-points had higher responsiveness for change in LPA than the other cut-points for the 5-s epoch but not for the 15- or 30-s epochs. There were some significant differences for MPA and VPA, although in most cases a significantly lower SRM for MPA corresponded to a significantly higher SRM for VPA for a given set of cut-points (as one would expect). Only one significant difference was detected for MVPA, with the Evenson cut-points being slightly more responsive than the Puyau cut-points for the 30-s epoch. Second, when examining potential differences among epoch lengths, the 5-s epoch had significantly higher SRM values for MVPA than the 15-s or 30-s epochs (for all cut-points). There were some minor differences in SRM values for other PA intensities, but these are sporadic and inconsistent among cut-points. There were no significant differences in SRM values for SED, LPA, MPA, or MVPA between the 15- and 30-s epochs. The only statistically significant difference between epochs was that the SRM for VPA with the Puyau cut-points was significantly higher with the 15-s epoch than with the 30-s epoch.

DISCUSSION

The ability to detect change in PA is important in many different situations, particularly in PA interventions. Although accelerometers are frequently used to measure PA before, during, and after an intervention, little research has assessed the responsiveness of accelerometry to detect changes in PA in youth. The current study addressed this issue by measuring the responsiveness to change of the Actical and ActiGraph accelerometers. Previous research has shown that epoch length (McClain, et al., 2008; Ressel, 2003) and choice of cut-points (Trost, Loprinzi, Moore, & Pfeiffer, 2011) can significantly alter predictions of PA. Thus, multiple epoch lengths and cut-points were used in this study to determine whether either of these variables affected the responsiveness to change of accelerometry.

The most significant finding from this study is that we observed high responsiveness to change for both accelerometers at all PA intensities, cut-points, and epoch lengths in a large sample of children and adolescents. Even with LPA, which had the smallest difference in time between the low- and high-intensity visits (4.4 min/hr), both accelerometers had SRM values above 0.8 (1.3–1.8 for Actical and 1.2–1.4 for ActiGraph) for detecting this difference, indicating high responsiveness to change for small changes in PA.

Due to known differences in the accuracy of different cut-points for measurement of PA (Trost, et al., 2011), it would seem that frequent activity intensity misclassification with certain cut-points would diminish an accelerometer’s responsiveness to change. However, our results show that responsiveness to change was only minimally affected at certain intensities by choice of cut-points. These results illustrate the robustness of accelerometers for detecting small changes in PA. Given the wide selection of cut-points used with the Actical and ActiGraph accelerometers, the robustness of these accelerometers for detecting change in PA is encouraging. Please note that our results do not provide insight into which of the cut-points tested have the highest measurement accuracy; rather, our results show that all cut-points tested provide high responsiveness to changes in PA.

Second, due to the sporadic nature of children’s activity (Bailey, et al., 1995), we expected that shorter epoch lengths would be more responsive to changes in PA than longer epoch lengths. For the ActiGraph, we did find significantly higher SRM values for MVPA when we used 5-s epochs compared to 15-s and 30-s epochs. However, no other PA intensity was significantly impacted by epoch length, and there were no consistent differences in SRM values between 15-s and 30-s epochs. The lack of differences between the 15-s and 30-s epochs was surprising given the findings by McClain et al., who reported that shorter epoch lengths in children yield better measurement accuracy and intensity classification than longer epochs (McClain, et al., 2008). Thus, our findings indicate that although estimates of PA may be more accurate with decreasing epoch length, there is a possible threshold effect of epoch length and accelerometer responsiveness.

Using accelerometry to evaluate the effectiveness of PA interventions in children is relatively new; most interventions conducted before 2006 using questionnaires or pedometers to obtain PA data (Dobbins, De Corby, Robeson, Husson, & Tirilis, 2009). Kriemler’s review identified several recent school-based interventions that used accelerometers to assess PA. These studies reported changes of 4.3–15.4 min/day for MPA and 0.0–7.8 min/day for VPA, with the majority of the change occurring during the intervention time (Kriemler, et al., 2011). The results of the current study indicate that the Actical and ActiGraph have high responsiveness to change when changes in PA were 6.6

and 8.9 min for LPA and MPA, respectively, providing evidence that accelerometers can detect changes in PA similar to those observed in interventions. Also, while the increase in VPA in the current study (12.3 min) was slightly higher than changes reported from recent interventions, it seems likely that responsiveness for detecting smaller changes in VPA will still be high given the high responsiveness observed with smaller changes seen in the other PA intensities. In other words, our findings illustrate that previous interventions using the Actical and ActiGraph accelerometers were using measurement tools that can accurately detect changes in PA. These results should give users of the Actical and ActiGraph accelerometers confidence that they will be able to determine if interventions are actually successful in changing PA patterns.

Moreover, as accelerometers have gained acceptance for use in interventions, they have often been used alongside other measures such as questionnaires for assessing PA. When both measures yield similar findings, it strengthens the findings of these studies. However, several interventions show conflicting results when using different PA measures (Caballero, et al., 2003; Haerens, et al., 2007). In circumstances like these, it can be difficult to decide which measure upon which to rely. The findings from our study indicate the utility of accelerometers for detecting changes in PA that may occur with interventions. Additionally, our findings support the use of accelerometers rather than questionnaires for determining changes in PA that may occur during and/or after intervention in children and adolescents.

Study Strengths and Limitations

This study has several notable strengths. First, a large sample and wide age range of participants were recruited from two different regions of the country, enhancing the generalizability of our findings. These participants engaged in a wide variety of structured and unstructured activities ranging from sedentary to vigorous intensities. Additionally, activities were performed in a field-based setting, allowing participants much more freedom to choose their activities. These two conditions enhance the generalizability and applicability of the study. Moreover, DO, a criterion measure of PA (Sirard & Pate, 2001), was used to confirm the difference in PA between the low- and high-intensity visits.

This study also had several limitations that should be considered. First, although our sample was relatively large and included a wide age range (6–16 years old), our results may not be applicable to older or younger pediatric populations or populations with different demographics (race, weight status, etc.) than our population. Second, DO was not conducted during sedentary time because participants were instructed to remain seated during this time. For the purpose of data analysis, it was assumed that this time was all classified as SED. The investigators were proactive about ensuring that participants remained seated, but it is possible that some participants may have moved around slightly during these sedentary-activity times. This condition likely had minimal impact on time spent in SED. Third, the low- and high-intensity visits elicited fairly large changes in time spent in each PA intensity (6.6–28.8 min), and it was not possible to determine if accelerometers are responsive to smaller changes in PA than 6.6 min. Finally, because typical interventions are less controlled than our simulation, responsiveness to change could be lower in true intervention settings.

Conclusions

In summary, this study serves as a first step in confirming that both the Actical and ActiGraph accelerometers are responsive to changes in PA. Since accelerometer use has dramatically increased in recent years in observational and intervention studies, it is important to confirm that accelerometry can be used to accurately and reliably detect changes/differences in PA. We have shown that the Actical and ActiGraph accelerometers have high responsiveness to change in PA during a simulated after-school program in school-age children. Additionally, we have shown the robustness of accelerometers for detecting change in PA, regardless of cut-point selection. It appears that shorter epoch lengths (i.e., 5-s) may be most responsive to changes in MVPA, but all epoch lengths showed high responsiveness to change in PA across all intensities, again illustrating the robustness of accelerometry for detecting meaningful change in PA. These findings provide strong evidence that both accelerometers can be used effectively for assessing the effectiveness of after-school and other structured programs for increasing PA in youth.

References

Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: An observational study. Medicine and Science in Sports and Exercise. 1995; 27(7):1033–1041. [PubMed: 7564970]

Bonomi AG, Goris AH, Yin B, Westerterp KR. Detection of type, duration, and intensity of physical activity using an accelerometer. Medicine and Science in Sports and Exercise. 2009; 41(9):1770–1777. [PubMed: 19657292]

Boreham C, Riddoch C. The physical activity, fitness and health of children. Journal of Sports Sciences. 2001; 19(12):915–929. [PubMed: 11820686]

Caballero B, Clay T, Davis SM, Ethelbah B, Rock BH, Lohman T, Stevens J. Pathways: A school-based, randomized controlled trial for the prevention of obesity in American Indian schoolchildren. American Journal of Clinical Nutrition. 2003; 78(5):1030–1038. [PubMed: 14594792]

Cohen, J. Statistical power analysis for the behavioral sciences. New York, NY: Academic Press; 1977.

Colley RC, Garriguet D, Janssen I, Wong SL, Saunders TJ, Carson V, Tremblay MS. The association between accelerometer-measured patterns of sedentary time and health risk in children and youth: Results from the Canadian Health Measures Survey. BMC Public Health. 2013; 13:200. [PubMed: 23497190]

Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. Journal of Applied Physiology. 2008; 105(3):977–987. [PubMed: 18635884]

Dobbins M, De Corby K, Robeson P, Husson H, Tirilis D. School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6–18. Cochrane Database of Systematic Reviews. 2009; (1):CD007651. [PubMed: 19160341]

Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences. 2008; 26(14):1557–1565. [PubMed: 18949660]

Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Medicine and Science in Sports and Exercise. 2005; 37(11 Suppl):S523–530. [PubMed: 16294115]

Godfrey A, Conway R, Meagher D, Olaighin G. Direct measurement of human movement by accelerometry. Medical Engineering & Physics. 2008; 30(10):1364–1386. [PubMed: 18996729]

Haerens L, De Bourdeaudhuij I, Maes L, Cardon G, Deforche B. School-based randomized controlled trial of a physical activity intervention among adolescents. The Journal of Adolescent Health. 2007; 40(3):258–265. [PubMed: 17321427]

Hart TL, Ainsworth BE, Tudor-Locke C. Objective and subjective measures of sedentary behavior and physical activity. Medicine and Science in Sports and Exercise. 2011; 43(3):449–456. [PubMed: 20631642]

Heil DP. Predicting activity energy expenditure using the Actical activity monitor. Research Quarterly for Exercise and Sport. 2006; 77(1):64–80. [PubMed: 16646354]

Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS. Validation of wearable monitors for assessing sedentary behavior. Medicine and Science in Sports and Exercise. 2011; 43(8):1561–1567. [PubMed: 21233777]

Kriemler S, Meyer U, Martin E, van Sluijs EM, Andersen LB, Martin BW. Effect of school-based interventions on physical activity and fitness in children and adolescents: A review of reviews and systematic update. British Journal of Sports Medicine. 2011; 45(11):923–930. [PubMed: 21836176]

Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R, Johnson CL. CDC growth charts: United States. Advance Data. 2000; (314):1–27. [PubMed: 11183293]

Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. Medicine and Science in Sports and Exercise. 2012; 44(11): 2243–2252. [PubMed: 22648343]

Malina, RM. Anthropometry. In: Maud, P.; Foster, C., editors. Physiological assessment of human fitness. Champaign, IL: Human Kinetics; 1995. p. 205-219.

McClain JJ, Abraham TL, Brusseau TA Jr, Tudor-Locke C. Epoch length and accelerometer outputs in children: Comparison to direct observation. Medicine and Science in Sports and Exercise. 2008; 40(12):2080–2087. [PubMed: 18981941]

Meiorin S, Pistorio A, Ravelli A, Iusan SM, Filocamo G, Trail L, Ruperto N. Validation of the Childhood Health Assessment Questionnaire in active juvenile systemic lupus erythematosus. Arthritis and Rheumatism. 2008; 59(8):1112–1119. [PubMed: 18668598]

Pfeiffer KA, McIver KL, Dowda M, Almeida MJ, Pate RR. Validation and calibration of the Actical accelerometer in preschool children. Medicine and Science in Sports and Exercise. 2006; 38(1): 152–157. [PubMed: 16394968]

Puhl J, Greaves K, Hoyt M, Baranowski T. Children's Activity Rating Scale (CARS): Description and calibration. Research Quarterly for Exercise and Sport. 1990; 61(1):26–36. [PubMed: 2091164]

Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. Obesity Research. 2002; 10(3):150–157. [PubMed: 11886937]

Ressel GW. AHA releases scientific statement on cardiovascular health in childhood. American Heart Association. American Family Physician. 2003; 67(3):645–646. [PubMed: 12588082]

Robusto KM, Trost SG. Comparison of three generations of ActiGraph activity monitors in children and adolescents. Journal of Sports Sciences. 2012; 30(13):1429–1435. [PubMed: 22857599]

Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. Journal of Science and Medicine in Sport. 2011; 14(5):411–416. [PubMed: 21616714]

Sirard JR, Pate RR. Physical activity assessment in children and adolescents. Sports Medicine. 2001; 31(6):439–454. [PubMed: 11394563]

Sothern MS, Loftin M, Suskind RM, Udall JN, Blecker U. The health benefits of physical activity in children and adolescents: Implications for chronic disease prevention. European Journal of Pediatrics. 1999; 158(4):271–274. [PubMed: 10206121]

Steele RM, van Sluijs EM, Cassidy A, Griffin SJ, Ekelund U. Targeting sedentary time or moderate- and vigorous-intensity activity: Independent relations with adiposity in a population-based sample of 10-y-old British children. American Journal of Clinical Nutrition. 2009; 90(5):1185–1192. [PubMed: 19776141]

Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, Pate R. Defining accelerometer thresholds for activity intensities in adolescent girls. Medicine and Science in Sports and Exercise. 2004; 36(7):1259–1266. [PubMed: 15235335]

Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Medicine and Science in Sports and Exercise. 2011; 43(7):1360–1368. [PubMed: 21131873] van der Zee CH, Kap A, Rambaran Mishre R, Schouten EJ, Post MW. Responsiveness of four participation measures to changes during and after outpatient rehabilitation. Journal of Rehabilitation Medicine. 2011; 43(11):1003–1009. [PubMed: 22031346]

Welk, GJ. Use of accelerometry-based activity monitors to assess physical activity. In: Welk, GJ., editor. Physical activity assessments for health-related research. Champaign, IL: Human Kinetics; 2002. p. 125-142.

Table 1

Summary of the two visits completed by participants.

	Low-intensity visit	High-intensity visit
Order of activities	Snack time (15 min)* Structured activity (20 min) Homework/rest (20 min)* Unstructured activity (20 min) Watching a movie (15 min)*	Snack time (15 min)* Structured activity (30 min) Homework/rest (15 min)* Unstructured activity (30 min)
Total activity time	40 min (20 min structured, 20 min unstructured)	60 min (30 min structured, 30 min unstructured)
Activity type	Light-to-moderate	Moderate-to-vigorous
Activity examples	Bowling, catch	Tag, basketball
Total observation time in each visit	4 children @ 10 min each Total of 40 min	6 children @ 10 min each Total of 60 min
Total duration of visit	90 min	90 min

* indicates that direct observation (DO) was not performed during these times. All time during these activities was coded as sedentary in the analysis.

Table 2

Descriptive statistics of participants.

	Total (n=208)	Girls (n=102)	Boys (n=106)
Age (years)	11.0 (2.7)	11.1 (2.7)	11.0 (2.7)
Height (cm)	146.6 (16.3)	146.0 (15.6)	147.3 (17.0)
Weight (kg)	43.9 (17.4)	43.3 (15.6)	44.5 (19.1)
BMI ($kg \cdot m^{-2}$)	19.4 (4.3)	19.4 (4.0)	19.5 (4.5)

Values are expressed as mean (SD).

Table 3

Time (min) in each PA intensity, as detected by CARS, in low- and high-intensity visits.

	Low-intensity visit	High-intensity visit	Difference between low-and high-intensity visits (min)	Difference in min/hr
SED	69.6 (10.4)	40.8 (8.6)[a]	− 28.8 (7.9)	−19.2 (5.3)
LPA	15.9 (5.3)	22.5 (7.4)[a]	+ 6.6 (6.6)	+4.4 (4.4)
MPA	0.8 (0.9)	9.7 (5.3)[a]	+ 8.9 (4.7)	+5.9 (3.1)
VPA	0.6 (0.7)	12.9 (4.3)[a]	+ 12.3 (4.0)	+8.2 (2.7)
MVPA	1.3 (1.2)	22.6 (7.7)[a]	+ 21.3 (5.5)	+14.2 (3.7)

Values for total counts expressed as mean (SD).

[a]indicates significant difference from low-intensity visit ($p < .05$).

Table 4

SRM values for Actical at 15-s and 30-s epochs.

		Puyau	Heil 1R	Heil 2R	Evenson
15-s epoch	SED	2.1 (1.9–2.3)	2.1 (1.9–2.3)	2.1 (1.9–2.3)	2.1 (1.9–2.3)
	LPA	1.6 (1.4–1.7)[c]	1.5 (1.3–1.7)	1.3 (1.1–1.5)[a]	1.4 (1.2–1.6)
	MPA	3.0 (2.8–3.2)[b,c,d]	1.9 (1.7–2.1)[a,d]	1.8 (1.6–2.0)[a,d]	1.2 (1.1–1.4)[a,b,c]
	VPA	2.1 (1.9–2.3)[b,c,d]	2.6 (2.4–2.8)[a,d]	2.4 (2.2–2.6)[a,d]	4.1 (3.9–4.2)[a,b,c]
	MVPA	4.5 (4.3–4.7)[c]	4.4 (4.2–4.6)[c]	3.7 (3.5–3.9)[a,b,d]	4.6 (4.4–4.8)[c]
30-s epoch	SED	2.1 (1.9–2.3)	2.1 (1.9–2.3)	2.0 (1.9–2.2)	2.1 (1.9–2.3)
	LPA	1.8 (1.6–2.0)[c]	1.7 (1.5–1.9)[c]	1.4 (1.2–1.6)[a,b,d]	1.7 (1.5–1.9)[c]
	MPA	3.2 (3.0–3.4)[b,c,d]	2.0 (1.9–2.2)[a,d]	1.9 (1.7–2.1)[a,d]	1.4 (1.1–1.6)[a,b,c]
	VPA	1.8 (1.6–1.9)[b,c,d]	2.3 (2.1–2.4)[a,d]	2.1 (1.9–2.3)[a,d]	3.8 (3.7–4.0)[a,b,c]
	MVPA	4.7 (4.5–4.9)[b,c]	4.4 (4.3–4.6)[a,c,d]	3.5 (3.3–3.6)[a,b,d]	4.7 (4.5–4.9)[b,c]

[a] indicates significant difference from Puyau cut-points.

[b] indicates significant difference from Heil 1R cut-points.

[c] indicates significant difference from Heil 2R cut-points.

[d] indicates significant difference from Evenson cut-points.

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Table 5

SRM values for ActGraph at 5-s, 15-s, and 30-s epochs.

		Freedson	Puyau	Treuth	Evenson
5-s epoch	SED	2.0 (1.8–2.2)	2.0 (1.8–2.2)	2.0 (1.9–2.2)	2.0 (1.9–2.2)
	LPA	1.3 (1.1–1.5)[f]	1.6 (1.4–1.7)[e,g,h]	1.3 (1.1–1.5)[f]	1.3 (1.1–1.5)[f]
	MPA	2.0 (1.9–2.2)[f,g]	3.0 (2.7–3.2)[e,g,h]	2.4 (2.3–2.6)[e,f,h]	1.8 (1.6–2.0)[f,g]
	VPA	2.8 (2.6–3.0)[f]	2.3 (2.1–2.5)[e,g,h]	2.7 (2.6–2.9)[f]	2.8 (2.7–3.0)[f]
	MVPA	3.5 (3.4–3.7)	3.4 (3.1–3.7)	3.4 (3.2–3.6)[h]	3.7 (3.4–3.9)[g]
15-s epoch	SED	2.0 (1.8–2.2)	2.1 (1.9–2.2)	2.0 (1.8–2.2)	2.0 (1.8–2.2)
	LPA	1.3 (1.1–1.5)	1.3 (1.1–1.5)	1.4 (1.2–1.6)	1.3 (1.1–1.5)
	MPA	1.8 (1.6–1.9)[f,g]	2.8 (2.6–3.0)[e,g,h]	2.1 (1.9–2.2)[e,f,h]	1.6 (1.4–1.8)[f,g]
	VPA	2.8 (2.6–3.1)[f]	1.6 (1.4–1.8)[e,g,h]	2.9 (2.7–3.1)[f]	3.1 (2.9–3.2)[f]
	MVPA	3.2 (3.0–3.3)	3.0 (2.8–3.2)[h]	3.1 (2.9–3.3)	3.3 (3.1–3.5)[f]
30-s epoch	SED	2.0 (1.8–2.2)	2.1 (1.9–2.3)	2.0 (1.8–2.3)	2.0 (1.8–2.2)
	LPA	1.3 (1.1–1.5)	1.2 (1.0–1.4)	1.3 (1.1–1.5)	1.3 (1.1–1.5)
	MPA	1.9 (1.7–2.0)[f]	2.9 (2.7–3.0)[e,g,h]	2.1 (1.9–2.3)[f,h]	1.8 (1.6–1.9)[f,g]
	VPA	2.6 (2.4–2.8)[f,h]	1.1 (0.9–1.3)[e,g,h]	2.7 (2.5–2.9)[f]	2.9 (2.7–3.1)[e,f]
	MVPA	3.1 (2.9–3.3)	3.0 (2.8–3.1)[h]	3.1 (2.9–3.2)	3.2 (3.1–3.4)[f]

[e] indicates significant difference from Freedson cut-points.

[f] indicates significant difference from Puyau cut-points.

[g] indicates significant difference from Treuth cut-points.

[h] indicates significant difference from Evenson cut-points.