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Secular Trends in Height Among Children During 2 Decades

The Bogalusa Heart Study

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Objective: To examine trends in height among 5- to 17-year-old children between 1973 and 1992.

Design: A panel design consisting of 7 cross-sectional surveys.

Participants: All schoolchildren residing in Bogalusa, La, were eligible. A total of 24 070 examinations were performed.

Results: During the study period, the mean height of schoolchildren increased by 0.70 cm per decade independently of race, sex, and age. Trends were most pronounced among preadolescents, blacks, and boys, with 9- to 12-year-old black boys showing a height increase of 1.8 cm per decade. We observed a decrease in the number of relatively short children (<10th percentile of height) and an increase in the number of tall children (>90th percentile of height). Because a secular trend was not seen among the 15- to 17-year-old children, our findings likely reflect an acceleration of maturation.

Conclusions: It has generally been assumed that secular increases in height among schoolchildren in the United States ceased by the mid-1900s. Our findings, which may be due to various environmental factors, demonstrate that care must be taken when using nonconcurrent reference data to assess the growth of children. Additional study is needed to determine if these secular trends are continuing and to examine possible explanations and consequences of these trends.

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Editor's Note: It is nice to have documentation of increases in height across 2 decades. Anyone who walked through doorways in buildings built a century or more ago "knew" this.

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BETWEEN 1800 and 1950, the height of children and adults in several European countries increased by more than 10 cm.[1-6(pp307-331)] In general, the largest increases in height (up to 2.5 cm per decade) were observed among 10- to 14-year-old children,[3,4,6(pp307-331)] reflecting a trend toward earlier maturation. The interpretation of historical data for North America is complicated by the large amount of immigration, but it is likely that comparable trends occurred.[7] Although the underlying cause of these secular height increases is uncertain,[7,8] several explanations have been proposed, with most focusing on improved environmental conditions, nutrition, or health care.

Secular height trends among youths in industrialized societies since the mid-1900s have been less consistent, and appear to have slowed or stopped in many developed countries.[2,5,8-11] Furthermore, it is generally assumed that height increases virtually ceased in the United States by the mid-1950s,[5,8,12] and no increases in the median heights of schoolchildren were seen between the 1960s and 1970s.[12,13] Recent secular height increases, however, have been observed among schoolchildren in Belgium (1960-1980),[14] Australia (1970-1983),[15] the Netherlands (1980-1989),[16] and England (1972-1990).[17] Although few details were given, substantial increases (up to 2.5 cm) in the heights of US schoolchildren were observed[13] between surveys conducted from 1976 to 1980 and 1988 to 1994. These recent findings suggest that the cessation of height trends in the United States during the 1950s and 1960s may have been only temporary.

Information on secular changes in height would provide information on nutritional status in early life, would help in

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PARTICIPANTS AND METHODS

STUDY POPULATION

The Bogalusa Heart Study is a community-based study of cardiovascular disease risk factors among schoolchildren and young adults.[23] Seven cross-sectional studies of schoolchildren, with participation rates of more than 80%, were conducted in ward 4 (Bogalusa, La) of Washington Parish, between 1973 and 1994[24]; most surveys were conducted during a school year, and are subsequently designated by the initial year of examination. (The 1990 population of Washington Parish, a fairly typical, biracial (one third black) community in the south, was ≈43 000.) With the exception of the first (1973) study, which had an upper age range of 14 years, each cross-sectional study targeted all 5- to 17-year-old schoolchildren in ward 4. Protocols were approved by appropriate institutional review boards, and informed consent was obtained from all participants.

Of the 24 171 examinations that were conducted, we excluded 11 children whose recorded race was other than white or black and 87 children who were missing either a weight or height measurement. Three measurements were also excluded among children who were examined at age 5 to 7 years in 1983 and 1984. A total of 24 070 observations from the 7 examinations were, therefore, included in the analyses. The repeated cross-sectional design resulted in 4812 participants examined 1 time only, 2915 examined 2 times, 2082 examined 3 times, and 1701 examined 4 or more times. Age was calculated as the difference between the birth and examination dates.

ANTHROPOMETRIC MEASUREMENTS

Using a manual height board, we measured each child's height twice to the nearest 0.1 cm, and the average of the 2 measurements was used in the analyses. The reproducibility of these height measurements was assessed in a 10% random sample in each cross-sectional study, with replicate measurements made 2 to 3 hours apart by the same observer. Based on 2518 replicates, the intraclass (within-observer) correlation coefficient for height was greater than 0.99. The mean absolute difference between the 2 measurements was 0.4 cm, and about 95% of the replicate measurements were within 1 cm of each other.

Although we focused on manually measured heights, it is conceivable that a bias (over time) in these measurements may have influenced the observed secular trends. We examined this possibility using data obtained with an automatic height board; this automatic instrument was used in all surveys except the 1992 survey, and measurements were available for 19 808 subjects. The Pearson correlation coefficient between the heights obtained with the manual and automatic board was greater than 0.99. Unless otherwise stated, all results are based on the manual height measurements.

STATISTICAL ANALYSES

Study-specific mean values of height were used to summarize the data, with levels adjusted for race, sex, and age differences across studies using regression analyses. (Because 15- to 17-year-old children were first examined in 1976, the initial 2 studies were combined in several analyses.) Differences in height trends across subgroups were examined by adding interaction terms to various regression models, and possible nonlinearity was assessed through the use of polynomial terms and restricted cubic splines.[25] Because there is an inverse association between obesity and age of sexual maturation,[26] several regression models assessed whether the secular height increases could be attributable to increases in obesity.

Secular height increases were also examined graphically using "lowess" (locally weighted scatterplot smoother) curves, a robust smoothing technique.[27] These curves were constructed using first-order regression models with a neighborhood width of 33%.

Because serial measurements from an individual are not independent, SAS statistical software, version 6.12 (PROC MIXED; SAS Institute Inc, Cary, NC), was used to compute regression coefficients and *P* values. It was assumed that the magnitude of the correlation between heights decreased with the interval between measurements (autoregressive structure), and robust SEs were calculated using a generalized estimating equation (empirical) option.[28] In age-stratified analyses, observations were treated as independent because only a small proportion of children within an age group were examined more than once.

the interpretation of growth standards, and may possibly have implications for the subsequent development of coronary heart disease and stroke.[18-20] In contrast to recent studies of schoolchildren in several European countries[14,16,17,21] and among selected groups in the United States,[22] there are few data for the general population of US schoolchildren. The present study examines changes in height among 5- to 17-year-old children in Bogalusa, La, between 1973 and 1992.

RESULTS

The distribution of the 24 070 height measurements by age group and year of examination is shown in **Table 1**. With the exception of 15- to 17-year-old children, who were first examined in 1976, there were approximately 20 years between the initial and final studies; the overall increase in height during this period was estimated to be 0.70 cm per decade. The largest increase was seen among 9- to 12-year-old children (≈1.1 cm per decade), and statistically significant increases in height (≈0.4-0.8 cm per decade) were also seen in most of the other age groups. There was little change, however, in the height of 15- to 17-year-old children between 1976 and 1992. Although most of the height increase appeared to occur after 1981, regression analyses provided little support ($P>.10$) for a nonlinear trend.

Several additional analyses of the height increases were then performed. Based on models that accounted for the nonindependence of serial measurements, the mean height of the 6698 children who were examined at least 2 times increased by 0.77 cm per decade (rather

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Table 1. Secular Trends in Height From 1973 to 1992*

Variable	Overall (N = 24 070)	Age, y: 5-6 (n = 3821)	7-8 (n = 3824)	9-10 (n = 4180)	11-12 (n = 4273)	13-14 (n = 4011)	15-17 (n = 3961)	Study Characteristics: Age, y†	Weight, kg
Year of study									
1973 (n = 3508)†	...	115 ± 6	127 ± 7	138 ± 7	150 ± 8	161 ± 9	...	...	...
1976 (n = 4065)	145 ± 21†	0.1	−0.1	0.1	−0.4	−0.5	168 ± 9†	11.5 ± 4.0	41.1
1978 (n = 3579)	0	0.3	−0.1	0.2	−0.2	−0.4	−0.4	11.2 ± 4.0	40.1
1981 (n = 3303)	0.3	0	0.2	1.1	−0.1	0.4	−0.5	11.0 ± 4.0	40.1
1983 (n = 3263)	0.8	0.5	0.3	1.5	1.2	0.7	−0.1	11.4 ± 4.0	43.2
1987 (n = 3236)	0.5	0.2	0.1	1.0	0.5	0.9	0.2	11.0 ± 4.0	41.9
1992 (n = 3116)	1.3	0.9	1.2	2.1	2.2	1.1	−0.2	11.4 ± 4.0	45.2
Change in height‡ per 10 y (SE), cm	0.70 (0.08)§	0.36 (0.14)‖	0.52 (0.14)§	1.06 (0.16)§	1.14 (0.17)§	0.83 (0.19)§	0.05 (0.20)	...	...
Race and sex differences¶									
Black-white	...	2.2	2.0	2.3	1.9	0	−0.1	...	...
Boy-girl	...	0.6	0.6	−0.5	−2.4	3.5	11.3	...	...

*Data are given as the estimated difference in mean height (measured in centimeters) from the mean level in the first examination unless otherwise indicated; a negative value indicates a decrease in the estimated mean height. These estimates are based on regression models that included indicator variables for the 7 studies, race-sex group (3 dummy variables), and age (linear, squared, and cubic terms). Ellipses indicate data not applicable.

†Data are given as the mean ± SD.

‡As assessed by a "chunk" test (df=6), the differences in height across the 7 examinations were statistically significant at P=.001 among the 9 to 10 and older age groups.

§P<.001.

‖P<.01.

¶A positive value indicates that the mean height is higher among blacks vs whites and among boys vs girls.

Table 2. Secular Trends in Height From 1973 to 1992*

Variable	Age, y: 5-8 Whites Boys (n = 2424)	5-8 Whites Girls (n = 2401)	5-8 Blacks Boys (n = 1402)	5-8 Blacks Girls (n = 1418)	9-12 Whites Boys (n = 2712)	9-12 Whites Girls (n = 2580)	9-12 Blacks Boys (n = 1589)	9-12 Blacks Girls (n = 1572)	13-17† Whites Boys (n = 2246)	13-17† Whites Girls (n = 2096)	13-17† Blacks Boys (n = 1442)	13-17† Blacks Girls (n = 1455)
Year of study												
1973 (n = 3508)‡	121 ± 8	120 ± 9	123 ± 9	123 ± 9	143 ± 9	145 ± 11	143 ± 9	147 ± 11	...	...	...	...
1976 (n = 4065)	−0.2	−0.5	0.5	0.6	0	−0.9	0.3	0	169 ± 10‡	161 ± 7‡	169 ± 10‡	161 ± 6‡
1978 (n = 3579)	−0.1	−0.1	0.6	0.2	−0.2	−0.7	0.3	1.0	0.2	−0.4	−0.8	−0.6
1981 (n = 3303)	−0.4	0.1	1.3	−0.1	0.4	−0.7	1.3	2.0	0.4	0.3	−0.9	−0.3
1983 (n = 3263)	−0.7	0.3	2.1	1.0	0.9	0.8	2.0	1.9	0.9	0	−0.1	0.5
1987 (n = 3236)	0.2	−0.4	1.3	−0.1	−0.3	0.1	2.4	1.6	0.6	0.7	0.5	0.4
1992 (n = 3116)	0.7	0.9	2.0	1.1	1.8	1.2	3.3	3.0	1.0	0.1	0.3	0.5
Estimated change in height per 10 y, cm	0.3	0.4	0.9§	0.4	0.7§	0.8§	1.8§	1.5§	0.6	0.3	0.5	0.5

*Data are given as the estimated difference in height (measured in centimeters) from levels in the first examination unless otherwise indicated. These estimates are based on regression models that include indicator variables for the 7 studies and age (linear, squared, and cubic terms).

†Ellipses indicate data not applicable, as those aged 15 to 17 years were not examined in 1973.

‡Data are given as mean ± SD.

§P<.001.

than the 0.70 cm per decade shown in Table 1). Furthermore, the observed height increases were slightly larger (0.8 cm per decade) if analyses were based on the automatic instrument (n = 19 808) than on manually measured heights. We also found that the height increases were mostly independent of the 4-kg increase in weight that occurred during the study period. Controlling for relative weight or triceps skinfold thickness, for example, reduced the overall height increase from 0.70 cm to approximately 0.60 cm per decade.

Height trends varied substantially by race and sex (**Table 2**). The largest increases were seen among black boys, with 5- to 8-year-old and 9- to 12-year-old boys showing increases of 0.9 and 1.8 cm per decade, respectively; furthermore, heights in these groups consistently increased in all years following 1973. Among 9- to 12-year-old children, the increase in the height of black girls was almost as large as that among black boys, while increases among white children were only about half as large. No statistically significant increase was seen in any

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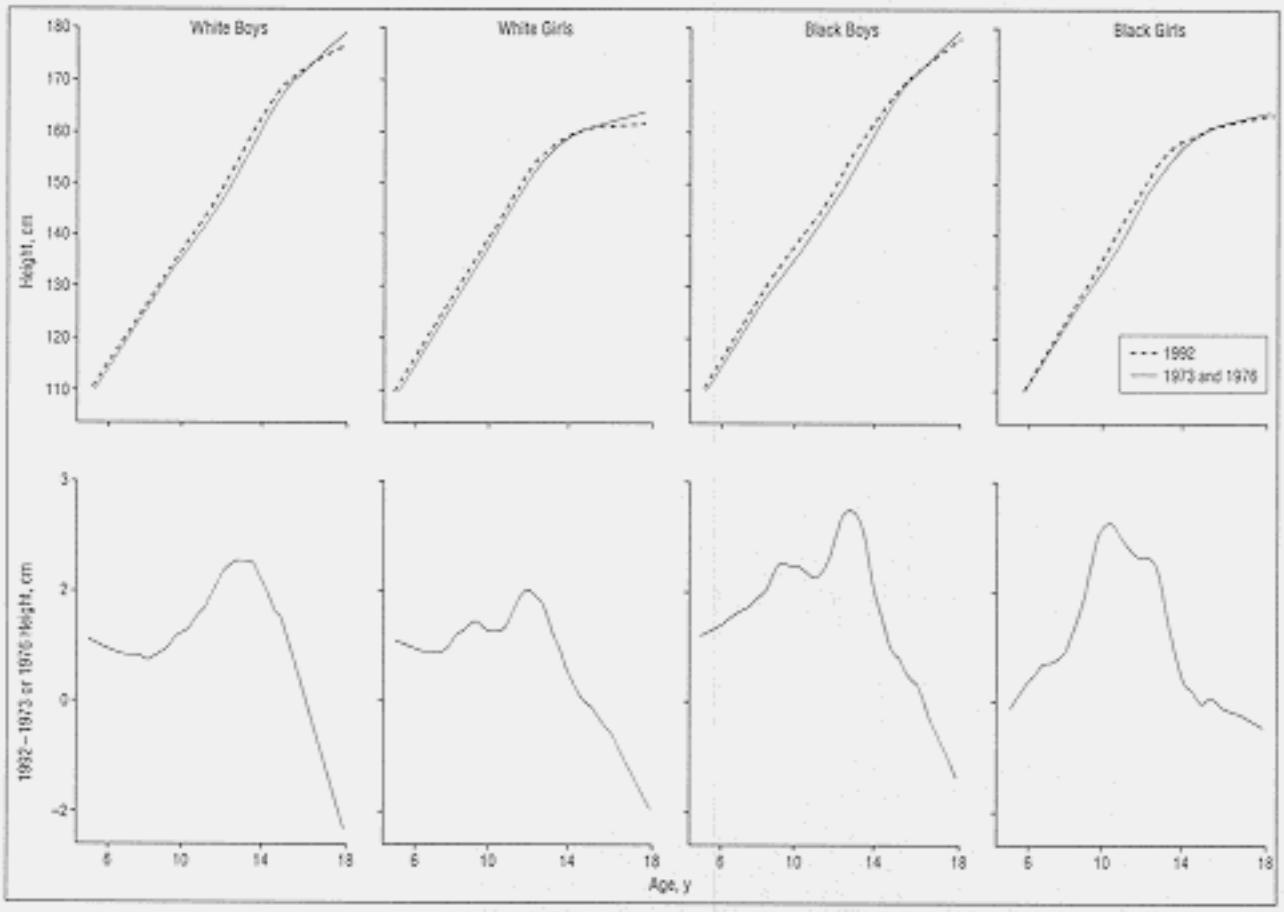

Figure 1. *Smoothed levels of height by age (upper panels) for the combined 1973 and 1976 examinations and for the 1992 examination. Lowess (locally weighted scatterplot smoother) curves were smoothed using a neighborhood width of 33%, and were constructed separately for each race-sex group and study period. The bottom panels show the estimated increases in height between the combined 1973 and 1976 examinations and the 1992 examination; a positive value represents an increase in height over the period.*

race-sex group among 13- to 17-year-old children. As assessed in regression models, the secular height increases varied significantly ($P<.01$ for each interaction) by age, race, and sex, with age being the most important effect modifier.

Smoothed levels of height are shown in the upper panels of **Figure 1** for the combined 1973 and 1976 studies and the 1992 study. In general, the relation of height to age was fairly linear up to age 13 years, with mean heights increasing by 5 to 6 cm/y; subsequent increases were either slightly smaller (4 cm/y) among boys or much smaller (≈1 cm/y) among girls. Secular height trends are emphasized in the lower panels, in which height increases (rather than actual heights) are shown on the y-axis. Among boys, the secular increase was largest at approximately age 13 years (whites, +2.6 cm; blacks, +3.5 cm), whereas the increase was largest among girls between the ages of 10 and 12 years (whites, +2.0 cm; blacks, +3.3 cm). These smoothed curves also suggested a negative secular trend among older adolescents, but various regression models indicated that the decreases among 17-year-old children were not statistically significant ($P>.20$).

We then examined (**Table 3**) if the secular trends could be attributed to a decrease in the number of short children (defined as a height <10th percentile based on race-, sex-, and age-specific levels in 1973 and 1976) or an increase in the number of tall children (height >90th percentile). If there had been no secular height trend, 10% of the children examined in 1992 would have been classified as short, and another 10% as tall; in contrast, 8% were found to be short, and 15% to be tall. Trends were most striking among black boys, with only 3% of the youngest children classified as short, and 29% of the 11- to 12-year-old children classified as tall. About 25% of the 9- to 10-year-old children examined in 1992 had a height above the 90th percentile.

Various percentiles of height for 12-year-old boys are shown in **Figure 2** for each of the 7 examinations. (This sex-age group showed the largest per decade increase in mean height during the study, with increases of 3.0 cm among blacks and 1.2 cm among whites.) Among black boys (top panel), there was an almost continuous increase in all height percentiles during the 20-year study period, with the 95th percentile increasing by approximately 10 cm and the fifth percentile increasing by approximately 7 cm. These changes would have resulted in a height of 156 cm being at the 75th percentile in 1973 but below the median in 1992. Height trends among white boys (bottom panel) were less consistent, with the fifth percentile remaining fairly constant (≈140 cm) and other percentiles increasing by 2 to 5 cm. A height

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Table 3. Proportion of Children in 1992 Considered to Be Short or Tall Based on Heights Measured in 1973 to 1977*

	Whites		Blacks		
Age, y	Boys (n = 864)	Girls (n = 883)	Boys (n = 660)	Girls (n = 709)	Overall (N = 3116)
Short					
5-6	10	8	3	9	7
7-8	6	6	5	10	7
9-10	8	10	8	8	9
11-12	11	5	4	7	7
13-14	4	8	5	10	7
15-17	4	13	13	9	11
Overall	8	8	7	9	8
Tall					
5-6	20	8	23	13	16
7-8	15	17	20	11	16
9-10	22	24	25	22	23
11-12	17	11	29	15	17
13-14	12	9	10	7	9
15-17	12	7	12	17	11
Overall	16	13	20	14	15

*Short indicates less than the 10th percentile of height; tall, greater than the 90th percentile of height. The heights of schoolchildren (n = 7573) examined in the 1973 to 1974 and 1976 to 1977 surveys were used for the calculation of the 10th and 90th percentiles. These percentiles were calculated within each race, sex, and (1-year) age group; the 52 race-sex-age categories ranged in size from 44 (17-year-old black boys) to 245 (10-year-old white boys), with a mean size of 146 children. Data show the proportion of subjects examined in the 1992 examination who were short or tall based on heights in 1973 to 1977.

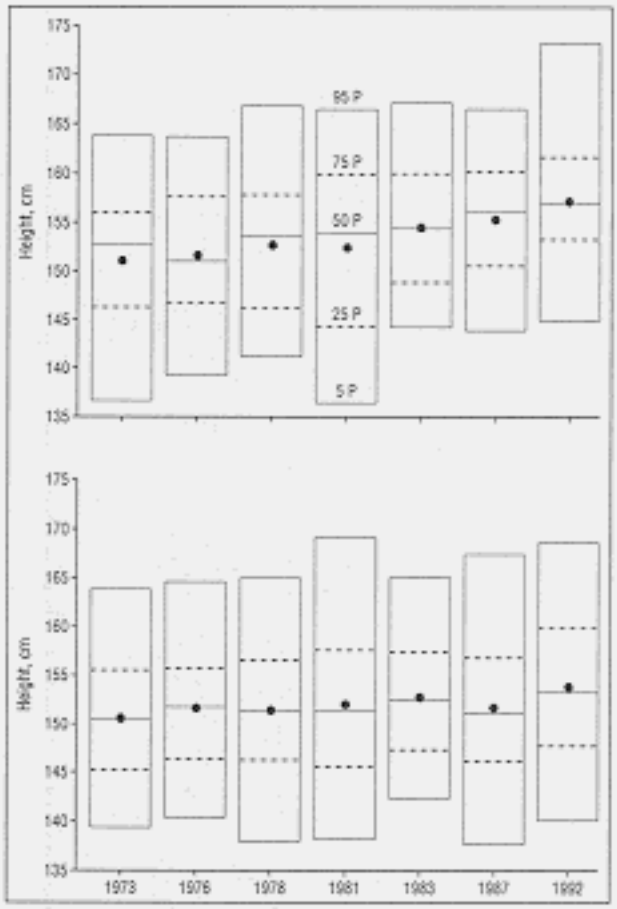

Figure 2. *Comparison of various height percentiles among 12-year-old black (top) and white (bottom) boys within each cross-sectional examination. Closed circles indicate the mean; solid lines at the top of each box, 95th percentile; solid lines at the middle of each box, 50th percentile; solid lines at the bottom of each box, fifth percentile; dashed lines in the upper part of each box, 75th percentile; and dashed lines in the lower part of each box, 25th percentile. Sample sizes within each study range from 34 to 88 (blacks) and from 69 to 151 (whites).*

of 156 cm among white boys would have been between the 70th and 80th percentiles in 1973 and 1992.

COMMENT

We found that the average height of schoolchildren in Bogalusa increased by 0.7 cm per decade between 1973 and 1992. These secular trends varied by (1) age, with the largest increases seen among 9- to 12-year-old children; (2) race, with larger increases among blacks; and (3) sex, with larger increases among boys. The relatively large height increase (+3.5 cm) seen among 9- to 12-year-old black boys during the study period is similar to that achieved during 6 months of growth. Secular trends were observed throughout the entire height distribution, with an increase in the number of tall children and a decrease in the number of short children. The lack of a secular trend among 15- to 17-year-old children suggests that there has been an increase in the tempo of growth (or rate of maturation) rather than in the final attained height. It is known that growth ceases at younger ages than in the early 1900s.[5]

Between 1800 and 1950, the average heights in several western countries increased by approximately 1.5 cm per decade among children and 2.5 cm per decade among adolescents.[1-5,6(pp307-331),7] Recent secular trends have been more variable, with children in some countries showing little or no change in height,[9-12] while increases of more than 1 cm per decade have been reported in other countries (Belgium, England, the Netherlands, and Australia).[14-17,29] It has been assumed that secular trends in height in the United States had stopped by the mid-1900s,[5,8,12] and there was little, if any, change in the heights of children between 1963 and 1975.[12] The present results, however, suggest that a secular trend in height may be reoccurring. In agreement with this possibility, national data[13] indicate that mean heights of US schoolchildren increased (up to 2.5 cm for some groups) between 1976 and 1980 (National Health and Nutrition Examination Survey 2) and between 1988 and 1994 (National Health and Nutrition Examination Survey 3). The magnitudes of these trends are substantial, but they are less than the 6 to 7 cm per decade increase seen among 15-year-old children between 1870 and 1955.[7]

Many explanations have been suggested for the secular height increases that have occurred in developed countries since 1800. Hypotheses include changes in the prevalence of growth-retarding illnesses, family size and child labor, the nutritional content of diet (particularly protein and calcium), housing, personal hygiene, health habits, and medical care.[3,6(pp221-239),8] Overnutrition during infancy may also be important, as formula-fed infants have a relatively high energy intake and are introduced to solid foods at an early age.[8] However, the underlying cause of

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the historical secular trends,[4] and those observed in the present study, is uncertain. Although it is possible that the height increases in the present study were influenced by trends in relative weight,[24,26] the observed height trends were largely independent of changes in weight and triceps skinfold thickness. Large secular increases in weight can occur without concomitant increases in height.[30]

Differences in secular trends in height by age have been observed by many investigators,[4,5,31] with the largest increases typically occurring between the ages of 9 and 13 years. An increase in the tempo of growth and a trend toward earlier maturation[2,6,27,32(pp171-203),33] could produce this age pattern, as 13-year-old children (for example) who were measured recently, but not in the past, may have experienced a pubertal growth spurt. (The annual height increase during the growth spurt varies greatly, but the median is ≈7 cm, and increments of 10-12 cm are not unusual.[5,32(pp95-109)]) The largest height increases in the present study occurred at the ages of 10 to 12 years (girls) and 13 years (boys), estimates that are close to the age of the peak height velocity.[32(pp95-109)] Other investigators[2,16,17,30] have also reported a larger secular height increase among boys than among girls, possibly due to differences in growth spurts.[32(pp171-203)]

We observed, as did Troiano and Flegal,[13] a substantial racial difference: height increases among 9- to 12-year-old children were almost twice as large among blacks as among whites. Growth and development are strongly influenced by socioeconomic conditions,[6(pp221-239),34] and secular height increases have sometimes varied by social class.[21,29] Although the characteristics responsible for the black-white contrasts in the secular height increases are uncertain, our findings may be related to changes in differences in health care, participation in breakfast and lunch programs at schools, or other environmental differences. The median heights of black children in Bogalusa were slightly greater than those of white children throughout the entire study period.

The secular trends that we observed may have implications for various diseases in adulthood. For example, early-maturing adolescents (defined by skeletal age, age at peak height velocity, or menarcheal age) have been found to have higher relative weights, thicker skinfolds, and a truncal fat distribution in later life[35,36]; a young age at menarche also increases the risk for breast cancer.[37] Although the incidence of cardiovascular disease is inversely related to adult height,[18-20] it is not certain if there is an association with the tempo of growth. As emphasized by Hauspie et al,[29] the maximization of secular height trends may not always be desirable.

Because secular trends can be confounded by changes in the composition of the study sample over time due to immigration, sample selection, or demographics,[38] it is likely that analyses performed in a relatively stable community with a high participation rate,[24] such as Bogalusa, may be particularly informative. Although it is possible that a selection bias may have occurred, this is unlikely to have had a major impact as (1) participation rates were high throughout the study period and (2) results did not vary substantially by the number of times a child was examined. Our results are likely to be generalizable to other populations of white and black children in the United States, but we cannot exclude the possibility that specific environmental changes occurred in Bogalusa but not in other parts of the nation. The similarity of our results, however, to national trends[13,39] makes this unlikely. Few of the participants in the Bogalusa Heart Study were Hispanic or Asian, and information on secular trends in these ethnic groups would be informative.

Although the secular height increases were proportionately smaller than the observed trends in being overweight,[24] our results emphasize the importance of using concurrent reference values to assess growth. Our findings may also have implications for the use of the Quetelet index (calculated as weight in kilograms divided by height in meters squared) to identify overweight children. Independently of sex and age, there is a moderate correlation ($r \approx 0.25$-0.30) between height and the Quetelet index, with the association strongest between the ages of 8 and 13 years. Among these children, a 2-cm increase in height is, on average, associated with a 0.4-kg/m^2 increase in the Quetelet index; this represents about 20% of the 1.5- to 2.0-kg/m^2 increase that was observed between 1973 and 1992.[24] Additional study is needed to determine if the secular height increases are present in other samples, to explore reasons for their occurrence, and to examine their potential impact on obesity and various diseases in adulthood.

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