

# How Much Activity Do Youth Get? A Quantitative Review of Heart-Rate Measured Activity

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**ABSTRACT.** *Objective.* Recommendations for adult physical activity have shifted from 20 to 60 minutes of continuous vigorous activity 3 to 5 times a week to accumulation of 30 minutes of moderate to vigorous physical activity most days of the week. Variations of these guidelines also have been suggested for children, based on the idea of accumulating moderate to vigorous physical activity throughout the day, rather than attaining vigorous physical activity in continuous blocks. The goal of this study was to assess accumulated amounts of physical activity at different intensities in children.

*Methods.* We reviewed 26 studies ( $n = 1883$ ) in youth aged 3 to 17 years that used heart-rate recording to measure physical activity in children to determine accumulated daily activity. Included were studies that provided time being active for at least 2 heart rate intensities at or above 120 beats/minute. Descriptive characteristics of the study groups were determined, and the influence of age, gender, and hours and days of observation on the slope of activity time as a function of percentage of heart rate reserve (HRR) was determined using hierarchical linear regression.

*Results.* Youth attained  $128.0 \pm 45.6$ ,  $47.1 \pm 14.9$ ,  $29.3 \pm 13.7$ , and  $14.7 \pm 6.0$  minutes/day between 20% to 40%, 40% to 50%, 50% to 60%, and greater than 60% HRR, respectively. Age was a significant predictor of the intercept and slope of the physical activity and %HRR relationship.

*Conclusion.* Youth of all ages attain >60 minutes/day of low-intensity physical activity and approximately 30 minutes/day of activity at traditional cardiovascular fitness training levels of 50% or more of HRR. Recommendations for youth activity are discussed. *Pediatrics* 2001; 108(3). URL: <http://www.pediatrics.org/cgi/content/full/108/3/e44>; activity, heart rate, exercise intensity, exercise duration.

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ABBREVIATIONS. ACSM, American College of Sports Medicine; CDC, Centers for Disease Control and Prevention; HRR, heart rate reserve; bpm, heart beats per minute;  $VO_{2max}$ , maximal oxygen consumption; METS, metabolic equivalents; MVPA, moderate to vigorous physical activity.

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The importance of a physically active lifestyle for reducing the risk of morbidity and mortality is well documented.<sup>1,2</sup> To encourage adoption of active lifestyles, the American College of Sports Medicine (ACSM) developed guidelines for the amount of physical activity required to produce health benefits. The original guidelines for youth and adults recommended attainment of 3 to 5 sessions of 20 to 60 minutes of continuous, high-intensity physical activity per week.<sup>3</sup> On the basis of epidemiologic and controlled research in adults on the health benefits of lower-intensity, less-structured physical activity<sup>4,5</sup> and the small percentage of the population who met original guidelines<sup>6</sup> and because modest increases in physical activity were most beneficial for those who were most sedentary,<sup>4,5</sup> the ACSM and the Centers for Disease Control and Prevention (CDC) revised the physical activity guidelines. The current recommendation is that adults and children who are older than 2 years accumulate 30 minutes of at least moderate-intensity physical activity on most but preferably all days of the week.<sup>7</sup> For youth, the shift in recommendations from continuous sessions of higher-intensity activity to allowing moderate-intensity activity to be accumulated over shorter bouts means that activities such as walking to school, playground activities, and some chores (eg, raking leaves) that would not meet the original duration or intensity standards for aerobic activity may count toward daily physical activity under the new standards. This may mean that more youth will meet the revised guidelines. Weyer et al<sup>8</sup> found that 17.4% of a sample of 109 obese adults met the previous activity guidelines as based on self-reported activity, but 33.9% of the participants met the revised guidelines.

Pediatric scientists have used the new recommendations to argue that physical activity rather than fitness should be encouraged.<sup>9</sup> Blair et al<sup>10</sup> provided models for ways in which physical activity can improve the health of youth. Physical activity can improve health directly by reducing body weight,<sup>11</sup> improving blood lipid concentrations, and reducing insulin sensitivity.<sup>12</sup> Activity during childhood also could produce changes that alter health later in life. For example, an active lifestyle could defer the development of obesity during adolescence, which predicts adult mortality, independent of adult weight.<sup>13</sup> Finally, developing an active lifestyle during childhood and adolescence may be predictive of being physically active in adulthood,<sup>14,15</sup> when significant

health benefits have been documented.<sup>4,5</sup> There is widespread belief that children are not active enough and that the amount of physical activity has been decreasing as the opportunities for pleasurable sedentary activities have increased.<sup>16</sup>

Within a wide range of activity intensities and amounts, it is likely that as physical activity accumulates, so do the health benefits, particularly with sedentary children. However, knowing how much physical activity to recommend for youth is difficult; public health guidelines have ranged from recommending 30 minutes/day<sup>7</sup> to recommending 60 minutes/day.<sup>17</sup> These guidelines generally are derived from information in adults, based on the amount of activity thought to provide health benefits.<sup>6</sup> Guidelines for children and adolescents are based on either adult recommendations or involve increasing the activity recommendations by an arbitrary amount.<sup>7,10</sup> The recommended increases are based on the observation that youth may already meet the adult guidelines<sup>17</sup> and that activity levels of youth decrease over time,<sup>16</sup> so to achieve the recommended amount of physical activity as an adult, children should start at a greater amount of physical activity. However, there is limited empirical evidence to recommend general guidelines, and goal-oriented recommendations may be preferable. For example, prevention may require a lower amount and/or intensity of physical activity than treatment of an existing problem.<sup>18</sup>

The primary purpose of this review was to examine the literature to provide an estimate of how much daily physical activity children attain. Objective methods for measuring physical activity in children include heart rate,<sup>19</sup> accelerometers,<sup>20</sup> and pedometers.<sup>19</sup> Heart rate is strongly related to oxygen consumption and energy expenditure across a wide range of values,<sup>21–25</sup> heart rate monitoring can be implemented in large groups with multiple heart rate monitors, and heart rate monitors can collect heart rate in small intervals over long periods of observation, facilitating the measurement of accumulation of short bouts of physical activity throughout the day.<sup>26–28</sup> Heart rate has been the most popular objective measurement of physical activity, and this review examined the results of 26 studies that used this approach.

## METHODS

Twenty-six articles that used direct heart rate measures of physical activity on a minute-by-minute or less basis were obtained from a search of Medline and from articles referenced in retrieved studies in spring 1999. Articles were coded in terms of sample gender and age, number of hours of recording per day, number of days of recording, definition of activity intensities, and average number of minutes at specific activity intensities. To provide a sample of enough data to estimate child physical activity, we included only studies that measured physical activity for at least 8 hours. To generate data on the amount of physical activity as a function of heart rate, we included only articles that provided data on more than 1 heart rate level. Each study provided multiple data points, with data grouped by heart rate level, gender, and age. For the purposes of this article, the amount of time spent at or above a particular percentage of heart rate reserve (HRR) for male or female children in an age range defined by the study was used to define a study group. For example, assume a study reported minutes of activity associated with 3 levels of heart rate levels for 1 gender and 1 age group. This study would provide 1 study

group with 3 data points. If this same study provided data for both male and female youth, then data would be available for 2 study groups, with 6 data points. We excluded multiple articles that reported data on the same participants to prevent overrepresentation of some samples in the review.

Four dependent measures were used to estimate activity intensity reported across the studies; 3 involved heart rate, and 1 used percentage of maximal oxygen consumption (%VO<sub>2max</sub>). The first measure was %HRR. Resting heart rate changes with age,<sup>29</sup> such that reaching a particular heart rate may require different intensities of physical activity on the basis of preexercise heart rate. HRR takes into account these changes in resting heart rate by calculating the difference between resting heart rate and maximal heart rate and calculating the percentage of the difference from resting to maximal heart rate. Research has shown that maximal heart rate is stable through childhood and adolescence at a heart rate of approximately 200 beats per minute (bpm),<sup>30</sup> which agrees well with observations collected in the studies that are reviewed here. Eleven study groups provided maximal heart rates of  $199.8 \pm 3.0$ .

The second heart rate measure provided in some studies was percentage of resting heart rate. Resting heart rate was subtracted from 200 to calculate HRR, and the percentage above resting heart rate was multiplied by HRR to estimate %HRR. Resting heart rate was provided for 27 study groups, ranging from 66 to 94 (mean:  $81.1 \pm 8.4$ ). When resting heart rate was not provided, heart rate for age and gender was used.<sup>29</sup> For example, if a child had a resting heart rate of 80, then a percentage of resting heart rate of 50% would equal a heart rate level of 120 bpm. A heart rate of 120 bpm would be 33% HRR ( $[(120 - 80)/(200 - 80) = 33\%]$ ).

The third heart rate measure reported was the number of minutes greater than a specific heart rate. The most common levels were 120, 140, 160, and 180 bpm. These numbers were converted to %HRR on the basis of measured or predicted resting heart rate. Finally, some studies provided %VO<sub>2max</sub>, which generally is equivalent to %HRR.<sup>3</sup>

Many intensities of physical activity could be recommended for youth. There is general agreement that the lower threshold for aerobic fitness effects is 50% of HRR.<sup>31</sup> However, it is possible that significant health benefits could be attained from being active at lower intensities. Pate et al<sup>17</sup> recommended that children be active for at least 60 minutes/day at intensities equivalent to at least 5 to 8 metabolic equivalents (METs; 1 MET = resting metabolic rate), which is equivalent to roughly 40% to 60% VO<sub>2max</sub>. The compendium of physical activity<sup>32</sup> defines moderate-intensity physical activity as activity equivalent to 3 METs or greater, which, using the conversion of Pate et al,<sup>17</sup> would be equivalent to approximately 25% HRR. To provide for the full range of activity definitions, we coded activity data between 20% and 40% HRR, 40% and 50% HRR, 50% and 60% HRR, and 60% HRR or greater. Youth who met the 20% to 40% of HRR criteria were not engaged in sedentary behavior, and all had a heart rate of at least 120 bpm, but this physical activity intensity was below aerobic training levels and below the amounts recommended by Pate et al.<sup>17</sup> Youth who reached 40% HRR met minimum guidelines for physical activity recommended by Pate et al,<sup>17</sup> and youth who reached 50% HRR met recommendations for aerobic fitness training effects. Time at 60% HRR also was coded to examine shifts in activity at intensities above minimal intensities for aerobic training effects. There were insufficient data points to examine time spent at higher exercise intensities.

## Analytic Plan

The basic descriptive characteristics of the study groups were calculated, with differences in minutes of overall physical activity and minutes at different %HRR intensities presented by categorical variables for age and gender. Factorial analyses of variance were used to evaluate differences in minutes of physical activity for these variables. These analyses should be interpreted cautiously, because there are different numbers of study groups for each study, and each data point is treated as though it were generated as an independent data point. To assess the generalizability of the results across cultures and geographical regions, we used analysis of variance to compare the amount of activity in the range of 50% to 60% HRR in the United States ( $n = 12$ ) and Europe ( $n = 15$ ), controlling for gender, age, and hours and days of observation.

The structure of the data was suited to hierarchical linear modeling. Hierarchical linear models were used to evaluate differences in the rate of change over time, and each study provided changes in physical activity within each study group as a function of %HRR. The categorization of %HRR differs between participants, but hierarchical linear models estimate the slope of physical activity change as a function of different %HRR, so it is not critical that the same %HRR measures be used in each study.

Hierarchical linear models provide for the opportunity to evaluate the influence of age, gender, number of hours of measurement per day, and the number of days of measurement on the relationship between physical activity and HRR. The first step assesses the trajectory of change in physical activity per increment of %HRR without predictors to determine whether there is sufficient between-participant variability in the rate of change to add additional predictors. The second step was used to model whether adding predictors of age, gender, hours of measurement, and number of days of measurement improve the prediction of the intercept and trajectory of the relationship between physical activity and HRR. The details of these hierarchical linear models are presented in the appendix.

## RESULTS

Table 1 shows the number, gender, age, hours of observation, days of observation, definition of moderate to vigorous physical activity (MVPA), and results in minutes per day for all data points in the 26 studies that were included. The country in which the data were collected is included to demonstrate the generalizability of this phenomenon across cultures. The entire sample was based on 1883 youth. Results were presented by gender for 1550 (81.2%) of the participants (49.75% male, 50.25% female). An additional 333 individuals participated in studies, but gender was not specified. The age ranged from 3 to 17 years of age. The samples sizes of the studies varied from 11 to 230.

Table 2 presents minutes of physical activity of the study groups, categorized by age and gender. Age interacted with physical activity intensity ( $F[4134] = 5.60$ ;  $P < .001$ ), with effects more marked at lower intensity levels. In addition, there was a difference by gender ( $F[1113] = 5.61$ ;  $P = .02$ ); boys (56.2 minutes/day) were more active than girls (47.4 minutes/day) across all intensity levels. The time spent in physical activity is inversely related to %HRR, as shown in the scatterplot of minutes of physical activity as a function of heart rate levels as shown in Fig 1. There was no effect of geographical location (Europe/United States) on activity at 50% to 60% HRR ( $P > .90$ ), with adjusted estimates of 32.8 minutes in Europe and 37.9 in the United States.

The first hierarchical linear model used the studies that included information on gender. Twenty-two study groups were not included in this analysis. The unconditional model (Table 3) showed significant ( $P < .001$ ) between-study group variation for initial level and rate of change. The conditional model showed that only chronological age ( $P < .05$ ) was a significant predictor for the intercept and rate of change. The addition of the predictor variables to the conditional model reduced unexplained variance in the intercept by 8.6% and the unexplained variance in the rate of change by 8.2%.

In a second set of models, gender was removed from the model and the studies that did not include information on gender of the participants were

added. Chronological age again was a significant predictor (Table 4) for the intercept ( $P < .005$ ) and rate of change ( $P < .01$ ). Addition of predictor variables reduced the unexplained variance in the intercept by 18.9% and the unexplained variance in the rate of change by 19.4%.

The influence of age on physical activity is shown in Fig 2, with data blocked by %HRR, and general criteria of 30 or 60 minutes/day indicated by dashed lines. Youth of all ages attained more than 60 minutes/day of low-intensity physical activity; children 12 years of age or younger attained 2 hours or more of activity at these intensities. Children at all ages attain approximately 30 minutes/day of activity at traditional aerobic training intensity levels of 50% or more HRR.

## DISCUSSION

The purpose of this review was to examine with the use of heart rate measurements published data that measured physical activity in children and adolescents. Heart rate measurement technology provides the opportunity to measure the accumulation of physical activity in short bouts during the day. Our findings suggest that youth attain a large amount of physical activity during the day. The average youth accumulates approximately 30 minutes/day of activity at an aerobic fitness training level and approximately 50 minutes/day at an intensity of 5 METS or greater. The amount of activity at these intensities was greater than expected as based on the perception that youth are sedentary.<sup>16</sup> However, the accumulation of 30 minutes/day of physical activity at 50% HRR through several bouts of physical activity may produce very different physiologic effects than 1 sustained bout of physical activity at this training intensity.

Prescribing physical activity on the basis of intensities needed to produce aerobic fitness may set the activity intensity too high, and many children may gain benefits from being active at a %HRR that is considerably lower than 50%. The volume of physical activity at any intensity may be a more important and realistic goal than having arbitrary thresholds to determine a beneficial intensity of physical activity,<sup>19</sup> and it is physical activity rather than aerobic fitness that is more generally associated with health benefits.<sup>9</sup>

Children attained approximately 50 minutes/day of physical activity at 40% HRR, which is equivalent to 5 METS or greater, and falls just below the recommendations of Pate et al<sup>17</sup> for 60 minutes/day of activity at this intensity. The criteria of 5 METS or greater still may be more than necessary to enhance health, particularly in very sedentary children. Physical activities at intensities of 30% to 40% HRR may not produce aerobic fitness improvement, but these intensities are far from the image of a television-watching couch potato and very sedentary child. The average child gets more than 2 hours/day of activity at this intensity, and the average adolescent is active at this intensity for more than 80 minutes/day. Although analysis of physical activity levels across the studies by gender showed greater amounts of physical activity for boys than girls, a similar rate of

**TABLE 1.** Studies That Used Heart Rate to Determine MVPA

Study	n	Gender	Observation				Results (Minutes)	Country
			Age	Hours	Days	Definition of MVPA		
Al-Hazzaa and Sulaiman <sup>42</sup>	65	M	7–12	8	1	>139 bpm	27.7	Saudi Arabia
						>159 bpm	9.4	
Armstrong et al <sup>43</sup>	85	M	11–16	12	3	>139 bpm	45.4	UK
						>159 bpm	18.7	
	11	F				>139 bpm	33.2	
Armstrong et al <sup>44</sup>	92	M	11–16	12	3	>159 bpm	10.8	UK
						>139 bpm	44.0	
	13	F				>159 bpm	19.2	
	8					>139 bpm	34.9	
Armstrong and Bray <sup>45</sup>	67	M	10.7	12	3	>159 bpm	11.5	UK
						>139 bpm	67.7	
	65	F				>159 bpm	32.4	
						>139 bpm	59.0	
Atomi et al <sup>46</sup>	11	M	9–10	12	3	>159 bpm	24.5	Japan
						60% VO <sub>2max</sub>	34.0	
						>120 bpm	130.0	
Durant et al <sup>47</sup>	60	M	5–7	12	1	>120 bpm	149.9	USA
						50%>RHR	103.8	
	66	F				>120 bpm	174.5	
Falgairrette et al <sup>48</sup>	30	M	7–11	12	7	50%>RHR	68.8	Belgium
						>140 bpm	72.3	
	34	F				>160 bpm	30.5	
						>140 bpm	51.1	
						>160 bpm	16.4	
Freedson <sup>49</sup>	66		3–5	12	1	>140 bpm	42.3	USA
						>160 bpm	12.2	
Gavarry et al <sup>50</sup>	13	M	11–13	12	7	>50% HRR	90.4	France
						>70% HRR	24.0	
	15		14–16			>50% HRR	50.0	
						>70% HRR	12.1	
	19	F	11–13			>50% HRR	91.3	
						>70% HRR	19.6	
	19		14–16			>50% HRR	87.9	
						>70% HRR	20.9	
Gilbey and Gilbey <sup>51</sup>	50	M	9	14	4	>140 bpm	46.1	Singapore
						>160 bpm	14.9	
	64	F				>140 bpm	30.5	
						>160 bpm	10.0	
Gilliam et al <sup>52</sup>	22	M	6–7	12	1	>120 bpm	167.0	USA
						>140 bpm	56.2	
						>160 bpm	20.9	
						>180 bpm	6.5	
	18	F				>120 bpm	116.0	
						>140 bpm	29.6	
						>160 bpm	9.4	
						>180 bpm	2.2	
Gilliam and MacConnie <sup>53</sup>	10	M	7	12	1	>120 bpm	148.7	USA
						>140 bpm	51.8	
						>160 bpm	18.4	
						>180 bpm	5.8	
Harro <sup>54</sup>	30		4–8	12	4	>140 bpm	31.0	Estonia
						>150 bpm	18.5	
	32					>140 bpm	37.5	
						>150 bpm	19.5	
Janz <sup>55</sup>	15	M	7–15	12	6	>130 bpm	136.8	USA
						>150 bpm	72.0	
	15	F				>130 bpm	93.6	
						>150 bpm	43.2	
Livingstone et al <sup>23</sup>	11	M	7–9	<16	2–3	>50% peak VO <sub>2</sub>	91.0	Ireland
						>70% peak VO <sub>2</sub>	35.0	
	9	F				>50% peak VO <sub>2</sub>	39.0	
						>70% peak VO <sub>2</sub>	30.0	
	8	M	12–15			>50% peak VO <sub>2</sub>	52.0	
						>70% peak VO <sub>2</sub>	10.0	
	8	F				>50% peak VO <sub>2</sub>	15.0	
						>70% peak VO <sub>2</sub>	8.0	
MacConnie et al <sup>56</sup>	59		6–7	12	1	>120 bpm	150.6	USA
						>140 bpm	46.5	
						>160 bpm	16.5	
						>180 bpm	5.0	

TABLE 1. Continued

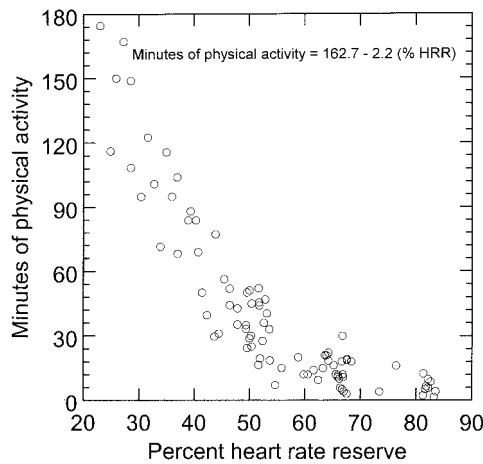
Study	n	Gender	Observation				Results (Minutes)	Country
			Age	Hours	Days	Definition of MVPA		
Maffeis et al <sup>24</sup>	13		9	>12	2-3	>50% peak VO <sub>2</sub>	42.0	Italy
Maffeis et al <sup>57</sup>	29		8-10	>12	3	>70% peak VO <sub>2</sub>	16.0	Italy
Pels and Geenen <sup>58</sup>	13	M	2nd	10	1	>50% peak VO <sub>2</sub>	18.0	USA
						>70% peak VO <sub>2</sub>	108.3	
						>120 bpm	44.2	
	12		5th			>140 bpm	22.1	
						>160 bpm	9.9	
						>180 bpm	71.3	
	9		7th			>120 bpm	25.0	
						>140 bpm	10.8	
						>160 bpm	4.1	
	10	F	2nd			>180 bpm	70.8	
						>120 bpm	24.3	
						>140 bpm	7.6	
	12		5th			>160 bpm	2.4	
						>180 bpm	72.6	
						>120 bpm	31.8	
	11		7th			>140 bpm	15.0	
						>160 bpm	5.2	
						>180 bpm	94.7	
Riddoch et al <sup>59</sup>	15	M	11-13	10	2-4	>120 bpm	35.2	Ireland
						>140 bpm	16.3	
						>160 bpm	8.6	
	8		14-16			>180 bpm	100.7	
						>120 bpm	24.3	
						>140 bpm	5.8	
	14	F	11-13			>160 bpm	1.6	
						>180 bpm	33.0	
						>50% peak AP	10.0	
	8		14-16			>70% peak AP	7.0	
						>50% peak AP	4.0	
						>70% peak AP	20.0	
Sallis et al <sup>60</sup>	18		5th	16	1	>50% peak AP	5.0	USA
						>70% peak AP	12.0	
	17		8th			>50% peak AP	3.0	
						>70% peak AP	115.5	
	15		11th			>120 bpm	44.9	
						>140 bpm	68.0	
	18		5th			>120 bpm	27.6	
						>140 bpm	83.7	
	19		8th			>120 bpm	40.3	
						>140 bpm	122.4	
15		11th grade			>120 bpm	42.7		
					>140 bpm	94.8		
Sallo and Silla <sup>28</sup>	25	M	7	10.5	1	>140 bpm	22.4	Estonia
						>157 bpm	53.6	
Sarıs et al <sup>61</sup>	89		4-6		1	>140 bpm	16.4	Netherlands
						>157 bpm	51.0	
						>176 bpm	14.0	
Simons-Morton et al <sup>62</sup>	27		3rd	12.5	1	>140 bpm	50.0	USA
						>157 bpm	12.0	
						>176 bpm	12.0	
Slooten et al (low altitude grp) <sup>63</sup>	29		8-12		1	>125 bpm	163.6	Bolivia
						>176 bpm	9.4	
						>125 bpm	153.6	
						>176 bpm	5.0	
						>180% RHR	40.1	
Welsman and Armstrong <sup>64</sup>	28	M	11-16	10	3	>200% RHR	20.0	UK
						>180% RHR	54.1	
						>200% RHR	29.2	
	45	F				>50% HRR	77.2	
						>60% HRR	46.8	
						>70% HRR	18.0	
						>80% HRR	16.1	
						>85% HRR	12.4	
						>140 bpm	36.0	
						>160 bpm	18.0	
						>140 bpm	30.0	
						>160 bpm	12.0	

Note: The age used for analyses was the mean within the age range.

**TABLE 2.** Characteristics of Study Groups by Age and Gender

Study Group	Minutes of Physical Activity at Levels of %HRR											
	20% to 40% HRR			40% to 50% HRR			50% to 60% HRR			60% to 70% HRR		
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD
All	33	128.0	45.6	27	47.1	14.9	28	29.3	13.7	34	14.7	6.0
Age (y)												
<7	24	137.4	48.1	5	46.4	11.9	10	25.2	14.2	16	15.5	4.6
7–12	5	118.4	25.0	4	46.7	20.2	6	35.7	10.2	7	12.9	6.0
>12	4	83.6	11.4	4	50.5	23.4	12	29.5	14.5	11	14.6	7.8
Gender												
Male	14	120.1	35.2	11	52.5	16.4	16	35.4	13.8	18	16.8	5.9
Female	10	116.5	33.1	13	42.1	14.1	8	20.2	6.3	13	11.0	4.8

*n* refers to number of data points, not total *n* being studied. SD indicates standard deviation.



**Fig 1.** Scatterplot of minutes of physical activity using different heart rate criteria to define activity level.

decrease in activity as a function of increases in %HRR was observed, and gender did not predict the slope of the relationship of HRR to time in physical activity.

Heart rate provides an indirect estimate of physical activity that makes assumptions on the basis of the linear relationship between heart rate and rate of oxygen uptake. A number of studies showed strong relationships between heart rate and direct measures of energy expenditure, including oxygen consumption or doubly labeled water.<sup>21–25</sup> The linearity that exists through most of the heart rate–energy expenditure relationship provides the opportunity to categorize intensity on the basis of heart rate. The precise relationship between heart rate and energy expenditure will differ as a function of aerobic fitness, gender, and age, and studies that use the relationship between heart rate and known energy expenditure to set cutoffs for moderate-intensity physical activity will be more valid than studies that use the same cutoffs for all children.

Heart rate changes quickly and is sensitive to detailed analyses of short-duration physical activities that can accumulate during the day. The increase and decrease of heart rate is different from direct measurements of movement, because increases in heart rate lag behind movement and may remain elevated after movement stops. An individual's heart rate will continue to be elevated after he or she ceases vigorous physical activity, which may lead to inflated

estimates of the number of minutes that the individual spent being active. The rate of return to baseline heart rate depends in part on the magnitude of change in heart rate, so activities that produce larger changes may have greater overestimates of physical activity. The rate of return to baseline heart rate also depends on fitness in that the return to resting will be faster in those who are more fit. In addition, heart rate may be less useful as a measure of exercise intensity at low or very high heart rates. Heart rate is sensitive to emotional stress, and at very low heart rates it may be difficult to differentiate the effects of stress versus physical activity. However, stress-induced changes are of much lower magnitude than exercise-induced changes and do not reach the magnitude usually associated with physical activity of even 20% HRR. The relationship between heart rate and oxygen consumption flattens out at very high heart rates, such that oxygen consumption increases even after heart rate has reached a maximal asymptote plateau, making heart rate an insensitive measure of energy expenditure at very great exercise intensities. Heart rate monitors usually involve wearing an electrode belt, which may influence the amount of physical activity, and children may not habituate as rapidly to wearing an electrode belt in comparison with less intrusive accelerometers, which would make our results an underestimate of true amounts of physical activity changes. Another limitation of heart rate monitors is that they may be removed or not put on during the observation period, during periods of vigorous activity such as swimming, and during periods of relative inactivity, such as showering.

A disadvantage of the present review is that 4 different methods of estimating the intensity of physical activity were used. Calculation of HRR uses resting and maximal heart rate, and in many cases these values were estimated on the basis of the participant's age and gender. The use of average data to develop estimates of HRR may be associated with a loss of resolution of physical activity intensity, but it is likely that underestimation and overestimation by using the estimates will even out, and the same trends would be observed with all parameters directly measured rather than estimated.

The physical activity data presented in this review are based on brief recordings of 1-minute intervals or less. The continuous assessment of usual activity

**TABLE 3.** Regression Coefficients From Unconditional and Conditional Hierarchical Linear Models for Physical Activity Time as a Function of %HRR for the Model That Included Gender as a Predictor

Fixed Effect	Unconditional Model				Conditional Model			
	Coefficient	SE	<i>t</i>	<i>P</i>	Coefficient	SE	<i>t</i>	<i>P</i>
Initial level	43.94	3.66	12.01	<.001				
Intercept					46.65	4.61	10.13	<.001
Age					-2.84	1.16	-2.44	.019
Gender					-6.13	6.78	-0.90	NS
Hours					2.41	1.28	1.88	.066
Days					0.36	1.63	0.22	NS
Rate of change	-1.887	0.169	11.18	<.001				
Intercept					-2.14	0.24	-8.97	<.001
Age					0.10	0.06	1.62	.11
Gender					0.003	0.35	0.01	NS
Hours					-.088	0.06	-1.43	.16
Days					-.04	.09	-0.47	NS

SE indicates standard error; NS, not significant.

**TABLE 4.** Estimates of Variance Components for Child Physical Activity in the Model Based on the Full Sample

Variance Component	Estimate	df	$\chi^2$	<i>P</i>
Unconditional model				
Initial level	594.13	59	451.69	<.001
Rate of change	1.08	59	140.88	<.001
Residual error	8376.20			
Model fit deviance	1815.71			
Conditional model				
Initial level	448.87	56	308.31	<.001
Rate of change	0.90	56	95.16	<.001
Residual error	8342.14			
Model fit deviance	1803.18			

patterns in children has provided the observation that children attain MVPA in very brief periods, rather than engage in 1 or 2 prolonged periods of activity.<sup>26,28</sup> These natural patterns of physical activity may be more reinforcing for children than the more common structured activity programs that require children to engage in long-duration, high-intensity exercise.<sup>27</sup> It would be interesting to contrast child physical activity programs that controlled for energy expenditure but contrasted multiple brief periods of activity with longer-duration activity, which are similar to comparisons of lifestyle versus structured activity programs in children<sup>33,34</sup> and adults.<sup>35,36</sup>

Although previous research established that bouts of activity as short as 10 minutes may provide health benefits in adults,<sup>37,38</sup> the benefits of short bouts of activity in youth have yet to be investigated. Future research should investigate whether bouts of such short duration provide the same level of health and fitness benefits as more extended bouts of activity. It also is important to consider the desired outcome of increases in physical activity. The activity amounts derived from heart rate presented here suggest that, on average, children are meeting the ACSM/CDC guidelines for physical activity of 30 minutes or more of MVPA per day. If youth-specific guidelines have the goal of increasing physical activity beyond current amounts, then it may be necessary to adopt a greater volume of physical activity per day to show benefits to health.<sup>10,17</sup> The 60 minutes/day of physical activity recommended by Pate et al<sup>17</sup> may be

more appropriate. If the goal is to match intensity of youth recommendations to those for adults and a criteria of 3 METS or greater is the guideline for moderate-intensity physical activity,<sup>32</sup> then most children attain 1 to 2 hours of activity at that level now.

Although the physical activity results suggest that many children attain large volumes of accumulated physical activity, few exercise scientists would suggest that children get enough activity. One recommendation that is based on the current findings might be that youth will have to increase to 120 to 150 minutes/day of total physical activity, based on child age. As the attraction of alternatives to physical activity increases and children's lives become busier, it may be very challenging to allocate sufficient time to physical activity. This represents the quandary of lower-intensity physical activity. As intensity decreases, the amount of time needed to attain activity of an equivalent total expenditure increases. In the guidelines for adults, the amount of time recommended for physical activity approximately doubled when recommendations shifted from 3 times/week of 30 minutes of vigorous physical activity to 30 minutes of MVPA most days of the week.

One alternative is to return to recommendations for higher-intensity, vigorous physical activity for youth, which would reduce the total time requirement for being physically active. In previous research by our group, we showed that children who were attempting to modify their physical activity using a lifestyle activity program chose to maximize the cost-benefit of physical activity time by engaging in aerobic exercise.<sup>33</sup> It is important to recognize potentially unique benefits of vigorous physical activity that is focused on enhancing aerobic fitness,<sup>39</sup> even while keeping in mind that this type of exercise recommendation may not be ideal for everyone. Future research should not only examine the typical characteristics of children's activity but also describe the children who do and do not lead sufficiently active lifestyles. Future research also should determine whether children who meet the revised guidelines are indeed significantly more healthy than children who are inactive or than children who attain

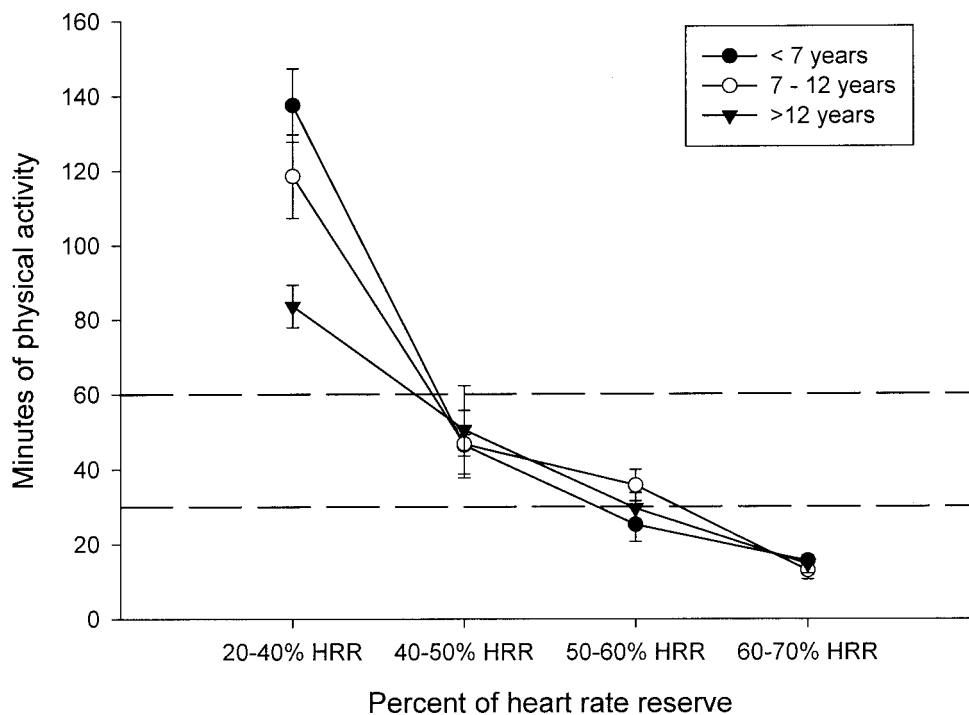


Fig 2. Minutes of physical activity at different percentages of HRR for children in 3 age groups (mean  $\pm$  standard error of the mean).

TABLE 5. Estimates of Variance Components for Child Physical Activity in the Model That Included Gender as a Predictor

Variance Component	Estimate	df	$\chi^2$	P
Unconditional model				
Initial level	614.02	51	777.14	<.001
Rate of change	1.07	51	116.32	<.001
Residual error	3496.89			
Model fit deviance	1502.55			
Conditional model				
Initial level	512.90	47	665.61	<.001
Rate of change	0.98	47	120.29	<.001
Residual error	3350.35			
Model fit deviance	1491.55			

their exercise in continuous bouts. Finally, research is needed to evaluate whether high volumes of lower-intensity physical activity represent a transition state for some children from being sedentary to engaging in aerobic fitness activities.

Another approach is to develop guidelines that are based on the amount of activity required to produce the behavioral or physiologic effects that are desired. The recommendations may be very different as based on child age, child baseline levels of physical activity, or the reason for suggesting an increase in physical activity. For example, in adults, the amount of physical activity needed to prevent obesity<sup>18</sup> may be very different from that needed to treat obesity,<sup>40</sup> which also may be different from the amount needed to maintain weight loss.<sup>41</sup> Most important, all of these guidelines are substantially greater than the amount of activity recommended in the current ACSM/CDC guidelines. For example, Saris<sup>18</sup> estimated that a woman would have to spend 105 minutes/day at MVPA to prevent obesity, and those who are successful at long-term weight maintenance expend an average of 2800 kcal/week in physical

activity.<sup>41</sup> An alternative to the use of one recommendation that fits all children is to identify the amounts of physical activity that are useful in promoting specific health goals and to develop recommendations that are based on these findings. Additional well-controlled, prospective, epidemiologic, and randomized controlled trials are needed to provide the evidence-based information needed to begin to specify these activity amounts.

## APPENDIX

The time in physical activity as a function of %HRR, age, gender, number of hours of measurement per day, and the number of days of measurement were represented in a 2-level hierarchical model, with time in physical activity across the %HRR amounts levels for each study group as level 1 units and characteristics of study groups as level 2 units. At level 1 (the within-study group model), each study group's time in physical activity ( $Y_{it}$ ) was represented by an individual trajectory that depended on an intercept ( $\pi_{0i}$ ), regression coefficient ( $\pi_{1i}$ ), and unique random error ( $e_{it}$ ), where  $t$  denotes time and  $i$  is each study group (Equation 1). The regression coefficient indicates the amount of change in time in physical activity per each increment in %HRR. HRR was group centered to make the intercept the mean because an HRR of 0 is not meaningful. In the second level (between-study group model), individual growth parameters were modeled among study groups (Equations 2 and 3). In Equation 2, the intercept ( $\pi_{0i}$ ) was modeled as the population mean for initial status ( $\beta_{00}$ ) plus random error ( $r_{0i}$ ), whereas in Equation 3, the rate of change ( $\pi_{1i}$ ) is a function of the population mean for the rate of change ( $\beta_{10}$ ) plus random error ( $r_{1i}$ ). Predictors of intercept for physical activity time were modeled in Equation 4, where  $\beta_{00}$  to  $\beta_{04}$  are the regression coefficients for the predictor variables  $X_{01i}$  to  $X_{04i}$ . Predictors of rate of change in physical activity time were modeled in Equation 5, where  $\beta_{11}$  to  $\beta_{14}$  are the regression coefficients for the predictor variables  $X_{01i}$  to  $X_{04i}$ .

$$\text{Equation 1} \quad Y_{it} = \pi_{0i} + \pi_{1i}(\%HRR) + e_{it}$$

$$\text{Equation 2} \quad \pi_{0i} = \beta_{00} + r_{0i}$$

$$\text{Equation 3} \quad \pi_{1i} = \beta_{10} + r_{1i}$$



**TABLE 6.** Regression Coefficients From Unconditional and Conditional Hierarchical Linear Models for Physical Activity Time as a Function of %HRR for the Model Based on the Full Sample

Fixed Effect	Unconditional Model				Conditional Model				
	Coefficient	SE	t	P	Coefficient	SE	t	P	
Initial level	46.43	3.58	12.97	<.001	45.88	3.22	14.23	<.001	
Intercept									
Age					-3.63	1.09	3.32	.002	
Hours					2.25	1.31	1.72	.091	
Days					-0.49	1.66	0.29	NS	
Rate of change	-2.21	0.18	11.82	<.001	-2.22	0.19	11.42	<.001	
Intercept									
Age					0.14	0.06	2.25	.028	
Hours					-0.07	0.07	1.67	NS	
Days					-.035	0.11	-0.31	NS	

SE indicates standard error; NS, not significant.

$$\text{Equation 4} \quad \pi_{0i} = \beta_{00} + \beta_{01}X_{01i} + \beta_{02}X_{02i} + \beta_{03}X_{03i} + \beta_{04}X_{04i} + r_{0i}$$

$$\text{Equation 5} \quad \pi_{1i} = \beta_{10} + \beta_{11}X_{01i} + \beta_{12}X_{02i} + \beta_{13}X_{03i} + \beta_{14}X_{04i} + r_{1i}$$

The first step in the analysis was to calculate unconditional models to determine whether there is sufficient between-participant variability to model successfully the predictors of rate of change in physical activity time as a function of HRR levels. Conditional models then were calculated, with factors included as predictors in the second level of age ( $X_{01i}$ ), gender ( $X_{02i}$ ), hours of measurement ( $X_{03i}$ ), and number of days of measurement ( $X_{04i}$ ). Age, hours, and days were centered around the sample mean, and the model was weighted by sample size. After the conditional models were calculated, the amount of variance that remained was calculated for rate of change by the formula: reduction of variance in physical activity change as a function of %HRR = rate of change in physical activity change unconditional model variance - rate of change in final model variance. For testing whether there was a significant amount of variation that may be explained by additional predictors or random variation,  $\chi^2$  tests examined whether the remaining variance in the conditional model was significantly different from 0. The reliability of the estimates of initial status and rate of change were calculated. Model fit deviance values also were generated to perform likelihood ratio tests to determine whether the reduction in variance components was significantly reduced in the conditional models. All models were weighted by study group N.

The first hierarchical linear model was based on the studies that included information on gender. Twenty-two data points were not included in this analysis. The regression components for this analysis are shown in Tables 3 and 5. A linear model fit the change in physical activity time (Physical activity time = intercept +  $\beta_1$  \* %HRR + error). This model showed significant between-participant variation for initial level (variance component = 614.02,  $\chi^2 = 777.14$ , df = 51,  $P < .001$ ) and for rate of change (variance component = 1.07,  $\chi^2 = 116.32$ , df = 51,  $P < .001$ ). Reliability for the intercept and rate of change in the unconditional model was 0.87 and 0.55, respectively.

Child age ( $\beta = -2.84$ ,  $t = 2.44$ ,  $P < .05$ ) was a significant predictor for the intercept in the conditional model, but gender, hours of measurement, and days of measurement were not significant predictors of either the intercept or the rate of change. The reliability of the intercept and the rate of change for the conditional model was 0.72 and 0.37, respectively. When predictor variables were added to the unconditional model in level 2, the unexplained variance in the intercept was reduced by 16.5% and the unexplained variance in the rate of change was reduced by 8.8%.

In the model without gender, studies that did not include information on gender were added (Tables 4 and 6). This model showed significant between-participant variation for initial level (variance component = 594.13,  $\chi^2 = 451.69$ , df = 59,  $P < .001$ ) and for rate of change (variance component = 1.08,  $\chi^2 = 140.88$ , df = 59,  $P < .001$ ). Reliability for the intercept and rate of change in the unconditional model was 0.76 and 0.41, respectively. In this conditional child model, child age ( $\beta = -3.63$ ,  $t = 3.32$ ,  $P < .002$ ) was a significant predictor for the intercept and for the rate of change

( $\beta = 0.14$ ,  $t = 2.25$ ,  $P = .028$ ). The reliability of the rate of intercept and the rate of change for the conditional model was 0.71 and 0.37, respectively. When level 1 predictor variables were added to the unconditional model, the unexplained variance in the intercept was reduced by 24.5% and the unexplained variance in the rate of change was reduced by 16.5%.

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## How Much Activity Do Youth Get? A Quantitative Review of Heart-Rate Measured Activity

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