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Surveillance of Youth Physical Activity and Sedentary Behavior With Wrist Accelerometry

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Abstract

Introduction—Accurate tracking of physical activity (PA) and sedentary behavior (SB) is important to advance public health, but little is known about how to interpret wrist-worn accelerometer data. This study compares youth estimates of SB and moderate to vigorous PA (MVPA) obtained using raw and count-based processing methods.

Methods—Data were collected between April and October 2014 for the National Cancer Institute's Family Life, Activity, Sun, Health, and Eating Study: a cross-sectional Internet-based study of youth/family cancer prevention behaviors. A subsample of 628 adolescents (aged 12–17 years) wore the ActiGraph GT3X+ on the wrist for 7 days. In 2015–2016, SB and MVPA time were calculated from raw data using R-package GGIR and from activity counts data using published cutpoints (Crouter and Chandler). Estimates were compared across age, sex, and weight status to examine the impact of processing methods on behavioral outcomes.

Results—ActiGraph data were available for 408 participants. Large differences in SB and MVPA time were observed between processing methods, but age and gender patterns were similar. Younger children (aged 12–14 years) had lower sedentary time and greater MVPA time (*p*-values <0.05) than older children (aged 15–17 years), consistent across methods. The proportion of youth with ≥60minutes of MVPA/day was highest with the Crouter methods (~50%) and lowest with GGIR (~0%).

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Conclusions—Conclusions about youth PA and SB are influenced by the wrist-worn accelerometer data processing method. Efforts to harmonize processing methods are needed to promote standardization and facilitate reporting of monitor-based PA data.

INTRODUCTION

The promotion of physical activity (PA) in children and adolescents is an important public health priority.[1] An established body of literature specifically indicates that regular participation in MVPA can lead to improvements in physical fitness, metabolic risk profiles, bone health, and mental health as well as reductions in body fatness.[2] Another public health consideration is minimizing youth sedentary behavior (SB), which is considered independent from PA.[3] Evidence indicates that children and adolescents spend approximately 7 hours/day being sedentary.[4, 5] Moreover, excessive time spent sedentary is associated with adverse cardiometabolic health profiles[6–8] and with decreased fitness[9] in youth.

Research on youth PA patterns and behavior has emphasized the use of accelerometry-based activity monitors owing to their ability to quantify the amount and temporal patterns of movement. However, efforts to utilize these monitors for surveillance applications have been hampered by lack of consensus on data processing methods and inherent limitations of accelerometer data as an indicator of behavior.[10] The challenges have been further compounded by the variability in PA outcomes due to the use of different devices, monitoring locations, and processing methods. Historically, the hip has been a primary attachment site for research using accelerometry-based devices. However, recent epidemiology studies (e.g., National Health and Nutrition Examination Survey, UK Biobank) have chosen to use wrist-worn monitors due, in part, to improved wear compliance of participants.[11] Emphasis in recent years has also been placed on processing of raw accelerometer data rather than monitor-specific "movement counts" with the goal of improving accuracy of assessment as well as comparability across monitors.[10] Methods have been proposed to process raw acceleration[12] and activity count data[13, 14] from wrist-worn accelerometers for youth. Given that the use of different processing methods can lead to different conclusions about youth activity levels (and relations to health), it is essential to clearly understand the potential implications of using one method over the other on activity outcomes in youth surveillance research. Therefore, the purpose of this study was to evaluate youth PA and SB using different wrist processing techniques, and to examine the impact of alternative methods on activity patterns by gender, age group, and weight status.

METHODS

Study Design

Data were collected between April and October 2014 as part of the National Cancer Institute's Family Life, Activity, Sun, Health, and Eating (FLASHE) Study: a cross-sectional, Internet-based surveillance study of youth/family behaviors related to cancer prevention. Additional details on the methodology of FLASHE are reported in this journal issue.[15, 16] Briefly, parent participants were recruited from the Ipsos Consumer Opinion Panel. Eligibility criteria included being aged ≥18 years and living with at least one child aged 12–17 years for at least 50% of the time; one eligible adolescent from the household was randomly chosen. Using balancing techniques, the selected sample for screening was balanced on: sex of the panel member, Census division, household income, household size, and race/ethnicity. FLASHE participants were randomly selected to participate in the Survey-Only group or the Survey + Motion Study group. Youth in this latter group were asked to wear an ActiGraph GT3X+ on their dominant wrist for 24 hours over 7 days. The ActiGraph, along with specific instructions on the device's appropriate use, was mailed to each participant. Each adolescent provided signed assent, and their parent or guardian provided signed informed consent before participation. The FLASHE Study was reviewed and approved by the U.S. Government's Office of Management and Budget, National Cancer Institute's Special Studies IRB, and Westat's IRB. Data were collected between April and October 2014. Height and weight were self-reported by the adolescents. Weight status was defined according to the Centers for Disease Control and Prevention growth charts (5th 85th percentile being normal weight, ≥85th percentile being overweight/obese).[17] Age was dichotomized: 12–14 years or 15–17 years.

Data Management

Raw ActiGraph accelerometer files were downloaded and then converted to 5-second epoch count data using the ActiLife software, version 5.0. Non-wear time periods captured with the algorithms of Choi et al.[18] and sleep time (10:00PM 6:00AM) were removed from both raw and count data for direct comparison. As data were collected across several time zones, the authors took into account time zone differences when processing data to standardize waking hours. The procedures for each data processing method are described below.

Raw accelerometer data—Raw acceleration data (collected at 100 Hz) were processed using the R-package GGIR, which is designed for processing multiday raw accelerometer data.[19] GGIR consists of two major processing components: Part 1 and Part 2. Part 1 generates an epoch-specific acceleration summary variable, called Euclidian Norm Minus One, which is calculated by subtracting the gravitational force from the vector magnitude of the three axis. Part 2 produces only "daily-level summary" files based on the acceleration summary data generated from Part 1. The daily summaries in Part 2 are generated using the intensity-specific milli-g cutpoints from Hildebrand and colleagues'[20] regression equations. However, these cutpoints only estimate minutes of moderate (3 METs) and vigorous (6 METs) PA, and are therefore unable to classify SB. Moreover, given that children have higher resting metabolic rates, the use of standard METs (i.e., 3.5 mL/kg/minute) needs to be adjusted to capture these differences.[21] For instance, METs <2 and >4 can provide more-accurate classifications of children's SB and MVPA, respectively.[22] Therefore, instead of using Part 2, the authors first derived milli-g cutpoints for SB (2 METs) and MVPA (4 METs) using the regression equations of Hildebrand et al.[20] (Appendix Table 1). Those cutpoints were then applied to the acceleration data (generated from Part 1) to obtain sedentary and MVPA time for every 5 seconds. This customized procedure was undertaken in Stata/SE, version 12 (syntax available upon request), and the authors verified that daily-level MVPA estimates from this procedure were identical to those from Part 2 of GGIR.

Activity counts data—Intensity-specific time estimates were determined using two sets of cut points: one developed by Crouter and colleagues,[23] and one developed by Chandler et al.[13] Each series of cutpoints included two separate sets of thresholds: one for vertical axis (VA) activity counts and one for vector magnitude (VM). The Crouter equations for VA counts assume 1.0 MET when aggregated 5-second VA counts are ≤35; otherwise, MET=1.592 + (0.0039 × VA counts/5 seconds). The Crouter equations for VM assume 1.0 MET when aggregated 5-second VM values are ≤100; otherwise, MET=1.475 + (0.0025 × VM/5 seconds). Crouter and colleagues[23] adjusted MET values for resting metabolic rates in deriving cutpoints, so no additional adjustments were made (i.e., 1.5 METs for SB, 3 METs for MVPA).

Chandler et al.[13] used receiver operating characteristic curve analyses to derive cutpoints for VA and VM, requiring no additional adjustments for METs. The cutpoints for the five processing techniques are presented in Appendix 1. The 5-second cutpoints were applied to 5-second epoch data, which were then collapsed into 1-minute epoch data. The Crouter methods using VA counts and VM will be referred to as CrouterVA and CrouterVM, respectively, hereafter. The Chandler methods using VA counts and VM will be referred to as ChandlerVA and ChandlerVM, respectively.

Statistical Analysis

In 2015–2016, ANOVA tests with Bonferroni adjustments for pairwise comparisons were run to investigate differences in sedentary time or MVPA time: (1) among the GGIR, Crouter, and Chandler methods; and (2) among levels of gender, age groups, and weight status for each processing technique. Two interactions terms (gender X age groups; gender X weight status) were included in each ANOVA. Equivalence testing was performed to investigate equivalence between methods using VA versus VM; 90% CIs of the VM methods were compared against equivalence regions defined as ±10% of the mean of the VA methods. The proportions of youth with ≥60 minutes of MVPA/day were compared across the three demographic variables.

RESULTS

Of a total of 628 ActiGraph data files that were received, 126 cases were excluded for the following reasons: no activity counts recorded (n=14), system errors from GGIR (n=2), or participants with no demographic information (n=110). From the remaining 502 participants in the data set, 94 additional participants were removed that did not wear the device for ≥10 hours/day on ≥4 monitoring days. The final data set used herein included 408 participants. The average number of valid days was 6.7, and the average daily wear time was 15.5 hours/day for all processing methods. There were 205 boys and 203 girls in the final data set. Participant characteristics are summarized in Table 1.

Table 2 presents estimates of SB and MVPA time for all participants and for each demographic variable for each method. Pairwise tests of significant differences are highlighted in the table but focus of the evaluation was on the variability among the methods. Estimates of SB were highest with the Chandler methods (range, 651.6–708.9 minutes/day), followed by the GGIR method (range, 635.6–657.1 minutes/day) and the

Crouter methods (range, 518.6–576.4 minutes/day). Estimates of MVPA followed an opposite pattern, with estimates being considerably higher from the Crouter methods (range, 100.0–134.4 minutes/day) than the Chandler methods (range, 46.6–73.3 minutes/day). GGIR yielded much lower estimates of MVPA, with values ranging from 8.0 to 12.8 minutes/day. It is important to also note the two VM methods yielded consistently higher estimates than the two VA methods. Equivalence tests showed that the VA and VM estimates lacked equivalence for both the Crouter and Chandler methods.

Few significant differences were found among gender, age, and weight status groups, and these patterns were generally consistent across methods. A significant age main effect was detected with all methods (i.e., *p*-values <0.05) with younger children having lower SB than older children. Significant gender X age interaction terms were found with the four count-based approaches (all *p*-values <0.05), but not with GGIR. In all cases, the age-related difference in SB was larger in boys than girls but the same pattern was evident (Appendix Figure 1). Interestingly, no significant differences were detected for gender and weight status main effects.

No significant differences in MVPA were found between boys and girls with the four count-based methods. However, significant differences were found for the age group and gender X age group interactions. There were clear age-related differences in levels of MVPA across methods. However, the plots of the interactions show consistently larger age-related differences in MVPA for boys than girls (Appendix Figure 2). The gender main effect with GGIR was significant, with greater MVPA time for boys (12.8 [SE=0.8] minutes/day) than girls (8.0 [SE=0.8] minutes/day). Similar to SB, there were non-significant differences in MVPA by weight status.

The proportion of youth who spent ≥60 minutes of MVPA/day varied considerably among methods (Table 3). With the GGIR method, 0% of youth were found to achieve the ≥60-minute target of MVPA, regardless of age, gender, or weight status. The proportions of children with ≥60 minutes of MVPA/day with the Crouter methods were substantially higher (range, 43.5%–69.0%) than those as assessed with the Chandler methods (range, 6.2% 23.2%). With the four count-based methods, the proportions of youth with ≥60 minutes of MVPA/day were higher for children aged 12–14 years than those aged 15–17 years, and higher for normal weight than for overweight/obese children. The proportions were consistently higher with the two VM methods than with the two respective VA methods.

DISCUSSION

This study evaluates the variability in estimates of PA and SB with emerging wrist-worn accelerometer data processing techniques and highlights that conclusions regarding youth behavioral patterns may depend upon the chosen processing method. Specifically, the authors explored differences in SB and MVPA outcomes when wrist-worn ActiGraph data are processed with either raw or count-based methods. The results revealed large differences in estimates of SB and MVPA with nearly tenfold differences evident in the estimated daily amounts of MVPA between the Crouter methods and GGIR method. The substantial differences (particularly, between counts and raw data) are attributable to the specific cutpoints used to classify intensities. For example, it may be that the true MVPA time is underestimated with the cutpoints used for GGIR whereas it is overestimated with the cutpoints used for counts data, but this information cannot be directly verified given the lack of criterion measures. It is important for future work to directly evaluate the validity of the different methods along with their corresponding cutpoints relative to gold standard methods.

A second goal in the analyses was to examine the impact of processing methods on activity patterns across different demographic subsamples. The relatively large differences in activity outcomes by age ranges identified herein are consistent with those reported in prior research that used hip-worn accelerometers. Specifically, a systematic review by Pate and colleagues[3] concluded that sedentary time as assessed with hip-worn accelerometers was higher in older children than in younger children. Using National Health and Nutrition Examination Survey data, Belcher et al.[24] also found higher SB as well as lower MVPA in older versus younger children: similar results for overweight/obese versus normal weight children, and for girls versus boys. A recent study by Cooper and colleagues[25] also identified a clear pattern of more sedentary time and less MVPA with increasing age using hip-worn ActiGraph data pooled from 27,637 children aged 2.8–18.4 years. In addition to the variation by age, Cooper et al.[25] found considerably higher MVPA time and prevalence of meeting the PA Guidelines in boys than in girls, with similar trends showing higher activity levels in normal weight children than in heavier children.

Interestingly, the authors observed negligible differences between boys and girls (except for MVPA from GGIR), and between normal-weight and overweight/obese children for both SB and MVPA. This observation contrasts with previous research that has found higher activity levels in boys versus girls[26, 27] and in normal-weight versus overweight/obese children.[28, 24, 25, 29] A potential explanation for this discrepancy is that the true activity levels of the participants did not vary by gender and weight status (due to sampling or response bias). However, it is possible that the wrist position masks gender differences that have previously been reported with other studies using hip-worn monitors. The three original studies[13, 20, 14] that reported on the five methods used herein did not include any demographic indicators (i.e., gender, age, or BMI) as predictors in their equations or cutpoints. Thus, it is possible that this feature may have made the methods insensitive to identifying variation of activity by gender or weight status. All five methods revealed variation by age groups but the direction of differences by age and weight status was not consistent across the five processing methods. It is not possible to explain the nature or causes of the wide disparities in methods but researchers and public health leaders should be aware that different wrist methods may yield disparate conclusions about youth activity behavior when examining age and gender patterns.

The lack of agreement in the methods for estimating youth activity profiles is a continued concern for evaluating PA and SB outcomes with accelerometry-based monitors. In addition to differences between raw and count-based approaches, this study also confirmed that estimates of MVPA based on VA and VM cannot be used interchangeably as comparisons showed lack of equivalence for both the Chandler and Crouter methods. The VM methods tended to yield higher estimates of MVPA and higher percentages of youth meeting the recommended level in the PA Guidelines. Previous studies evaluating hip-worn ActiGgraph relative to criterion measures in children found that methods using VM performed better than methods using VA.[30–32] So, emphasis in future studies should be on the use of VM to promote better standardization of outcomes. However, the large differences between the two VM methods (and with the raw GGIR method) still document the problems associated with drawing inferences about activity levels from wrist monitors for population surveillance.

Several studies have provided insights into the differences in outcomes between wrist and hip-worn monitors. For example, studies have compared raw data versus counts data both from hip-worn GT3X+ and its comparison with wrist-worn GENEActiv,[33] and hip versus wrist placement using counts data from the GT3X+.[34] Fairclough and colleagues[33] found substantially higher MVPA time when hip-worn GT3X+ data were processed using counts cutpoints developed by Evenson et al.[35] (i.e., 72 minutes/day) as opposed to GGIR (i.e., 50 minutes/day), findings which are consistent with the magnitude/direction of differences in the present study. Calibration/cross-validation research by Trost and colleagues[34] showed that machine learning techniques for hip (91%) and wrist placement (88%) exhibited similar accuracy in classifying seven different classes types of activities in 52 children. Greater attention to validating various processing methods for hip and wrist relative to strong criterion measures may inform epidemiologic studies in determining not only youth activity patterns but also their relationships with health indicators.

Limitations

This study has some limitations that should be considered when interpreting the results. First, none of the methods has been cross-validated in independent studies so it is impossible to determine which processing technique is more accurate than the other based on the present data set. Second, participants were recruited from a consumer opinion panel. Thus, although balancing techniques were used, it is not a nationally representative sample, which may limit generalizability. However, as the goal was not to provide normative data in youth, this is less of a concern. Also, the age range of the study that proposed GGIR (7–11 years) is lower than that of the current study (12–17 years). It is possible that cutpoints would be different for older adolescents but it is not clear how they would vary without further evaluation. Another limitation is that height and weight were self-reported by the participants. Moreover, the authors had to make an assumption that every participant slept between 10:00PM and 6:00AM given the lack of sleep log data.

CONCLUSIONS

Overall, use of different processing methods resulted in substantially large differences in estimates of both SB and MVPA with particularly large differences between raw data and count-based methods. When examining the data by subgroup, younger children spent less sedentary time and more MVPA time compared with older children, but no sizable differences were observed between boys and girls, and between normal-weight and overweight/obese children. Conclusions about youth activity patterns from accelerometry-based monitors are directly dependent on the type of data being processed (i.e., raw versus counts) as well as the processing algorithms used to reduce the data. Researchers using wrist-worn accelerometry should take this into consideration in designing/implementing/evaluating studies aimed at understanding complex underlying nature of youth behavioral patterns and its relationship with health indicators. Moreover, efforts to harmonize various processing methods are needed to directly compare youth activity levels across different studies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

YK conceptualized the study idea, performed data management and data analysis, and drafted an initial version of the manuscript. PH contributed to developing the methodology of this study and writing the method section as well as managing the collected data. PS and LE were involved in the discussions on designing the research project and contributed to developing the methodology of this study. EH, DLW, FP, and GW conceptualized and implemented the research project. All authors critically reviewed and approved of the final version of the manuscript. The views and opinions expressed in this paper are those of the authors only and do not necessarily represent the views, official policy or position of the U.S. DHHS or any of its affiliated institutions or agencies, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

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Table 1

Participants' Demographic Characteristics

Variables	Total (n=408)	Boys (n=205)	Girls (n=203)
Age, yrs	14.5 (1.6)	14.5 (1.6)	14.5 (1.5)
Age group, n (%)			
12–14yrs	203 (49.8)	101 (48.8)	103 (50.7)
15–17yrs	205 (50.3)	105 (51.2)	100 (49.3)
Height, cm	166.3 (10.6)	170.7 (11.1)	161.8 (7.9)
Weight, kg	62.4 (16.5)	65.8 (17.0)	58.9 (15.2)
BMI, kg/m^2	22.4 (4.8)	22.3 (4.5)	22.4 (5.2)
Weight status, n (%)			
Normal weight	269 (65.9)	130 (63.4)	139 (68.5)
Overweight/Obese	139 (34.1)	75 (36.6)	64 (31.5)

Note: Weight status was determined based on the Centers for Disease Control and Prevention growth charts (5th–85th percentile being normal weight, ≥85th percentile being overweight/obese for boys and girls)

Table 2

Comparisons of Sedentary Time and MVPA Time Between Different Processing Methods

	Processing Techniques, M±SE				
Comparisons	**GGIR**	**CrouterVA**	**CrouterV M**	**ChandlerV A**	**ChandlerV M**
SB					
All	**646.7±4.5**[a,b,c]	**564.6±4.5**[c,d,e]	**536.1±4.5**[c, d]	**700.8±4.5**[e]	**664.0±4.5**
Gender					
Boys	647.0±6.7	566.1±7.0	536.9±7.3	703.4±5.7	668.1±6.0
Girls	645.6±7.0	561.3±7.3	533.2±7.6	697.1±5.9	658.2±6.3
Age group					
12–14 years	**635.6±6.7**[f]	**551.0±7.0**[f,g]	**518.6±7.3** [f,g]	**691.6±5.7** [f,g]	**651.6±6.0** [f,g]
15–17 years	657.1±6.6	576.4±7.0	551.6±7.2	708.9±5.6	674.7±6.0
Weight status					
Normal weight	646.3±5.6	565.2±5.9	537.0±6.1	700.6±4.8	664.2±5.1
Overweight/obese	646.4±7.9	562.1±8.3	533.2±8.5	699.9±6.7	662.0±7.1
MVPA					
All	**10.6±1.8**[a,b,c, d]	**106.9±1.8**[c,d]	**125.8±1.8**[c, d]	**52.0±1.8**	**66.9±1.8**
Gender					
Boys	**12.4±0.8**[h]	107.5±3.3	123.4±3.7	52.8±1.9	65.1±2.4
Girls	8.4±0.8	106.5±3.4	129.0±3.9	51.2±2.0	68.8±2.5
Age group					
12–14 years	**12.8±0.8** [f,g]	**114.0±3.3** [f,g]	**134.4±3.7** [f,g]	**57.4±1.9** [f,g]	**73.3±2.4** [f,g]
15–17 years	8.0±0.8	100.0±3.2	117.9±3.7	46.6±1.9	60.7±2.3
Weight status					
Normal weight	11.2±0.7	107.1±2.8	126.0±3.1	52.5±1.6	67.3±2.0
Overweight/obese	9.7±0.9	107.0±3.8	126.4±4.4	51.5±2.3	66.6±2.8

Note: All values indicate mean ± SE (minutes/day). Weight status was determined based on the Centers for Disease Control and Prevention growth charts (5th–85th percentile being normal weight, ≥85th percentile being overweight/obese for boys and girls). All tests were performed at an alpha level of 5%, with Bonferroni adjustments for post-hoc comparisons. Between-method differences were tested only for 'All' participants. Boldface indicates statistical significance (p<0.05).

[a]Indicates significant differences relative to CrouterVA based on ANOVA.

[b]Indicates significant differences relative to CrouterVM based on ANOVA.

[c]Indicates significant differences relative to ChandlerVA based on ANOVA.

[d]Indicates significant differences relative to ChandlerVM based on ANOVA.

[e]Indicates significant equivalence with CrouterVM for CrouterVA, or ChandlerVM for CrouterVA based on equivalence testing with 10% equivalence zone.

[f]Indicates significant differences between younger (12–14 years) and older (15–17 years) kids based on ANOVA.

[g]Indicates significant interaction terms between gender and age groups for boys; significant differences between younger (12–14 years) and older (15–17 years) boys based on ANOVA.

[h]Indicates significant differences between boys and girls based on ANOVA.

ChandlerVA, Chandler method using vertical axis counts; ChandlerVM, Chandler method using vector magnitudes; CrouterVA, Crouter method using vertical axis counts; CrouterVM, Crouter method using vector magnitudes; M, Mean; MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior

Table 3

Proportions of Youth With ≥60 Minutes of Moderate-to-Vigorous Physical Activity Per Day

		Gender		Age group		Weight status	
Methods	**All**	**Boys**	**Girls**	**12–14yrs**	**15–17yrs**	**Normal weight**	**Overweight/obese**
GGIR	0%	0%	0%	0%	0%	0%	0%
CrouterVA	50.7%	49.3%	52.2%	58.0%	43.5%	51.4%	49.4%
CrouterVM	63.8%	64.1%	63.6%	69.0%	58.7%	63.9%	63.8%
ChandlerVA	7.4%	8.2%	6.5%	8.5%	6.2%	7.9%	6.4%
ChandlerVM	19.4%	15.7%	23.2%	23.2%	15.7%	20.7%	16.9%

Note: Weight status was determined based on the Centers for Disease Control and Prevention growth charts (5th–85th percentile being normal weight, ≥85th percentile being overweight/obese for boys and girls).

ChandlerVA, Chandler method using vertical axis counts; ChandlerVM, Chandler method using vector magnitudes; CrouterVA, Crouter method using vertical axis counts; CrouterVM, Crouter method using vector magnitudes