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Estimated Physical Activity in Adolescents by Wrist-worn GENEActiv Accelerometers

Sarah G Sanders, RN, MS¹, Elizabeth Yakes Jimenez, PhD, RDN, LD^{1,2}, Natalie H Cole, MS³, Alena Kuhlemeier, MA⁴, Grace L McCauley, MPH⁵, M. Lee Van Horn, PhD⁶, Alberta S. Kong, MD, MPH^{1,7,8}

¹Division of Adolescent Medicine, Department of Pediatrics, University of New Mexico (UNM), Albuquerque, NM;

²Division of Epidemiology, Biostatistics and Preventive Medicine, Department of Internal Medicine, UNM, Albuquerque, NM;

³Department of Health, Exercise, & Sports Sciences, UNM, Albuquerque, NM

⁴Department of Sociology, UNM, Albuquerque, NM;

⁵Clinical & Translational Science Center, UNM, Albuquerque, NM;

⁶Department of Individual, Family and Community Education, UNM, Albuquerque, NM;

⁷Department of Family and Community Medicine, UNM, Albuquerque, NM;

⁸UNM Prevention Research Center Albuquerque, NM

Abstract

BACKGROUND: Reports of physical activity (PA) measured via wrist-worn accelerometers in adolescents are limited. This study describes PA levels of adolescents at baseline of an obesity prevention and weight management trial.

METHODS: Adolescents (n=930) at 8 high schools wore an accelerometer for up to 7 days, with average acceleration values of <50 mg, >150mg and >500mg considered sedentary, moderate, and vigorous PA respectively. We used a three-level mixed effects generalized linear model in which PA was regressed on sex, weight status and day of the week. PA for each day was nested within students and students were nested within schools, with random effects included for both.

RESULTS: Adolescents accumulated a median 40 minutes of daily moderate to vigorous PA (MVPA). MVPA was significantly different for teens with obesity versus teens with normal weight (–5.4 min/d, $p = 0.03$), boys versus girls (16.3 min/d, $p < 0.001$), and Sundays versus mid-week (–16.6 min/d, $p < 0.001$). Average minutes of sedentary time increased on weekends (Saturday: 19.1 min/d, $p < 0.001$, Sunday: 44.8 minutes, $p < 0.001$) relative to mid-week, but did not differ by sex or weight status.

CONCLUSIONS: Interventions to increase PA in adolescents may benefit from focusing on increasing weekend PA and increasing MVPA in girls.

Keywords

students; schools; exercise; obesity

BACKGROUND

Physical activity (PA) is a key component of health that facilitates weight loss and maintenance, and decreases the risk of diabetes, cardiovascular disease, and other chronic diseases^{1,2}. Adolescent guidelines for PA recommend 60 or more minutes of active time per day, to include mostly moderate intensity, and at least some vigorous intensity activity daily¹. Sedentary time recommendations are not yet established, however the American Academy of Pediatrics recommends limiting sedentary time by keeping time spent using electronic media below two hours per day³.

Self-report and accelerometers are commonly used to measure activity amount and intensity in epidemiologic studies. When measured by self-report, a large percentage of adolescents fail to meet activity recommendations: only 27.1% high school students nationwide reported at least 60 min/day of MVPA on all seven days in the past week (2013 YRBSS)⁴.

Accelerometers, small electronic devices that measure gravitational accelerations that occur with movement, provide device-based measures of free-living MVPA. In a nationally representative sample of U.S. children using waist-worn accelerometers, 8% of adolescents ages 12–15 years engaged in 60 minutes or more of MVPA on at least 5 of 7 days⁵.

More recently, physical activity researchers have begun reporting data from accelerometers worn on the wrist. In 2011, NHANES began measuring PA with an accelerometer placed on the wrist, indicating expanded acceptance of data derived from the wrist. Participants are likely to be more compliant with wearing accelerometers on the wrist, which may improve the representativeness of the data collected⁶. Validation studies for the GENEActiv wrist-worn accelerometer (GA) were first published for youth in 2013⁷. Studies reporting MVPA measured at the wrist in adolescents are limited and vary in location (United Kingdom, United States and Spain), in the type of accelerometer used, and in how the data were processed and reported, resulting in widely varying estimates of average daily MVPA^{8–13}.

The objective of this study is to describe the physical activity levels measured by wrist accelerometer in a group of 930 adolescents at baseline of an obesity prevention and weight management cluster-randomized controlled clinical trial in school-based health centers. We will examine differences by sex, weight status and day of week, with the hypotheses that boys do more physical activity than girls, that teens with overweight and obesity do less physical activity than teens with normal weight and that teens do less physical activity on the weekend versus weekdays.

METHODS

Participants and settings.

Participants were recruited from eight public high schools in the Southwestern United States from February 2014 to November 2015 for a cluster-randomized controlled trial of an

adolescent obesity prevention and weight management intervention in school-based health centers. High schools with functioning school-based health centers and at least 700 enrolled students were eligible to participate if they also had at least 40% Hispanic youth and similar physical activity resources and food environments. This baseline, cross-sectional analysis is comprised of data collected during the first study visit. The University of New Mexico Health Sciences Center Human Research Protections Office approved the study protocol. Written informed assent and consent to participate in the study were obtained from adolescents and their parents, respectively.

Study staff primarily recruited participants when teens arrived at the school with their parents or guardians to register for the school year in person. Additional recruitment occurred: 1) during the classes of teachers who were interested in the study; 2) during required 9th grade physical education classes; 3) during practices of school coaches who were interested in the study; and 4) at lunchtime. A total of 991 study participants were enrolled. Inclusion criteria comprised enrollment in the 9th or 10th grade at a participating school and the provision of written informed assent and consent to participate in the study for the two-year duration. Exclusion criteria included: 1) blood pressure in the range of stage 2 hypertension; 2) a diagnosis of type 1 or type 2 diabetes; 3) use of oral or injectable corticosteroids, antipsychotics and/or medications for the treatment of diabetes, hypertension and/or hyperlipidemia; 4) inability to perform moderate to vigorous physical activity or not ambulatory; 5) a score of 20 or more on the EAT-26 eating disorder risk screening questionnaire; 6) developmental disorders that affect weight or the ability to understand the study procedures or counseling; and 7) pregnancy.

Instrumentation.

PA was assessed using the GENEActiv triaxial accelerometer (GA) (Activinsights Ltd, Cambs, United Kingdom). The GA is a small (43×40×13mm), lightweight (16g), waterproof device that collects raw acceleration data in the range of $\pm 8g$. It was selected because it outputs raw acceleration data; has been validated in children^{7,14}; has sufficient battery life, memory storage, and water-resistance to be worn 24 hours/day; and has higher reported compliance rates than hip worn accelerometers¹⁰.

Participants were instructed to wear the GA continuously for 7 days on the non-dominant wrist. The devices were set to record at 30 Hz. The 30 Hz frequency was chosen to allow for the collection of a reasonable number of data points over a 24 hour per day 7 day protocol to facilitate data storage, transfer, and analysis. The research team deemed that sampling 30 times per second was sufficient to capture the majority of movements performed by teenage children, although it is possible that some movement was not captured at this frequency.

Data reduction.

Accelerometry data were downloaded with the GENEActiv software version 2.2 and saved in raw format as binary files containing acceleration data for x, y and z movement axes. Accelerometer files were read into R and summarized with package GGIR, version 1.5, using the ENMO metric and with no imputation^{15–17}. The auto-calibration and detection of sustained abnormally high values included in the GGIR package were employed; none of the

files met the post-calibration error exclusion threshold of 0.02g¹⁸. Non-wear was defined using GGIR defaults as 60 minutes in which the non-wear score was 2 or greater¹⁵. The non-wear score is based on the value range of each axis calculated for 60-minute windows with 15 minute sliding windows. More details can be found in the supplementary document to van Hees et al¹⁵. PA values were calculated over 1 minute epochs. Since GGIR does not have an automated report for accelerometer wear for a custom day, we needed to process the metadata to obtain the number of wear minutes in the 5 AM to 11 PM day. Sixty second epochs facilitated this as it resulted in substantially less metadata.

We used an 18-hour “wear day” (from 5am to 11pm) as the maximum amount of wear a student could have in a given data collection day. We have used this approach in previous trials to exclude time during which most youth are sleeping^{19,20}. It is critical to exclude sleep intervals for the weighted approach described below to avoid over-weighting participants who wore the accelerometer during sleep in the analysis. Data outside the 5am to 11pm period and any data beyond 8 days were not included in analysis.

Minutes of physical activity were classified into four categories: sedentary, light activity, moderate activity, and vigorous activity. Sedentary activity was defined as accelerometer registered average acceleration below 50 mg (1mg = 0.001 gravity) for the epoch. The threshold of 50 mg for sedentary time was chosen based on a study by Hildebrand in 2016²¹: adults age 21–61 had a mean readout of 45.8 mg for sedentary activities. We rounded to 50 mg so as not to give the impression of over-precision. Light activity was set at average acceleration between 50 and 150 mg, moderate activity at average acceleration between 150 and 500 mg, and vigorous activity (VPA) at average acceleration greater than 500 mg. These threshold choices are supported by a methodological study by Hildebrand²². The GA wrist threshold for 3 METS for adults (18 and up) was 93 mg, whereas the threshold for children (ages 7–11) was 192mg. Choosing a threshold that lies between the two makes sense for adolescents. The 150 mg threshold also corresponds with that chosen by Rowlands et al²³ to most closely match the large repository of ActiGraph physical activity data analyzed with cut points published by Trost et al²⁴. Similarly, Hildebrand set 418 mg and 696 mg vigorous activity thresholds for adults and children²², respectively, and we chose a value in-between (500 mg) as a starting point for vigorous activity. Moderate and vigorous physical activity (MVPA) minutes are the sum of each participant’s moderate and vigorous activity minutes for each day that physical activity data were collected. We examined daily sedentary time, MVPA and VPA as the primary variables, as they are often associated with negative (sedentary time) or positive (MVPA, VPA) health outcomes^{25–28}.

Anthropometric assessments.

Participants’ height and weight were measured by anthropometrists who were trained and standardized approximately every six months during the baseline data collection period. Height and weight were measured in light clothing, without shoes. Height was measured using a portable stadiometer (Seca Model 213, Chino, CA, USA) to the nearest 0.1 cm and weight was measured using a portable electronic scale (Seca Model 770, Chino, CA, USA) to the nearest 0.1 kg, using procedures described by Lohman et al and the National Health and Nutrition Examination Survey Anthropometric Procedures Manual²⁹. Duplicate

measurements were taken for all weight and height measurements and averaged for analysis. A third measurement was taken if the first two measurements differed by >1.0 cm and >0.5 kg for height and weight, respectively. If three measurements were taken, the mean value of the closest two measurements was used for analysis.

Calculation of anthropometric indices.

Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). BMI percentiles were generated using the Center for Disease Control and Prevention (CDC)'s age- and sex-specific LMS BMI-for-age charts for ages 2–20 years³⁰. Participants were considered overweight or obese if their BMI percentiles were between 85–94.9 or ≥95, respectively.

Statistical analyses.

Statistical analysis were completed in R (version, 3.4.1). In order to account for non-wear of accelerometers, we used a recently described repeated measures approach in which PA for each day during which the accelerometer was worn for more than 30 minutes is the outcome³¹. Each day included is weighted using inverse probability weights that reflect the proportion of non-wear. Thus, a day in which the accelerometer was worn for 1 hour would be weighted such that it impacts the results by 1/18th compared to a day in which the accelerometer was worn from 5 AM till 11 PM (the entire time frame possible each day). The advantage of this approach is that it is quite simple to implement, and that it uses all available data while appropriately accounting for the amount of PA data available for each person-day.

The limitation of this approach is that it assumes that the rate of PA observed for the period in which the accelerometer was worn is reasonably representative of that individual's PA. Thus, for example, someone who just wears the accelerometer when they exercise would bias the results upwards, although the extent of bias is limited by the fact that they will be down weighted based on limited wear time. From the 991 students enrolled in the study, data from 930 (94%) of the participants were included in the analysis: 30 GA were lost, 19 GA malfunctioned, 10 participants' data were dropped due to processing issues and two participants did not complete the protocol.

Analyses used a 3-level mixed effects generalized linear model in which daily sedentary time, MVPA and VPA were separately regressed on sex, weight status and day of the week using the NLME package in R³². In order to model the daily effects, one day needed to be included as a reference; we choose Wednesday as the middle of the week. To account for clustering in the data, daily sedentary time, MVPA and VPA for each day were nested within students, and students were nested within schools, with random effects included for both.

RESULTS

Characteristics of the 930 participants are described in Table 1. By study design, approximately 40% of participants were overweight or obese. The majority of participants (n=807; 87%) wore the accelerometer for the full 18 hours on 3 or more days. Participants did a median of 40 minutes of MVPA per day (25th, 75th percentile: 18 minutes, 75 minutes)

and 1 minute of VPA per day (25th, 75th percentile: 0 minutes, 5 minutes), and were sedentary for a median of 820 minutes per day (25th, 75th percentile: 739 minutes, 906 minutes). Table 2 presents descriptive statistics for participant sedentary time, MVPA and VPA, overall and by sex. Overall, 35% of participants averaged 60 minutes or more of MVPA per day, with 48% of boys and 24% of girls meeting this guideline.

Table 3 presents the association of minutes of sedentary time, MVPA and VPA with day of the week, sex and weight status. In the multivariable model, MVPA was significantly different for teens with obesity versus teens with normal weight (−5.4 min/d, $p = 0.03$), for boys versus girls (16.3 min/d, $p < 0.001$), and for weekend versus week days, with the least amount of MVPA on Sunday versus Wednesday (−16.6 min/d, $p < 0.001$). A similar pattern was noted for VPA, with teens with obesity (−2.9 min/d, $p < 0.001$) and teens with overweight (−1.5 min/d, $p = 0.01$) performing less VPA than teens with normal weight, with boys doing more VPA than girls (4.1 min/d, $p < 0.001$) and with less VPA on Saturday (−1.4 min/d, $p < 0.001$) and Sunday (−2.3 min/d, $p < 0.001$) compared to Wednesday. Average minutes of sedentary time increased on weekends (Saturday: 19.1 min/d, $p < 0.001$, Sunday: 44.8 minutes, $p < 0.001$) and decreased on Friday (−21.1 min/d, $p < 0.001$) relative to mid-week, but average minutes of sedentary time did not differ by sex or weight status.

DISCUSSION

Our study adds to the limited literature available on raw acceleration data measured at the wrist in a large group of U.S. adolescents ages 13 to 18 years. Adolescents did a median of 40 minutes and an average of 53 minutes of MVPA per day. About one-third of participating adolescents met the recommended level of physical activity (60 minutes of MVPA per day). We found that participants with obesity did significantly less MVPA and VPA than participants with normal weight. Boys were on average more active than girls, and participants were less active on the weekend than they were during the week.

Comparing our findings to those from other accelerometer studies in adolescents is difficult due to expected differences between countries and differences in the accelerometer and processing methods used. Kim's study of 408 adolescents in the US used a different wrist accelerometer (ActiGraph) and a cutoff of 370mg for MVPA, resulting in an estimated average of 10.8 MVPA minutes per day⁹. Owen's study of 234 girls in the UK used ActiGraph accelerometers on the wrist and a cutoff for MVPA of 201mg, and found an estimated average of 26.9 minutes per day¹¹. Scott's study of eighty-nine 13–14 year-olds in the UK used GA accelerometers and a completely different method to calculate MVPA than that used in our study, resulting in an estimated average of about 30 minutes per day¹⁰. Rowland's report of 1,734 girls in the UK used somewhat similar processing methods to our study, but with a different cut-off (200 mg) and resulted in an estimated average of 45.5 minutes of MVPA per day¹².

As might be expected, our estimated average MVPA per day was higher than results from a waist-worn Actigraph accelerometer study of an nationally representative sample of U.S. youth: 30.5 minutes of MVPA per day for 12–19 year olds⁵. This may be because raw acceleration values are higher on the wrist than on the waist when measured in the lab.

Accelerometers placed on the wrist are positioned to capture movement that hip-placed accelerometers do not, such as arm movement when seated. As a result, estimates of PA are generally higher from wrist-worn accelerometers compared to waist worn accelerometers^{14,22,33}. The increased acceleration values should be consistent within our study, and thus should not affect interpretation of our comparisons related to sex, weight and day of the week. Other possible explanations for our higher MVPA results include a highly motivated study population, and longer wear times. Because the GA is waterproof and worn on the wrist in this study, average wear time in our study was high. Capturing activity for larger amounts of time might naturally yield higher MVPA levels than studies with less average wear time. In the context of the 18 hour wear day, our participants spent an average of 4.9% of the day doing moderate to vigorous physical activity, 0.5% of the day doing vigorous physical activity, and were sedentary 75.9% of the day.

The choice of utilizing 60 second epochs to determine physical activity intensity level is another possible limitation of the study. While this method saved considerable time and effort and made it feasible for this study to be completed, it sacrificed the use of shorter epochs (10 seconds or less) that are typically used when evaluating children's physical activity. Teenagers ages 14 to 18 years old are emerging adults, accruing physical activity patterns more and more similar to those of adults: for instance, sitting in class at public high school for much of the day, and potentially working outside of the school day. Despite the fact that we used different processing methods including a lower frequency (30 Hz as opposed to 100 Hz) and longer epochs (60 second vs 5 second), our estimates of mean MVPA in the girls in our study (mean 46 minutes, SD 41 minutes) were not hugely different from Rowlands' 2018 report of MVPA in girls in the UK using GA accelerometers on the wrist (mean 45.5 minutes, SD 20.0 minutes)¹².

Our finding that MVPA differed by weight status is similar to previous findings. Adolescents with overweight or obesity report participating in less physical activity than those with a lower BMI percentile according to results from a large nationally-representative sample of U.S. high school students³⁴. In a large study of children ages 3 to 18 from the International Children's Accelerometry Database (waist-worn accelerometers only), Cooper et al. found that children with overweight and obesity were less active than normal weight children from age seven onwards³⁵. Similarly, Trost et al. found that children in 4th to 6th grade who were overweight or obese did significantly lower amounts of MVPA measured by waist-worn accelerometers³⁶.

Our results show a difference of 1.5 to 3 minutes of vigorous activity between weight categories. Although this difference is small, it may have important health effects. In a cross-sectional study of physical activity intensity and health in Canadian youth, tertiles of VPA minutes per day measured by waist-mounted accelerometers ranged from 1.39 (low), to 3.59 (moderate), to 8.74 (high)²⁸. Within this limited range of minutes of VPA, students in the high tertile displayed lower BMI-z score, lower waist circumference, and higher fitness compared to students in the lowest tertile, and risk of high systolic blood pressure and overweight status declined in a dose-dependent manner²⁸. Kidokoro et al. found that VPA just over 8 minutes per day (measured by a uniaxial accelerometer, body placement not reported) could reduce the likelihood of low fitness in girls³⁷.

Our results are also consistent with previous findings that boys are more active than girls; twice as many boys met the PA guidelines compared to girls. In a study using accelerometers at the waist, Trost et al. observed that boys are 6 times more likely than girls to meet the recommended guidelines for physical activity because they have greater overall levels of MVPA³⁶.

Finally, our weekday results are consistent with other studies in that Fridays are the most active day overall, and weekends the least active, as measured by waist-mounted accelerometers^{38,39}. Dossegger et al. found that Friday is the most active day in children and adolescents between the age of 3 and 18 years old, and Saturday, Sunday, and Monday are the least active days in their study that used Actigraph accelerometers (body placement not reported)⁴⁰.

This study has some limitations. Our baseline dataset is not meant to be representative of teens in New Mexico. Participants were motivated to enroll in a two-year study focused on nutrition and PA. Students already participating in organized sports may have enrolled more frequently than those not in sports due to our recruitment methods. In addition, teens with parents who accompany them to school registration events and teens actively participating in required PE classes and may have different activity patterns than the general population. Students were enrolled in traditional public schools, so students in private or alternative/charter schools are not represented. Students with medical and developmental conditions that affect physical activity were also excluded.

We approximated sleep hours by including only 18-hour days from 5AM until 11PM. As a result, students who wore the accelerometers while sleeping during the 18-hour window will have increased values for sedentary activity. In addition, MVPA occurring between the hours of 11 pm to 5 am was not included; however, this seems likely to be of minimal concern except in rare cases (individuals who are active very late in the day or very early in the morning). An alternative approach would have been to use the GGIR estimates for waking hours. We elected not to use this option because utilizing the GGIR estimates would have required substantial additional coding time. Future research should include improved measures of sleep time, especially when the focus is sedentary activity.

Conclusions.

Measurement, processing and analysis of physical activity data from the wrist must be standardized in order to make meaningful comparisons across different studies and provide a consistent representation of the level of physical activity that youth are achieving. MVPA and VPA differ significantly by weight status, sex and day of the week, offering potential opportunities for intervention. Low MVPA and high sedentary time on weekends may provide a prime opportunity to implement interventions for increasing PA. Girls, with consistently lower levels of PA as a group, clearly require more support to achieve recommended levels of MVPA. Interventions for managing weight in adolescents may also benefit from a focus on increasing MVPA and VPA.

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Table 1:

Demographic Characteristics

Characteristic	N = 930
Mean age (yr) $\pm$ SD	15.5 $\pm$ 0.72
Female, n (%)	516 (55)
Hispanic, n (%)	798 (86)
Race, n (%)	
Non-Hispanic White	118 (13)
American Indian	27 (3)
Black	32 (3)
Other/Multiple	32 (3)
No Race selected, only Ethnicity selected	721 (78)
Income, n (%)	
<\$40,000	648 (70)
\$40,000 - \$74,999	163 (17)
\$75,000	85 (9)
Unknown	34 (4)
Parent Education level, n (%)	
Less than high school	290 (31)
High school graduate	226 (24)
Some college	262 (28)
College graduate	145 (16)
Unknown	7 (1)
BMI percentile category, n (%)	
Under/Normal Weight (<85th percentile)	571 (61)
Overweight (85th – 94th percentile)	183 (20)
Obese (95th percentile)	176 (19)

BMI, body mass index

Table 2:

Baseline activity estimates for study participants, overall and by sex

Activity Level	<u>All participants (n=930)</u>		<u>Females (n= 516)</u>		<u>Males (n=414)</u>	
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)
Sedentary (mins/day)	819 (121)	820 (739–903)	820 (119)	820 (741–905)	819 (123)	821 (736–908)
MVPA (mins/day)	53 (46)	40 (18–75)	46 (41)	35 (16–62)	62 (51)	49 (22–90)
VPA (mins/day)	5 (11)	1 (0–5)	3 (8)	0 (0–3)	7 (13)	1 (0–9)

MVPA, moderate to vigorous physical activity; VPA, vigorous physical activity.

Table 3:

Association of minutes of sedentary time, moderate to vigorous physical activity (MVPA) and vigorous physical activity with day of the week, sex and weight status^a

	Sedentary		MVPA		Vigorous	
	Minutes	SE	Minutes	SE	Minutes	SE
Intercept	809.4 ^{**}	6.4	50.4 ^{**}	2.3	4.5 ^{**}	0.5
Day of the week						
Sunday	44.8 ^{**}	4.6	-16.6 ^{**}	1.7	-2.3 ^{**}	0.4
Monday	0.7	4.3	1.2	1.6	0.6	0.4
Tuesday	6.2	4.2	-3	1.6	0.2	0.4
Wednesday	Reference					
Thursday	-3.2	4.2	0.4	1.6	0.5	0.4
Friday	-21.1 ^{**}	4.3	4.3 [*]	1.6	-0.2	0.4
Saturday	19.1 ^{**}	4.5	-10.1 ^{**}	1.7	-1.4 ^{**}	0.4
Sex						
Male	-2.4	5.0	16.3 ^{**}	2.0	4.1 ^{**}	0.4
Female	Reference					
Weight status						
Obese	10.2	6.4	-5.4 [*]	2.6	-2.9 ^{**}	0.6
Overweight	2.5	6.3	-0.7	2.5	-1.5 [*]	0.6
Normal weight	Reference					
Underweight	8.4	15.0	-1.3	6	-0.2	1.4

^aDetermined using a three-level mixed effects generalized linear model in which sedentary, MVPA, and vigorous minutes per day were regressed on sex, weight status and day of the week (NLME package in R). To account for clustering, PA for each day was nested within students and students were nested within schools, with random effects included for both.

* P<0.05

** P<0.001