Moderate-to-Vigorous Physical Activity From Ages 9 to 15 Years

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Context Decreased physical activity plays a critical role in the increase in childhood obesity. Although at least 60 minutes per day of moderate-to-vigorous physical activity (MVPA) is recommended, few longitudinal studies have determined the recent patterns of physical activity of youth.

Objective To determine the patterns and determinants of MVPA of youth followed from ages 9 to 15 years.

Design, Setting, and Participants Longitudinal descriptive analyses of the 1032 participants in the 1991-2007 National Institute of Child Health and Human Development Study of Early Child Care and Youth Development birth cohort from 10 study sites who had accelerometer-determined minutes of MVPA at ages 9 (year 2000), 11 (2002), 12 (2003), and 15 (2006) years. Participants included boys (517 [50.1%]) and girls (515 [49.9%]); 76.6% white (n=791); and 24.5% (n=231) lived in low-income families.

Main Outcome Measure Mean MVPA minutes per day, determined by 4 to 7 days of monitored activity.

Results At age 9 years, children engaged in MVPA approximately 3 hours per day on both weekends and weekdays. Weekday MVPA decreased by 38 minutes per year, while weekend MVPA decreased by 41 minutes per year. By age 15 years, adolescents were only engaging in MVPA for 49 minutes per weekday and 35 minutes per weekend day. Boys were more active than girls, spending 18 and 13 more minutes per day in MVPA on the weekdays and weekends, respectively. The rate of decrease in MVPA was the same for boys and girls. The estimated age at which girls crossed below the recommended 60 minutes of MVPA per day was approximately 13.1 years for weekday activity compared with boys at 14.7 years, and for weekend activity, girls crossed below the recommended 60 minutes of MVPA at 12.6 years compared with boys at 13.4 years.

Conclusion In this study cohort, measured physical activity decreased significantly between ages 9 and 15 years.

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Physical inactivity is connected to an increase in obesity and the associated morbidity and chronic diseases among youth.[1-4] Expert opinion[5-8] and empirical studies[9] suggest that children need a minimum of 60 minutes of moderate-to-vigorous physical activity (MVPA) per day, a standard proposed by the US Department of Agriculture.[10]

How many youth meet this standard is unclear. Most population-based surveys have relied on self-report data with questionable validity, and studies that have used objective measures of physical activity have typically involved small samples. Accelerometers provide objective measurement of physical activity and the feasibility of collecting accelerometer data on large samples has been demonstrated.[11] To describe patterns and demographic determinants of physical activity relative to recommended guidelines, our study used data from the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development birth cohort, a large sample of US children from 10 geographic locations. Monitored physical activity data were collected longitudinally beginning in 2000 when children were 9 years old until they were 15 years old.

METHODS

Study Population

The NICHD Study of Early Child Care and Youth Development is a multisite study originally designed to determine the effects of nonmaternal care on the development of children. Participants were recruited in 1991 from designated community hospitals at 10 university-based data collection sites: (1) Little Rock, Arkansas; (2) Irvine, California; (3) Lawrence, Kansas; (4) Boston, Massachusetts; (5) Philadelphia, Pennsylvania; (6) Pittsburgh, Pennsylvania; (7) Charlottesville, Virginia; (8) Seattle, Washington; (9) Hickory and

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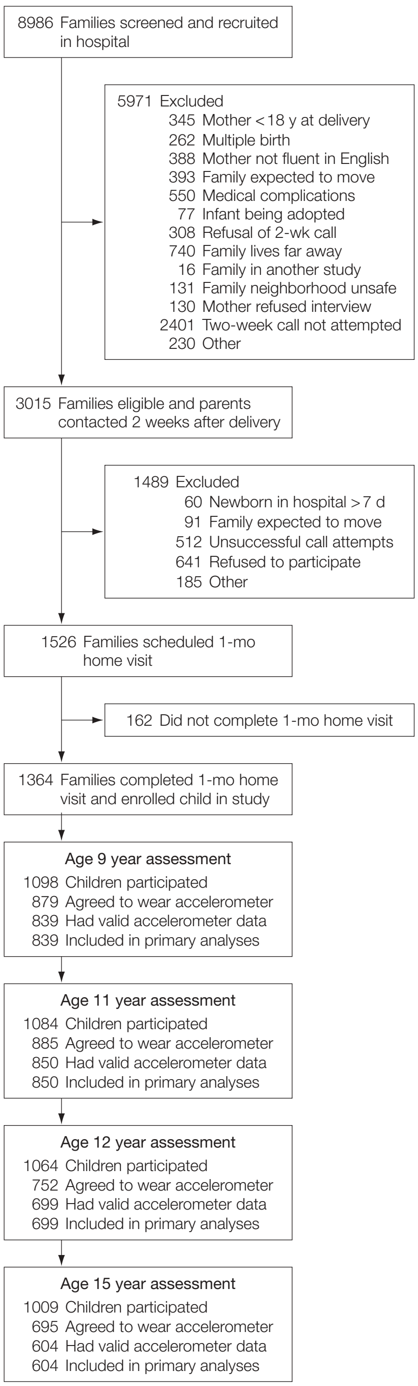
Figure 1. Flow Diagram of Participants in the NICHD Study of Early Child Care and Youth Development Birth Cohort



NICHD indicates National Institute of Child Health and Human Development

Morganton, North Carolina; and (10) Madison, Wisconsin. Recruitment and selection procedures are described in detail[12] and study procedures are described on the study Web site (http://secc.rti.org). Children were followed from birth to 15 years with a common study protocol, including interview, home, school, and neighborhood observations. For all study data collection protocols, including the accelerometer, human subjects institutional review boards at each university and the data coordinating center approved voluntary, written informed consents from participating families. All children gave verbal or implied assent by wearing the monitor. At age 9 year assessments, only 2 of the site institutional review boards did not require assent.

Healthy newborns, discharged within 1 week of birth, of English-speaking mothers were recruited. When the target child was 2 weeks old, attempts were made to contact 3015 families who met eligibility criteria to enlist their participation (FIGURE 1). Of 1526 families scheduled, 1364 families actually completed the 1-month home visit and became study participants. There were no significant differences between these 1364 families and the 1990 US population[13] based on ethnicity (80.3% white in US population vs 80.4% in cohort) and household income (household income information available for 1273 families; \$36 520 in US population and \$37 948 in cohort). The NICHD Study of Early Child Care and Youth Development cohort had a slightly higher percentage of married couple family households than the US population (76.7% vs 74.2%, $P = .04$).

Between age 1 month and 9 years, approximately 20% of the original cohort was lost to follow-up, with moving and lack of time the major reasons for attrition (Figure 1). Dropouts were more likely to have lower maternal education ($P < .001$) and be nonwhite ($P = .03$). Retention in the sample of higher income and white individuals might be expected to bias toward higher activity levels. Between ages 9 and 15 years, the cohort lost an additional 8%. Differential dropout as a function of sex, family income, maternal education, or race/ethnicity was not found between the ages of 9 to 15 years, but children with lower body mass index (BMI, calculated as weight in kilograms divided by height in meters squared) at age 9 years were more likely to remain in the sample ($P = .01$). Retention of children with lower BMI might be expected to bias toward higher levels of activity. When we compared 9-year-old children with activity data at age 15 years with 9-year-old children without data at age 15 years, we found no difference between the 2 groups in terms of their distributions of activity across the entire range of physical activity recorded at age 9 years. This implies we did not lose the most active youth between the ages of 9 and 15 years.

Height and Weight

Height and weight data were obtained when children were 9, 11, 12, and 15 years. Height was measured following a standardized procedure with children standing with shoes off, feet together, and their backs to a calibrated 7-foot measuring stick fastened to a wall. Weight was measured following a standardized procedure using a physician's 2-beam scale. Body mass index was calculated as indicated above. Body mass index was converted to BMI percentile to obtain the relative position of the child's BMI number among children of the same sex and age.[14]

Demographic and Child Characteristics

Child sex and race/ethnicity defined by the mother were recorded at 1 month. Race/ethnicity was defined as white or nonwhite (black, Hispanic, Asian, and other) and was collected to compare the characteristics of the study sample with the eligible population and because ethnicity is associated with patterns of use of child care. Maternal education in years was obtained by interview at 1 month. Family income collected from parents when the child was 9 years was converted to an income-to-needs ratio based on federal poverty levels for each family size (ratio of <2.0 is considered low income).[15] Data collection sites were grouped by region (Northeast:

Pittsburgh and Philadelphia, Pennsylvania, and Boston, Massachusetts; South: Little Rock, Arkansas, Charlottesville, Virginia, and Hickory and Morgantown, North Carolina; Midwest: Lawrence, Kansas, and Madison, Wisconsin; and West: Irvine, California, and Seattle, Washington).

Monitored Physical Activity

The amount of physical activity each child engaged in across a typical week was measured by using an accelerometer (Computer Science Applications Inc, Shalimar, Florida) set so that it recorded minute-by-minute movement counts. Accelerometer-determined physical activity was offered to the entire cohort at ages 9, 11, 12, and 15 years. Participation in wearing the monitor was high (80.1% at 9 years, 81.6% at 11 years, 70.7% at 12 years, and 68.9% at 15 years). At 9 years, 95.4% of children who agreed to wear monitors had at least 4 valid days of data; the comparable numbers at ages 11, 12, and 15 years were 96.0%, 93.0%, and 86.9% (Figure 1). The 2 reasons most often given for refusing to wear the monitors were inconvenience and concerns for the appearance around the waist of the 1.5×1.5 inch monitor. The slightly lower participation of adolescents wearing the monitor has been noted in other studies.[16]

Participants wore the monitor on a belt around the waist during waking hours for 7 days, including 2 weekend days and 5 weekdays, excluding showering, bathing, water sports, or contact sports. These constraints on wearing the monitor (common to all accelerometer studies) resulted from manufacturers' suggestions and safety concerns (eg, possible bruising or injury). Decisions about when to remove monitors were made by participants and coaches. Information from participant activity logs and patterns of observed counts indicate that the degree of underestimation of overall activity was minimal, and only for a few children during 1 or 2 days of the total activity recorded.

The number of counts recorded by the accelerometer was used to estimate the energy expended in moderate (3.0-5.9 metabolic equivalent tasks [METs]), vigorous (6.0-8.9 METs), and very vigorous (>9.0 METs) activity, based on the age-specific equation of Freedson et al[17]:

$$\text{METs} = [2.757 + (0.0015 \times \text{count}) - (0.08957 \times \text{age in years}) - (0.000038 \times \text{count} \times \text{age in years})].$$

Accelerometer data were downloaded to the same computer used to initialize them. A complete day of activity data was defined as extending from the first nonzero accelerometer count after 5 AM until one of the following criteria was met: (1) 60 consecutive minutes of zero counts after 9 PM; (2) 30 consecutive minutes of zero counts after 10 PM; or (3) the last nonzero count before midnight, whichever came first. Once the number of minutes for any given day was calculated, the total number of accelerometer counts was computed; then invalid days (too short a measurement time, implausible total count for the time recorded, zero counts, or any record shorter than 4 days) were flagged for removal. Rules for removal were based on patterns observed from visual inspection of the data for 9-year-old children.

After calculating the total number of minutes spent wearing the monitor and number of minutes spent in moderate, vigorous, or very vigorous activity, these minutes were summed to represent the total amount of time each child spent each day in MVPA. The mean minutes per day of MVPA was calculated and used as the index of total activity for each day the monitor was worn. Mean minutes were then computed for weekdays and for weekends.

Between-day intraclass reliability coefficients were calculated following the procedures outlined in Baumgartner.[18] Four-day reliabilities for minutes of MVPA averaged 0.73, 7-day reliabilities averaged 0.81, and 2-weekend day reliabilities averaged 0.54 across ages 9, 11, 12, and 15 years. Although the estimated reliabilities for weekend MVPA are only moderate, the method used to produce the estimates was not optimal in that data collected on Saturdays was compared with data collected on Sundays and the structure of activity in most US households tends to be different on those 2 weekend days. Because the data collected from participants indicates no less consistency in compliance with protocols for wearing of accelerometers on weekdays and weekends, it is likely that the weekend data are as valid an indicator of weekend physical activity (on average) as the weekday data are as an indicator of weekday activity.

Statistical Procedures

All statistical analyses were conducted by using SAS version 9.1.3 (SAS Institute Inc, Cary, North Carolina) and all hypotheses were tested using 2-sided tests. Significant differences between children who had activity data and those who did not were determined for all categorical variables using χ^2 tests and Fisher exact test when cell counts were small. Differences in continuous variables between these groups were determined using *t* tests assuming unequal variance or the Kruskal-Wallis test.[19]

For descriptive purposes, minutes of MVPA on weekdays and weekend days were categorized as follows: less than one-half hour, one-half to 1 hour, 1 to 2 hours, and more than 2 hours. This permitted calculation of the percentage meeting the 60-minute guideline and easily understood intervals reflecting the range of MVPA over the ages measured.

To examine weekday and weekend patterns of MVPA longitudinally from ages 9 to 15 years and to explore the effects of demographic factors on activity, 5 quadratic growth curve models[20] were constructed for both weekdays and weekends by using PROC MIXED (SAS Institute Inc). This allowed the calculation of a mean trajectory of weekday and weekend minutes of MVPA as well as the estimation of each child's weekday and weekend trajectory. All models used restricted maximum likelihood estimates, which results in a less biased estimate because both fixed and random effects are treated as unknowns. We tested the baseline model with a homoscedastic error structure against the baseline model with a heteroscedastic error structure by using the likelihood ratio test and determined that the heteroscedastic error structure improved the model fit for both the weekday and weekends ($P < .001$). As a result, all models were run assuming unequal residual variance and an unstructured covariance matrix.

The first (baseline) models were quadratic models with age treated as a continuous variable. The weekday model can be expressed as:

$$y_{ij} = \beta_0 + u_{0j} + (\beta_1 + u_{1j}) \times (\text{centered age}_{ij}) + \beta_2 \times (\text{centered age}_{ij})^2 + r_{ij}$$

where y_{ij} is the expected mean weekday minutes of MVPA at time i for child j; centered age_{ij} is the child's age centered at the age 9 year assessment for child j at time i; β_0 is the mean weekday minutes of MVPA at the age 9 year assessment (fixed intercept); u_{0j} is the random intercept for child j; β_1 is the linear rate of change in mean weekday minutes of MVPA (fixed slope); u_{1j} is the random linear slope for child j; β_2 is the acceleration in the change of mean weekday minutes of MVPA (fixed acceleration); and r_{ij} is the residual term for child j at time i.

The weekend model can be expressed as:

$$y_{ij} = \gamma_0 + u_{0j} + \gamma_1 \times (\text{centered age}_{ij}) + \gamma_2 \times (\text{centered age}_{ij})^2 + r_{ij}$$

and differs from the weekday model in that γ_0 represents the mean weekend minutes of MVPA at the age 9 year assessment (fixed intercept) and γ_2 represents the acceleration in the change of mean weekend minutes of MVPA (fixed acceleration). We were unable to treat age as a random effect in the weekend models because the intercept and slope were highly correlated and the variance of the centered age parameter was not significant, leading to convergence problems. The high negative correlation between the intercept and linear slope indicated that the rate of decline in mean weekend minutes of MVPA was greater for those children who had more minutes of MVPA on the weekends at age 9 years.

Model 2 added sex as a fixed covariate predicting intercepts and linear slopes. Model 3 replaced sex with low income status at age 9 years as the covariate predicting the intercepts and linear slopes. Model 4 examined the combined predictive ability of sex, low income, mother's education, race/ethnicity, region, BMI percentile, low income by sex interaction, low income by BMI percentile interaction, and low income by region interaction all predicting the intercepts and linear slopes. Model 5 examined whether sex moderated any of the findings from model 4 by adding interactions with sex to all the terms in model 4; only 1 of the interactions was significant and model fit was not improved (data not shown). For all models, continuous covariates were centered: mother's education was centered at the mean education level and BMI percentile was grand mean centered. All interaction variables were calculated by using the centered variables.[21] At each time point, children who had valid accelerometer data were excluded from the growth curve model if they were missing data on any of the covariates included in the model. As a result, the number of children included varies across the models.

Correlations between the estimated random effects from the baseline model (model 1) for weekday and weekend intercepts and weekday slope were also examined. Paired *t* tests were used to test for mean differences between the weekday and weekend intercepts for the first 3 models (baseline, sex, and income).

RESULTS

TABLE 1 describes the study cohort. Relatively more girls than boys had valid accelerometer data at age 9 years, and relatively more boys than girls had valid accelerometer data at age 15 years. Because boys are generally more active than girls, this would be expected to support increased activity between ages 9 and 15 years if sex were the primary influencing factor. A total of 1032 children had valid activity measurements for at least 1 of the 4 assessments (9, 11, 12, and 15 years) and were included in these analyses. The sample was 50.1% boys and 76.6% white; 24.5% lived in low-income families. Children included in the analysis sample differed from those without any activity data in that they were more likely to be female (n=1364; $\chi^2_1 = 4.29$; $P = .04$) and to have mothers with more education (mean [SD], 14.4 [2.4] years vs 13.8 [2.7] years; $t_{(523)} = -3.82$, $P < .001$). No differences were noted for race/ethnicity (white vs nonwhite) between the children in the analysis sample and those without any activity data.

Activity Results

FIGURE 2 shows the distribution of mean minutes of MVPA for monitored physical activity during the week and on weekends. Both the mean minutes of MVPA and the range of minutes spent in MVPA decreased as children moved into adolescence. TABLE 2 shows the mean minutes of weekday and weekend MVPA for boys, girls, and the sample combined. At 9 years, children engaged in MVPA approximately 3 hours per day on both weekdays and weekends. By 15 years, adolescents were only engaging in MVPA for 49 minutes per weekday and 35 minutes per weekend day.

The percentage of children who met the recommended activity guidelines of 60 minutes of MVPA per day on weekdays and weekends decreased from 9 years to 15 years (TABLE 3). At 9 and 11 years, almost all children met the guidelines, but by 15 years, only 31% and 17% met guidelines on weekdays and weekends, respectively.

Results of Growth Curve Analyses

TABLE 4 and TABLE 5 provide the significant findings for the growth curve models describing weekday and weekend activity, respectively. Both weekday and weekend MVPA showed significant linear decreases in MVPA between 9 and 15 years (model 1) of 38 and 41 minutes per year, respectively; however, the significant quadratic effect shows that the rate of decline leveled off as children entered adolescence. There was a high negative correlation (−0.93) between the weekday intercept and the linear slope at 9 years, indicating that children who were more active at 9 years tended to decrease activity more rapidly over time. At 9 years, children spent more time in MVPA on the weekdays than they did on the weekends (mean [SD] difference, 2.22 [21.54]; 95% confidence interval [CI], 0.89-3.55; $t_{(1012)}=3.28$; $P=.001$), but children who were more active during the week also tended to be more active on the weekend ($r=0.59$).

Boys spent more time in MVPA at 9 years than girls did (190 vs 172 minutes per weekday, and 185 vs 172 minutes per weekend, respectively), but the linear decrease in MVPA on the weekdays and weekends was the same for both boys and girls (model 2). At age 9 years, boys were more active on the weekdays than they were on the weekends (mean [SD] difference, 4.49 [22.09]; 95% CI, 2.56-6.41; $t_{(506)}=4.57$; $P<.001$), although girls were equally active during the week and on weekends (mean [SD] difference, −0.29 [19.51]; 95% CI, −1.99 to 1.42; $t_{(505)}=-0.33$; $P=.74$). As shown in FIGURE 3, girls were below the recommended 60 minutes of MVPA on weekdays at approximately 13.1 years (95% CI, 12.9-13.3) compared with boys at 14.7 years (95% CI, 14.3-15.3); and for weekend activity, girls were below the recommended 60 minutes of MVPA at 12.6 years (95% CI, 12.3-12.8) compared with boys at 13.4 years (95% CI, 13.2-13.7).

As model 3 indicates, children from low-income families were more active at age 9 years on weekdays than were children from higher-income families (188 vs 178 minutes per weekday); no differences were found for weekend activity. Income status was unrelated to changes in weekday or weekend activity. Both children from low-income and higher-income families spent more time in MVPA at age 9 years on weekdays than on weekends (low-income families: mean [SD] difference, 4.04 [22.34]; 95% CI, 1.13-6.96; $t_{(227)}=2.73$; $P=.007$; and higher-income families: mean [SD] difference, 2.29 [20.49]; 95% CI, 0.77-3.81; $t_{(697)}=2.95$; $P=.003$).

When all covariates were considered simultaneously (model 4), boys, children from low-income families, and children with lower BMI percentiles were shown to be significantly more active at 9 years on both weekdays and weekends. Sex was the stron-

Table 1. Descriptive Characteristics of the NICHD Study of Early Child Care and Youth Development Cohort

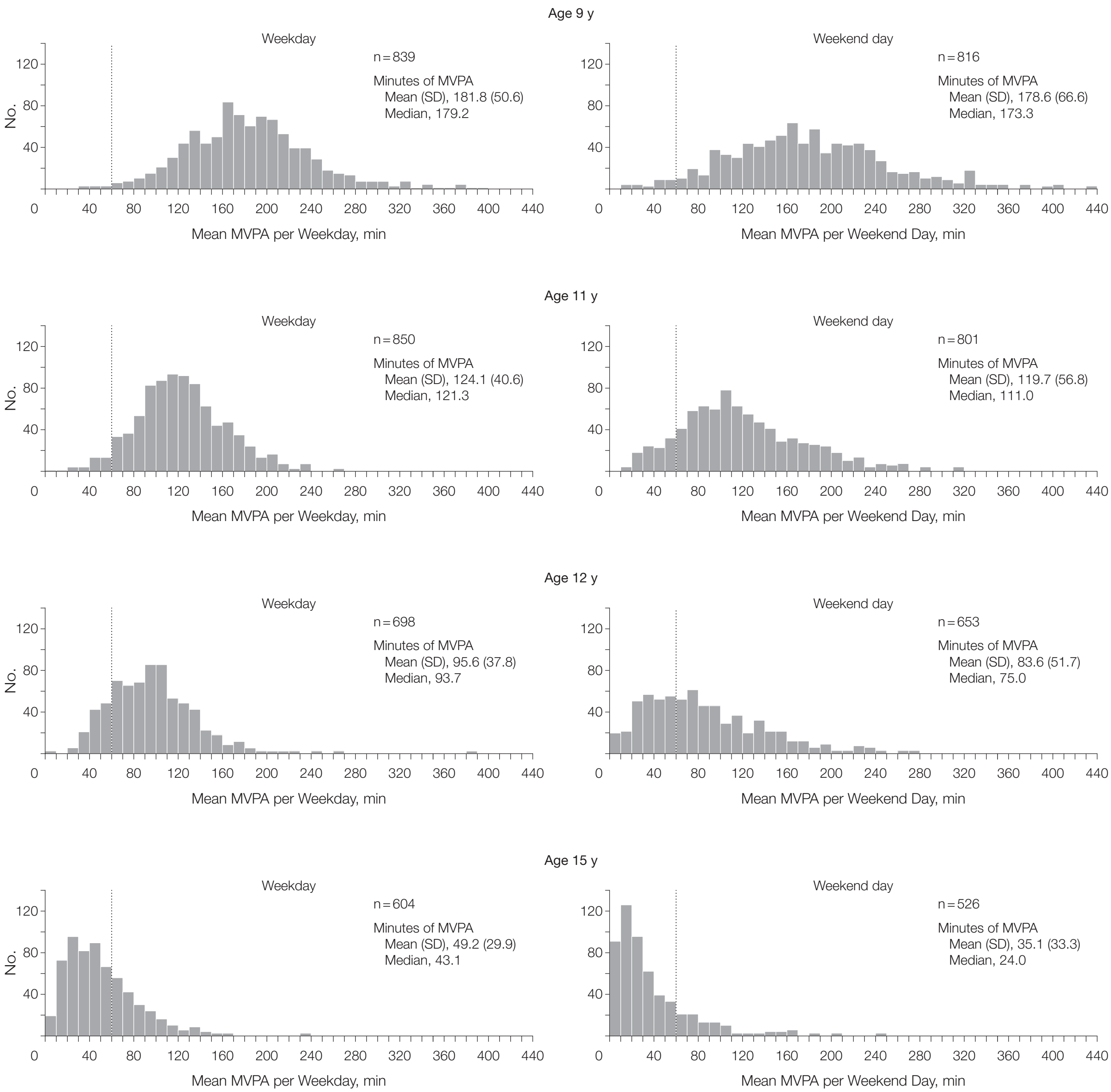
		No. (%) of Participants							
		Age 9 Years		Age 11 Years		Age 12 Years		Age 15 Years	
Characteristic	Total Cohort	Active in the Assessment	Valid Accelerometer Data	Active in the Assessment	Valid Accelerometer Data	Active in the Assessment	Valid Accelerometer Data	Active in the Assessment	Valid Accelerometer Data
Original cohort	1364 (100)	1098 (80.5)	839 (61.5)	1084 (79.5)	850 (62.3)	1064 (78.0)	699 (51.2)	1009 (74.0)	604 (44.3)
Age, mean (SD), y		NA	9.0 (0.3)	NA	10.7 (0.3)	NA	11.9 (0.3)	NA	15.0 (0.2)
Sex									
Female	659 (48.3)	543 (49.5)	431 (51.4)	540 (49.8)	434 (51.1)	532 (50.0)	351 (50.2)	506 (50.1)	280 (46.4)
Male	705 (51.7)	555 (50.5)	408 (48.6)	544 (50.2)	416 (48.9)	532 (50.0)	348 (49.8)	503 (49.9)	324 (53.6)
Race/ethnicity[a]									
White	1042 (76.4)	852 (77.6)	651 (77.6)	834 (76.9)	646 (76.0)	820 (77.1)	532 (76.1)	781 (77.4)	454 (75.2)
Nonwhite	322 (23.6)	246 (22.4)	188 (22.4)	250 (23.1)	204 (24.0)	244 (22.9)	167 (23.9)	228 (22.6)	150 (24.8)
Low-income family at age 9 years									
Yes	NA	234 (23.8)	193 (24.4)	232 (23.9)	196 (24.8)	231 (24.1)	164 (25.1)	219 (23.7)	150 (26.6)
No	NA	748 (76.2)	598 (75.6)	738 (76.1)	593 (75.2)	729 (75.9)	489 (74.9)	705 (76.3)	413 (73.4)
Mother's education, mean (SD), y[b]	14.2 (2.5)	14.4 (2.5)	14.4 (2.4)	14.4 (2.5)	14.4 (2.4)	14.4 (2.4)	14.3 (2.4)	14.4 (2.5)	14.3 (2.4)
BMI percentile, median (IQR)[c]	NA	69.4 (46.3)	70.6 (45.8)	69.5 (51.8)	69.2 (51.4)	69.2 (51.7)	69.0 (51.5)	70.1 (41.8)	71.0 (40.3)
Region		**(n = 927)**	**(n = 771)**	**(n = 909)**	**(n = 756)**	**(n = 895)**	**(n = 638)**	**(n = 833)**	**(n = 543)**
Midwest	264 (19.4)	217 (19.8)	179 (21.3)	210 (19.4)	177 (20.8)	208 (19.5)	160 (22.9)	194 (19.2)	137 (22.7)
Northeast	399 (29.3)	343 (31.2)	246 (29.3)	338 (31.2)	262 (30.8)	334 (31.4)	199 (28.5)	318 (31.5)	161 (26.7)
South	430 (31.5)	308 (28.1)	230 (27.4)	302 (27.9)	229 (26.9)	296 (27.8)	188 (26.9)	279 (27.7)	184 (30.5)
West	271 (19.9)	230 (20.9)	184 (21.9)	234 (21.6)	182 (21.4)	226 (21.2)	152 (21.7)	218 (21.6)	122 (20.2)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); IQR, interquartile range; NA, not applicable; NICHD, National Institute of Child Health and Human Development.
[a] Race/ethnicity was defined by the mother and recorded at 1-month interview. Nonwhite included black, Hispanic, Asian, and other.
[b] Mother's education reported during the 1-month interview.
[c] BMI percentile indicates the relative position of the child's BMI number among children of the same sex and age.[14]

gest discriminator of weekday activity with effect sizes approximately double that of income level (0.21 for sex vs 0.10 for income level) and BMI percentile (0.21 for sex vs 0.12 for BMI percentile). Boys spent 21 more minutes per weekday in MVPA than girls did; children from low-income families spent 9 more minutes per weekday in MVPA than higher-income children did; and a 10% increase from the approximate mean BMI percentile of 65 was associated with 2 fewer minutes of MVPA per weekday for 9-year-old children. When sex interactions were added in model 5, the BMI percentile finding held for boys but not girls (data not shown).

For weekend activity, sex and BMI percentile had similar effect sizes (0.10 and 0.09, respectively), although the effect size for children from low-

Figure 2. Total Weekday and Weekend Day MVPA Distributions by Age



MVPA indicates moderate-to-vigorous physical activity. Dotted vertical line indicates the recommended 60 minutes per day of MVPA for children.[10] One child at age 12 years was missing weekday data and was only included in the weekend day analysis.

income families was smaller (0.06). Boys spent 18 more minutes per weekend day in MVPA than girls did; children from low-income families spent 11 more minutes per weekend day in MVPA than children from higher-income families did; and a 10% increase from the approximate mean BMI percentile of 65 was associated with 3 fewer minutes of MVPA per weekend day for 9-year-old children.

Children from low-income families and children with lower BMI percentiles had faster linear decreases in MVPA on both weekdays and weekends. Also, the weekday MVPA of children living in the Midwest and South decreased at faster rates than children living in the West and Northeast. In general, these effects, although significant, were quite small. For example, the decrease in MVPA time each year for children in low-income families was approximately 1 minute more per day on weekdays and 5 minutes more per day on weekends compared with children from higher-

Table 2. Mean Minutes of Moderate-to-Vigorous Physical Activity per Day

	Mean (SD), min					
	Weekday			Weekend		
Age, y	Boys	Girls	Both	Boys	Girls	Both
9	190.8 (53.2)	173.3 (46.4)	181.8 (50.6)	184.3 (68.6)	173.3 (64.3)	178.6 (66.6)
11	133.0 (42.9)	115.6 (36.3)	124.1 (40.6)	127.1 (59.5)	112.6 (53.2)	119.7 (56.8)
12	105.3 (40.2)	86.0 (32.5)	95.6 (37.8)	93.4 (55.3)	73.9 (45.8)	83.6 (51.7)
15	58.2 (31.8)	38.7 (23.6)	49.2 (29.9)	43.2 (38.0)	25.5 (23.3)	35.1 (33.3)

Table 3. Percentage of Children's Weekday and Weekend Day Activity by Age and Minutes of MVPA

	Age, y							
	Weekdays				Weekends			
MVPA, min	9	11	12	15	9	11	12	15
<30	0.0	0.6	1.0	30.5	0.5	2.7	13.3	58.9
30-59	0.4	3.3	15.6	38.9	1.8	9.6	24.5	24.3
60-119	9.5	44.9	60.6	28.0	16.5	44.4	40.3	14.1
≥120	90.1	51.2	22.8	2.6	81.1	43.2	21.9	2.7

Abbreviation: MVPA, moderate-to-vigorous physical activity.

Table 4. Weekday and Weekend Growth Curve Models Examining the Change in Moderate-to-Vigorous Physical Activity Between Ages 9 and 15 Years (Models 1-3)[a]

	Weekday Physical Activity			Weekend Physical Activity		
	F Value	Estimate	Effect Size	*F* Value	Estimate	Effect Size
Model 1 (n = 1032 weekday, n = 1013 weekend)						
Intercept, min		180.91			178.70	
Age	1419.70[b]	–38.21	0.74	674.77[b]	–41.19	0.56
Age × age	334.90[b]	2.69	0.45	156.86[b]	2.85	0.28
Model 2 (n = 1032 weekday, n = 1013 weekend)						
Intercept, min		172.02			172.36	
Sex	42.19[b]	18.00	0.20	15.34[b]	13.12	0.08
Age	1341.00[b]	–38.36	0.71	658.02[b]	–41.70	0.54
Age × sex	0.24	0.29	0.02	1.02	0.74	0.03
Age × age	336.21[b]	2.68	0.44	157.57[b]	2.85	0.28
Model 3 (n = 942 weekday, n = 926 weekend)						
Intercept, min		178.35			176.18	
Low-income household at age 9 years	8.35[c]	9.65	0.10	3.34	7.37	0.04
Age	1337.73[b]	–38.18	0.74	611.19[b]	–40.86	0.55
Age × low income	3.04	–1.16	0.06	1.79	–1.14	0.04
Age × age	330.49[b]	2.72	0.45	145.67[b]	2.84	0.28

[a] For low-income household at age 9 years, 1 indicates low income and 0 indicates not low income; for sex, 1 indicates male and 0 indicates female. Child's age is centered at age 9 years.
[b] $P < .001$.
[c] $P < .01$.

income families. Similarly, a 10% decrease from the approximate mean BMI percentile of 65 was associated with an additional less than 1 minute per day per year decrease in MVPA. Regional differences accounted for an additional decrease in weekday MVPA of less than 4 minutes per day per year.

COMMENT

In our longitudinal study where physical activity was carefully measured using accelerometers from ages 9 to 15 years in a large geographically diverse population of US children, we observed a steep decrease in MVPA with age. At 9 years, almost all children were well above the recommended 60 minutes of MVPA on both weekdays and weekends, but by 15 years only 31% met the guidelines on weekdays and only 17% on weekends. Although age and sex were the most important determinants of MVPA from 9 to 15 years, low family income, lower BMI percentile, and residing in the Midwest or South also significantly increased the

Table 5. Weekday and Weekend Growth Curve Models Examining the Change in Moderate-to-Vigorous Physical Activity Between Ages 9 and 15 Years (Model 4)[a]

	Model 4 Weekday (n = 903)			Model 4 Weekend (n = 884)		
Predictors	*F* Value	Estimate	Effect Size	*F* Value	Estimate	Effect Size
Intercept		166.54			160.20	
Low-income household at age 9 years	8.74[b]	8.96	0.10	7.85[b]	11.34	0.06
Mother's education	0.01	0.06	0	0.01	0.07	0.00
Sex	39.36[c]	21.26	0.21	20.07[c]	18.30	0.10
Race/ethnicity	0.01	−0.29	0	3.78	−9.08	0.04
Region	1.50			1.54		
Midwest		7.54	0.05		11.28	0.04
Northeast		−2.39	0.02		10.14	0.04
South		1.49	0.01		8.04	0.03
West		0 [Reference]	0 [Reference]		0 [Reference]	0 [Reference]
BMI percentile	15.77[c]	−0.23	0.12	16.82[c]	−0.30	0.09
Low income × sex	0.67	−5.68	0.03	1.58	−10.65	0.03
Low income × region	0.50			0.80		
Low income × Midwest		7.32	0.02		−1.30	0.00
Low income × Northeast		12.17	0.04		11.82	0.02
Low income × South		5.08	0.02		13.07	0.02
Low income × West		0 [Reference]	0 [Reference]		0 [Reference]	0 [Reference]
Low income × BMI percentile	0.09	−0.04	0.01	1.58	−0.19	0.03
Age	1153.32[c]	−37.65	0.70	501.91[c]	−38.59	0.51
Age × low income	4.13[d]	−1.47	0.08	5.55[d]	−4.53	0.08
Age × mother's education	0.09	0.04	0.01	0.02	0.03	0.00
Age × sex	0.61	−0.54	0.03	0.17	−0.38	0.01
Age × ethnicity	0.92	0.74	0.04	2.87	1.76	0.05
Age × region	5.30[b]			2.11		
Age × Midwest		−3.08	0.12		−3.35	0.08
Age × Northeast		0.30	0.01		−2.08	0.05
Age × South		−2.01	0.08		−1.91	0.05
Age × West		0 [Reference]	0 [Reference]		0 [Reference]	0 [Reference]
Age × BMI percentile	4.42[d]	0.03	0.07	4.54[d]	0.04	0.07
Age × low income × sex	1.51	1.71	0.05	2.38	2.85	0.05
Age × low income × region	0.47			0.79		
Age × low income × Midwest		−1.90	0.03		2.42	0.03
Age × low income × Northeast		0.22	0		2.90	0.03
Age × low income × South		−1.00	0.02		−0.20	0.00
Age × low income × West		0 [Reference]	0 [Reference]		0 [Reference]	0 [Reference]
Age × low income × BMI percentile	0.02	0	0	1.23	0.04	0.04
Age × age	329.11[c]	2.84	0.47	122.83[c]	2.76	0.27

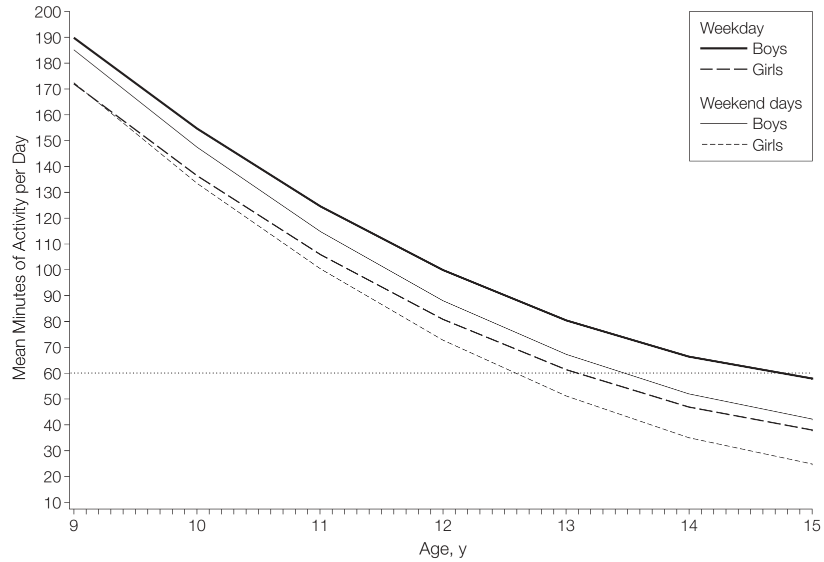
Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).
[a] For low-income household at age 9 years, 1 indicates low income and 0 indicates not low income; for sex, 1 indicates male and 0 indicates female; and for race/ethnicity, 1 indicates nonwhite and 0 indicates white. Mother's education is mean centered; BMI percentile is grand mean centered; and child's age is centered at age 9 years.
[b] $P < .01$.
[c] $P < .001$.
[d] $P < .05$.

rate of decline in MVPA. Nonetheless, when differences for income, BMI percentile, and geographic region were translated into minutes per day per year, the magnitude of effect was small. Each of these effects was linked to a decrease in MVPA of less than 4 minutes per day per year on the weekdays and less than 5 minutes per day per year on the weekends.

Decreasing levels of MVPA have been shown in other studies. The most recent National Health and Nutritional Examination Survey (NHANES) data[22] using accelerometer-measured physical activity in a representative US sample also revealed that physical activity decreases dramatically across age groups between childhood and adolescence and continues to decrease into adulthood. For example, using a higher cutoff of METs required to determine MVPA, the NHANES results showed that 42% of children aged 6 to 11 years obtained the recommended 60 minutes per day of physical activity, whereas only 8% of adolescents achieved this goal.[22] Among adults, adherence to the recommendation to obtain 30 minutes per day of physical activity is less than 5%.[22] In addition, earlier cross-sectional studies conducted on smaller samples of both US and European youth documented decreasing activity with increasing age, with evidence indicating that boys are more active than girls.[23-28] The Centers for Disease Control and Prevention Youth Risk Behavior Surveys and other large sample studies that measure physical activity using self-report[29,30] also find activity to decrease with age, but the overall amount of MVPA reported in these studies tends to be much higher than accelerometer-based studies.

A particular strength of our study lies in the repeated examination and longitudinal analysis of physical activity during both weekdays and weekend days at ages 9, 11, 12, and 15 years for a cohort born when the obesity epidemic was well under way. Another strength derives from our use of objective accelerometer measurement of physical activity in a much larger sample with a higher mean adherence rate for wearing the monitor over 7 days (55%) than the recent NHANES study (26%).[22]

Figure 3. Average Weekday and Weekend Minutes of MVPA by Sex



MVPA indicates moderate-to-vigorous physical activity. Dotted horizontal line indicates the recommended 60 minutes per day of MVPA for children.[10] Graphs were generated from estimates obtained from growth curve model 2, which included intercepts, age, sex, age × sex, and age × age to describe change in MVPA on weekdays and weekends between ages 9 and 15 years. Girls cross below the recommended 60 minutes of MVPA per day at approximately 13.1 years (95% CI, 12.9-13.3) for weekday activity and 12.6 years (95% CI, 12.3-12.8) for weekend activity; boys cross below the recommended 60 minutes of MVPA per day at approximately 14.7 years (95% CI, 14.3-15.3) for weekday activity and 13.4 years (95% CI, 13.2-13.7) for weekend activity.

Our study has limitations. First, our sample is not nationally representative because the study sites were selected on the basis of National Institutes of Health review; therefore, the findings are not fully generalizable to the US population. That said, the recruited sample closely matched the US population at the time of initial recruitment with regard to income and race/ethnicity. Moreover, the sample was diverse in ethnicity, socioeconomic status, and household membership. Unfortunately, there were relatively small numbers of certain racial/ethnic minorities, limiting the ability to analyze subsamples.

Second, an unavoidable bias is due to the fact that accelerometers tend to underestimate activity of youth who frequently engage in contact sports or swimming because the accelerometer is not worn at these times. Whether the numbers of such children increase with age is unknown, but this factor is unlikely to account for the dramatic decrease in overall activity noted. Children would have had to engage in contact sports for a significant number of hours every monitored day to influence the results for overall activity.

Third, separating age from secular trends in longitudinal data is technically difficult. Because of the historic timing of data collection for this study (ie, during the rapid escalation of obesity in the United States), it is possible that declining trajectories in MVPA may represent a secular rather than a developmental phenomenon. However, accelerometer data collected as part of the NHANES cross-sectional study in a single year (2003) showed similar patterns of decline in physical activity in children between ages 6 to 11 years and ages 15 to 19 years.

A fourth potential limitation pertains to the uncertain reliability of weekend MVPA data. Because the pattern of decline on weekends mirrors the pattern of decline observed on weekdays, it appears that the weekend measure is a valid indicator. Generally speaking, children appear to be slightly less active on weekends than on weekdays, suggesting that families may not be encouraging children to engage in active play or that weekend competing priorities result in less activity.

Accelerometers are a new method to measure physical activity for public health purposes. The technology has continued to develop and has improved since our study was initiated in 2000. There is no single accepted protocol across studies for setting accelerometer-based cutoff points for MVPA.[31] The study by Pate et al[32] found that applying different cutoff points resulted in significant differences in the classification of sixth grade girls meeting the 60-minute recommendation (estimates varied from <1% to 11% to 87.7%, respectively, depending on whether the cutoff points were 4.6 MET, 3.8 MET, or 3.0 MET). In our study, we used the 3.0 MET cutoff, reflecting the most liberal cutoff point. However, striking decreases in activity were observed from 9 to 15 years. Overall, by 15 years, a minority of adolescents were meeting the recommended 60 minutes per day of MVPA, even by the most liberal standard. Other than the study by Strong et al,[9] there is limited data substantiating the 60-minute recommendation in terms of important clinical outcomes. Thus, one task for future research in this area is to examine the amount of MVPA required to affect child health outcomes.

More research is also needed to understand the reasons for such substantial decreases in youth activity. Further study and more precise descriptions of the immediate activity environment, such as whether youth are located in urban, suburban, or rural areas; availability of safe places to be active; and quality of school-based physical education may explain some of the individual and regional differences noted in this and other studies.

The data in our cohort confirm a significant decrease of activity from ages 9 to 15 years in the United States. This decrease augurs poorly for levels of physical activity in US adults and potentially for health over the course of a lifetime. Consequently, there is a need for program and policy action as early as possible at the family, community, school, health care, and governmental levels to address the problem of decreasing physical activity with increasing age.[4]

Author Contributions: Dr Nader had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
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Acquisition of data: Nader, Bradley, O'Brien.
Analysis and interpretation of data: Nader, Bradley, Houts, McRitchie, O'Brien.
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