PHYSICAL INACTIVITY IS CONNECTED TO AN INCREASE IN OBESITY AND THE ASSOCIATED MORBIDITY AND CHRONIC DISEASES AMONG YOUTH. Expert opinion and empirical studies 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.

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. 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 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.
MODERATE-TO-VIGOROUS PHYSICAL ACTIVITY IN CHILDREN AGED 9 TO 15 YEARS

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

8986 Families screened and recruited in hospital
5971 Excluded
345 Mother <18 y at delivery
262 Multiple birth
388 Mother not fluent in English
393 Family expected to move
550 Medical complications
77 Infant being adopted
308 Refusal of 2-wk call
740 Family lives for away
16 Family in another study
131 Family neighborhood unsafe
130 Mother refused interview
2401 Two-week call not attempted
230 Other

3015 Families eligible and parents contacted 2 weeks after delivery
1489 Excluded
60 Newborn in hospital >7 d
91 Family expected to move
512 UNSUCCESSFUL call attempts
641 Refused to participate
185 Other

1526 Families scheduled 1-mo home visit
162 Did not complete 1-mo home visit

1364 Families completed 1-mo visit and enrolled child in study

Age 9 year assessment
1098 Children participated
879 Agreed to wear accelerometer
839 Had valid accelerometer data
839 Included in primary analyses

Age 11 year assessment
1084 Children participated
985 Agreed to wear accelerometer
950 Had valid accelerometer data
850 Included in primary analyses

Age 12 year assessment
1064 Children participated
752 Agreed to wear accelerometer
699 Had valid accelerometer data
699 Included in primary analyses

Age 15 year assessment
1009 Children participated
695 Agreed to wear accelerometer
604 Had valid accelerometer data
604 Included in primary analyses

NICHD indicates National Institute of Child Health and Human Development

Morganton, North Carolina; and (10) Madison, Wisconsin. Recruitment and selection procedures are described in de-
tail12 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 population13 based on ethnicity (80.3% white), maternal education (51.1% some college vs 51.8% completed college), and household income (household income 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 al17:

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

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 \( \chi^2 \) 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 models20 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 be-
cause 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 heteros-
cedastic error structure improved the
model fit for both the weekday and weekends (P < .001). As a result, all
models were run assuming unequal res-
idual variance and an unstructured co-
variance matrix.

The first (baseline) models were qua-
dratic models with age treated as a con-
tinuous 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 \( \text{age}_{ij} \) is the child’s age cen-
tered at the age 9 year assessment for child
\( j \) at time \( i \); \( \beta_0 \) is the mean
weekday minutes of MVPA at the age 9 year
assessment (fixed intercept); \( u_{0j} \) is the
random intercept for child \( j \); \( \beta_1 \) is the
linear rate of change in mean weekday
minutes of MVPA (fixed slope); \( u_{1j} \) is the
random linear slope for child \( j \); \( \beta_2 \) is
the acceleration in the change of mean
weekday minutes of MVPA (fixed ac-
celeration); and \( r_{ij} \) is the residual term
for child \( j \) at time \( i \).

The weekend model can be ex-
pressed as:

\[ y_{ij} = y_0 + u_0 + \gamma_1 \times (\text{centered age}_{ij}) + \gamma_2 \times (\text{centered age}_{ij})^2 + r_{ij} \]

and differs from the weekday model in
that \( y_0 \) represents the mean weekend
minutes of MVPA at the age 9 year as-
sessment (fixed intercept) and \( \gamma_2 \)
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 week-
end models because the intercept and
slope were highly correlated and the
variance of the centered age param-
eter was not significant, leading to con-
vergence problems. The high negative
relation 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 covar-
iate 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/eth-
nicity, 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 cov-
ariates were centered: mother’s edu-
cation was centered at the mean edu-
cation level and BMI percentile was
grand mean centered. All interaction
variables were calculated by using the
centered variables. 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 chil-
"内涵"包括两个固定和随机效应，被处理为未知。我们测试了
基线模型与具有同方差的误差结构的基线模型
与具有异方差的误差结构的基线模型的优劣，结果
表明该误差结构的模型对于工作日和周末的
预测模型较好（P < .001）。因此，所有
模型都运行了不平衡的残差方差和非对角线协
方差矩阵。

第一个（基线）模型是二次模型，年龄
被作为连续变量处理。工作日模型
可以表示为：

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

其中，\( y_{ij} \) 是第 \( i \) 个工作日
中第 \( j \) 名儿童的平均
MVPA 分钟数；centered
\( \text{age}_{ij} \) 是在第 9 岁评估
时第 \( j \) 名儿童
的中心年龄；\( \beta_0 \) 是
固定效应的平均
工作日 MVPA 时间
（固定截距）；\( u_{0j} \) 是
随机截距
第 \( j \) 名儿童；\( \beta_1 \) 是
线性变化
在第 \( i \) 个工作日
的平均 MVPA 时间
（固定斜率）；\( u_{1j} \) 是
随机线性斜率
第 \( j \) 名儿童；\( \beta_2 \) 是
在第 \( i \) 个工作日
内 MVPA 时间
的加速度
（固定加速）；和 \( r_{ij} \) 是
第 \( j \) 名儿童
在第 \( i \) 个工作日
的时间
残差项。

工作日模型可以表示为：

\[ y_{ij} = y_0 + u_0 + \gamma_1 \times (\text{centered age}_{ij}) + \gamma_2 \times (\text{centered age}_{ij})^2 + r_{ij} \]

并且和工作日模型有差
异在于，\( y_0 \) 表示
为第 \( i \) 个周末
中第 \( j \) 名儿童的平均
MVPA 分钟数
的固定效应
（固定截距）且
\( \gamma_2 \) 表示
为在变化
的周末平均
MVPA 时间
的加速度
（固定加速）。
我们无法将
年龄作为
随机效应
在周末模
型中，因为截
距和斜率
高度相关
且
中心年龄参数
的方差
不显著，导致
收敛问题。
高负相关
的截距和
直线斜率
指示了斜率的
下降速率
在周六早晨
MVPA 更大
对于那些在
周末有着
更多分钟
MVPA 的儿
童。
ever, 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 week-

days 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; \( t_{(1002)} = 4.57; P < .001 \)), although girls were equally active during the week and on weekends (mean [SD] difference, \(-0.29 [19.51]; 95\% \text{ CI, } -1.99 \text{ to } 1.42; t_{(985)} = -0.33; P = .74 \)). 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; \( t_{(687)} = 2.95; P = .003 \)).

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total Cohort</th>
<th>Age 9 Years</th>
<th>Age 11 Years</th>
<th>Age 12 Years</th>
<th>Age 15 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. (%) of Participants</td>
<td>Active in the Assessment</td>
<td>Valid Accelerometer Data</td>
<td>Active in the Assessment</td>
<td>Valid Accelerometer Data</td>
</tr>
<tr>
<td>Original cohort</td>
<td>1364 (100)</td>
<td>1098 (80.5)</td>
<td>839 (61.5)</td>
<td>1084 (79.5)</td>
<td>850 (60.4)</td>
</tr>
<tr>
<td>Age, mean (SD)</td>
<td>NA</td>
<td>9.0 (0.3)</td>
<td>10.7 (0.3)</td>
<td>11.9 (0.3)</td>
<td>15.0 (1.2)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>659 (48.3)</td>
<td>431 (51.4)</td>
<td>532 (60.0)</td>
<td>506 (50.1)</td>
<td>260 (46.4)</td>
</tr>
<tr>
<td>Male</td>
<td>705 (51.7)</td>
<td>540 (61.4)</td>
<td>532 (60.0)</td>
<td>506 (50.1)</td>
<td>260 (46.4)</td>
</tr>
<tr>
<td>Race/ethnicitya</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>1042 (76.4)</td>
<td>651 (77.6)</td>
<td>532 (60.0)</td>
<td>506 (50.1)</td>
<td>260 (46.4)</td>
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<tr>
<td>Nonwhite</td>
<td>322 (23.6)</td>
<td>188 (22.4)</td>
<td>204 (24.0)</td>
<td>167 (23.9)</td>
<td>150 (24.8)</td>
</tr>
<tr>
<td>Low-income family at age 9 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>234 (28.3)</td>
<td>193 (24.4)</td>
<td>231 (24.1)</td>
<td>164 (25.1)</td>
<td>150 (26.0)</td>
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<tr>
<td>No</td>
<td>748 (76.2)</td>
<td>598 (75.6)</td>
<td>729 (75.9)</td>
<td>489 (74.9)</td>
<td>413 (74.3)</td>
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<tr>
<td>Mother’s education, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(n = 927)</td>
<td>14.2 (2.5)</td>
<td>14.4 (2.5)</td>
<td>14.4 (2.5)</td>
<td>14.4 (2.4)</td>
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<td>(n = 777)</td>
<td>13.9 (2.4)</td>
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<td>13.9 (2.4)</td>
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<tr>
<td>(n = 909)</td>
<td>14.3 (2.5)</td>
<td>14.4 (2.5)</td>
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<tr>
<td>(n = 756)</td>
<td>14.1 (2.5)</td>
<td>14.2 (2.5)</td>
<td>14.2 (2.4)</td>
<td>14.2 (2.4)</td>
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<tr>
<td>(n = 895)</td>
<td>14.2 (2.5)</td>
<td>14.3 (2.5)</td>
<td>14.3 (2.4)</td>
<td>14.3 (2.4)</td>
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<tr>
<td>(n = 638)</td>
<td>14.3 (2.5)</td>
<td>14.4 (2.5)</td>
<td>14.4 (2.4)</td>
<td>14.4 (2.4)</td>
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<tr>
<td>(n = 833)</td>
<td>14.4 (2.5)</td>
<td>14.5 (2.5)</td>
<td>14.5 (2.4)</td>
<td>14.5 (2.4)</td>
<td>14.5 (2.4)</td>
</tr>
<tr>
<td>(n = 543)</td>
<td>14.5 (2.5)</td>
<td>14.6 (2.5)</td>
<td>14.6 (2.4)</td>
<td>14.6 (2.4)</td>
<td>14.6 (2.4)</td>
</tr>
</tbody>
</table>

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.

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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-income families was larger (0.21). 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.
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

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

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

<table>
<thead>
<tr>
<th>MVPA, min</th>
<th>Weekdays</th>
<th>Weekend</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>30-59</td>
<td>0.4</td>
<td>1.8</td>
</tr>
<tr>
<td>60-119</td>
<td>9.5</td>
<td>16.5</td>
</tr>
<tr>
<td>≥120</td>
<td>90.1</td>
<td>81.1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model 1 (n = 1032 weekday, n = 1013 weekend)</th>
<th>Intercept, min</th>
<th>Age</th>
<th>Age × age</th>
</tr>
</thead>
<tbody>
<tr>
<td>F Value</td>
<td>Estimate</td>
<td>Effect Size</td>
<td>F Value</td>
</tr>
<tr>
<td>180.91</td>
<td>-38.21</td>
<td>0.74</td>
<td>178.70</td>
</tr>
<tr>
<td>334.90</td>
<td>2.69</td>
<td>0.45</td>
<td>156.86</td>
</tr>
</tbody>
</table>

Model 2 (n = 1032 weekday, n = 1013 weekend)

<table>
<thead>
<tr>
<th>Intercept, min</th>
<th>Age</th>
<th>Sex</th>
<th>Age × sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.02</td>
<td>13.34</td>
<td>0.20</td>
<td>13.12</td>
</tr>
<tr>
<td>28.06</td>
<td>0.71</td>
<td>0.04</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Model 3 (n = 942 weekday, n = 926 weekend)

<table>
<thead>
<tr>
<th>Intercept, min</th>
<th>Low-income household at age 9 years</th>
<th>Age</th>
<th>Age × low income</th>
</tr>
</thead>
<tbody>
<tr>
<td>178.36</td>
<td>9.65</td>
<td>0.10</td>
<td>7.34</td>
</tr>
<tr>
<td>133.73</td>
<td>-38.18</td>
<td>0.74</td>
<td>40.86</td>
</tr>
<tr>
<td>3.04</td>
<td>-1.16</td>
<td>0.06</td>
<td>-1.14</td>
</tr>
</tbody>
</table>

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.

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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>
<thead>
<tr>
<th>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)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictors</td>
</tr>
<tr>
<td>F Value</td>
</tr>
<tr>
<td>Estimate</td>
</tr>
<tr>
<td>Effect Size</td>
</tr>
<tr>
<td>F Value</td>
</tr>
<tr>
<td>Estimate</td>
</tr>
<tr>
<td>Effect Size</td>
</tr>
<tr>
<td>Midwest</td>
</tr>
<tr>
<td>Northeast</td>
</tr>
<tr>
<td>South</td>
</tr>
<tr>
<td>West</td>
</tr>
<tr>
<td>BMI percentile</td>
</tr>
<tr>
<td>Low income × sex</td>
</tr>
<tr>
<td>Low income × region</td>
</tr>
<tr>
<td>Low income × Midwest</td>
</tr>
<tr>
<td>Low income × Northeast</td>
</tr>
<tr>
<td>Low income × South</td>
</tr>
<tr>
<td>Low income × West</td>
</tr>
<tr>
<td>Low income × BMI percentile</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Age × low income</td>
</tr>
<tr>
<td>Age × mother’s education</td>
</tr>
<tr>
<td>Age × sex</td>
</tr>
<tr>
<td>Age × ethnicity</td>
</tr>
<tr>
<td>Age × region</td>
</tr>
<tr>
<td>Age × Midwest</td>
</tr>
<tr>
<td>Age × Northeast</td>
</tr>
<tr>
<td>Age × South</td>
</tr>
<tr>
<td>Age × West</td>
</tr>
<tr>
<td>Age × BMI percentile</td>
</tr>
<tr>
<td>Age × low income × sex</td>
</tr>
<tr>
<td>Age × low income × region</td>
</tr>
<tr>
<td>Age × low income × Midwest</td>
</tr>
<tr>
<td>Age × low income × Northeast</td>
</tr>
<tr>
<td>Age × low income × South</td>
</tr>
<tr>
<td>Age × low income × West</td>
</tr>
<tr>
<td>Age × low income × BMI percentile</td>
</tr>
<tr>
<td>Age × age</td>
</tr>
</tbody>
</table>

**Abbreviation:** BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

<sup>a</sup>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.

<sup>b</sup>P < .01
<sup>c</sup>P < .001
<sup>d</sup>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) data22 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-report29,30 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

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
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.

Study concept and design: Nader, Bradley, Houts, O'Brien.

Acquisition of data: Nader, Bradley, O'Brien.

Analysis and interpretation of data: Nader, Bradley, Houts, McRitchie, O'Brien.

Drafting of the manuscript: Nader, Houts, McRitchie. Critical revision of the manuscript for important intellectual content: Nader, Bradley, Houts, McRitchie, O'Brien.

Statistical analysis: Nader, Houts, McRitchie.

Obtained funding: Nader, Bradley, O'Brien.

Administrative, technical, or material support: Nader, Bradley, O'Brien.

Study supervision: Nader, Bradley, Houts, O'Brien.

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Role of the Sponsor: The NICHD Study of Early Child Care and Youth Development Steering Committee, which includes an NICHD project director, was responsible for the design and conduct of the study, the collection, management, analysis, and interpretation of the data, and the preparation, review, and approval of the manuscript.

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Disclaimer: The content is solely the responsibility of the authors and does not represent the official views of the Eunice Kennedy Shriver NICHD, the National Institutes of Health, or the individual members of the NICHD Early Child Care Research Network.

Statistical Contributions: Patti S. Freedson, PhD (University of Massachusetts, Amherst), provided assistance with protocol development of accelerometer measurement. Dr Freedson received compensation for her contribution. Barbara V. Alexander (RTI International, Research Triangle Park, North Carolina) provided data management related to the study. We thank the children and families that have participated since the birth of a child in 1991.

REFERENCES


