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Number 164

Forced Vital Capacity of Children 6-11 Years

United States

Forced vital capacity measurements of children 6-11 years, United States, 1963-65, by chronologic age, sex, race, stature, and sitting height are presented and discussed.

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In accordance with specifications established by the National Center for Health Statistics, the Bureau of the Census, under a contractual arrangement, participated in planning the survey and collecting the data.

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FORCED VITAL CAPACITY OF CHILDREN 6-11 YEARS

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INTRODUCTION

This report presents data on forced vital capacity (FVC) of children ages 6-11 years in the United States, by age, sex, race, stature, and sitting height obtained in Cycle II of the Health Examination Survey (HES) as the most reliable of the ventilatory parameters measured on a 6-liter Collins Vitalometer. This publication, one of a series reporting the findings from the Health Examination Survey, assesses the healthy growth and development of children. There is discussion and appraisal of these data considered as clinical standards; the discussion stresses their epidemiologic value and their consideration as one of the many physical and physiologic parameters of the growing child. At the end of the report is a list of recommended adjusting factors to these reported values, and the critical unanswered questions are identified.

The Health Examination Survey, conducted by the National Center for Health Statistics from 1959 to 1970 to collect and analyze health-related data on the American people *through direct examination of selected subjects,* was a succession of separate programs (or "cycles"); each cycle lasted from 2 to 4 years. Since 1971 the Survey has been called the Health and Nutrition Examination Survey (HANES) because it assumed the additional responsibility of assessing nutritional status.

Cycle I of HES, conducted from 1959 to 1962, obtained information on the prevalence of certain chronic diseases and the distribution of a number of anthropometric and sensory characteristics in 18-70-year-old civilian noninstitutionalized people living in the conterminous United States. The general plan and operation of the survey and Cycle I have been described in two previous reports,[1,2] and most of the results were published in other Series 11 reports of *Vital and Health Statistics.*

Cycle II, conducted from July 1963 to December 1965, involved selection and examination of a probability sample of noninstitutionalized children in the United States aged 6-11 years. In this program, 96 percent of the 7,417 children selected for the sample were examined. The examination had two emphases. The first concerned factors related to healthy growth and development as determined by a physician, a nurse, a dentist, and a psychologist; the second concerned a variety of somatic and physiologic measurements performed by specially trained technicians. The detailed plan and operation of Cycle II and the response results are described in *Vital and Health Statistics,* Series 1, Number 5.[3] A comparable program of examinations and data collection for youths aged 12-17 years, Cycle III, was completed in 1970, and the plan and operation are described in Series 1, Number 8.[4] Many of the findings on growth and development have also been published.

The present report is the first in a series of HES spirometry reports that will present and discuss findings from the U.S. population aged 6-75 years. Several, more technically specialized, methodologic reports will also be included in this series. Although the present report considers only FVC, subsequent reports will consider many additional spirometric parameters and their interrelationships among themselves and with other physical, physiologic, and behavioral variables that are obtained in the HES examinations. Spirometric data using increasingly sophisticated spirometry equipment and techniques and collected in cycles subsequent to these currently reported Cycle II data will have been recorded on magnetic tape.

Besides being the first in a series of HES spirometry publications on all ages, the present report also is part of the HES series on parameters of human growth and development, especially the physiologic ones (namely, physician's examination of heart and lungs, medical and exercise history, spirometric testing, chest X-ray, EKG, measurements of blood pressure, physical exercise capacity, hand-grip strength, and hematocrit determinations).

Analysis of these present data was first begun in 1966, but an almost endless succession of methodologic and interpretive problems delayed completion for publication from 1969, as originally estimated, to the present time. Besides requiring several major methodologic substudies, the multiplicity of problems also required shelving two of the original three spirometric variables that were measured—forced expiratory volume at 1 second ($FEV_{1.0}$) and forced expiratory flow rate between 25 percent and 75 percent of the FVC ($FEF_{25\text{-}75\%}$). They have been shelved temporarily or permanently; only FVC is reported at this time.

The first problem encountered in 1966—and still the most serious—was that the spirometric recordings of many of the children contained obvious technical flaws, in most cases procedural errors by the subjects. A preliminary assessment estimated that between 10 and 20 percent of the subjects' spirograms so obviously did not represent a properly performed maximum expiratory effort that they would have to be discarded; those of the remainder appeared "probably acceptable." This naturally forced the following question (which has been asked again and again): "Are these data *worth* trying to clean up for publication; that is, will the resultant quality and uniqueness of the data, together with the great quantity and quality of other data collected on the subjects to which the spirometry findings can be related, justify both the enormous additional effort (and possible failure) and eventual formal publication?"

The cost/benefit considerations can be summarized: (1) the extent and severity of the technical imperfections in the data; (2) the feasibility of culling the technically flawed data and adjusting the remaining data; (3) the time, effort, and money required for this effort; (4) the quality of the final product and the spinoff methodologic side benefits; (5) the meagerness of other published spirometry data from these age groups; (6) the probable value of population-wide estimates of "developing" ventilatory function as one of the parameters of physiologic and somatic growth and development of children obtained by HES.

The complicated sequence of procedures by which the data from all of the original recordings were technically reassessed and edited in the attempt to adjust them and to arrive at the "best current U.S. estimates of FVC values for children 6-11 years of age in the United States, 1963-65" is described in detail in a companion methodologic report.[5] An adjustment to produce "best-estimated values" could never be completed because several essential adjusting factors are still missing; instead, these factors are discussed, listed, and summarized. Separate publication in the National Center for Health Statistics methodologic series was chosen for the other report because of the great amount of technical detail (both spirometric and epidemiologic-statistical), which would appeal to a limited audience with specialized interests and skills, and also to preserve the narrative continuity and rationale of the entire editing-adjusting process. However, every effort has been made to keep this report (which presents the actual findings of FVC, stature, and sitting height) as self-contained as possible with the caveat that the population estimates reported here have been edited by deleting 1,129 subjects' spirometric recordings (15.9 percent) because of technical flaws and imputing by stepwise multiple regression their values together with those of 187 other subjects (2.6 percent) whose spirograms were either lost or never obtained.

This long undertaking would have been a foolhardy one without the benefit of encouragement, advice, and criticism of many colleagues over the years. Three colleagues require special thanks: David Discher and Giles Filley for their help with matters of spirometry, pulmonary physiology, and chest diseases; and Robert Reed who assisted with biostatistical perspective.

METHOD

At each of 40 locations preselected randomly throughout the United States (see appendix for survey design), the children were brought to the centrally located mobile center for an examination which lasted about 2½ hours. Six children were examined in the morning and six in the afternoon. They were transported to and from school or home.

When the children entered the center, their oral temperature was taken and a cursory screening for acute illness was made; if illness was detected in a child, he was sent home and examined at a later date. The examinees changed into shorts, cotton sweat socks, and a light, sleeveless top and proceeded to different stages of the examination, each child following a different route. There were six different stations where examinations were conducted simultaneously, and the stations were exchanged so that by the end of 2½ hours each child had undergone essentially the same procedures by the same examiners but in a different sequence. At three of these stations a pediatrician, a dentist, and a psychologist did the testing, and at the other three stations well-trained technicians performed a number of other examinations (chest and hand-wrist X-rays, hearing and vision tests, respiratory function tests and electrocardiography, a bicycle exercise test, a battery of body measurements, and a grip-strength test).

Spirometry Measurement

Respiratory function was assessed on each child by means of a set of forced expiratory spirograms (FES) obtained from a 6-liter Collins Vitalometer. Each child was instructed in the test procedure[a] by the technician, who actually demonstrated the maneuver.

[a]The set of instructions used was based on the standard instruction booklet (alternative procedure) supplied by the equipment manufacturer. Although the authors suspected (retrospectively) that this closed procedure (as distinguished from the more commonly used open procedure whereby the subject reaches maximal inspiration using ambient air) might have been a significant cause of underestimation of FVC due to the inhibition of maximal inhalation in a large proportion in children, a subsequent substudy, which is described in the methodologic report, demonstrated otherwise. We conclude that the choice of the open or closed system has no discernible effect on FVC in young children.

The procedure required that the subject, standing comfortably erect, be fitted with a nose clip (considered necessary to prevent expiratory air leakage among young children) and a disposable cardboard mouthpiece (with lips sealed tightly to prevent air leakage) that was inserted into the rubber hose leading to the spirometer; when reasonably comfortable with this, the subject was to *maximally* inhale (from a state of "resting respiration") and then *forcefully* expire *all* his air as *rapidly* and *completely* as possible. During the maneuver the attending technician verbally exhorted the subject to blow out *all* his air as hard as possible. One or two practice trials were usually performed; and then, at least two, but seldom more than three, trials were recorded, with special care taken to insure that the spirometer's breathing tube was not looped or kinked. (A kinked tube could cause air turbulence and result in an increased airway resistance which, in turn, could artificially diminish flow-rate measurements.)

Prior to each day's testing, the barometric pressure was noted and recorded. In addition, the room temperature was recorded before each examination. The water level in the spirometer was carefully maintained within 1½ inches of the top of the bell cannister to prevent excessive spirometer dead space, which would cause an underreading of the recorded signal.

The spirometer (Collins Vitalometer) (figure 1) is a water-sealed counterbalanced, lightweight cylindrical bell that is filled or emptied during exhalation and inhalation, respectively. Its dis-

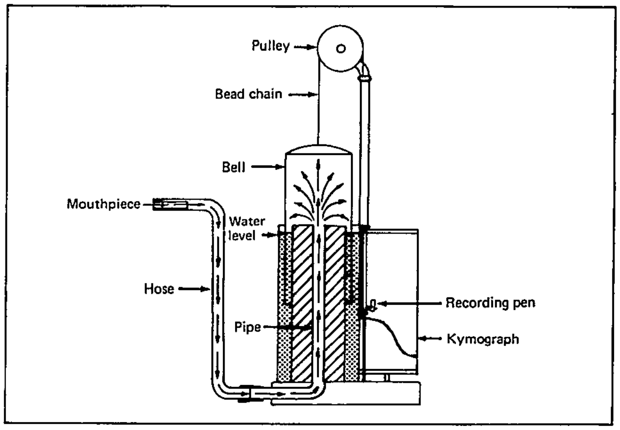

Figure 1. Schematic drawing of a wet system spirometer

placements are recorded on a moving chart (kymograph). The writing device is connected to the bell by a pulley system. The kymograph is driven by a motor at a constant speed of 32 millimeters per second.

The resultant kymographic tracing is a time-volume coordinate providing a monotonically increasing signal which ultimately reaches a plateau and should be free from inhalation artifacts (figure 2). From this waveform, calculation of volume and flow-rate measurements are made by careful measurement of specified time and volume increments.

The best trial of each child's recorded set of forced expiratory spirograms was chosen to be measured.

The three measurements made on the best trial were:

1. Forced vital capacity (FVC), the largest volume measured on complete forced expiration after the deepest inspiration.

2. Forced expiratory volume at 1 second ($FEV_{1.0}$), the volume of air expired during the first second of the FES.

3. Forced expiratory flow rate between 25 percent and 75 percent of the FVC ($FEF_{25\text{-}75\%}$), the average rate of flow during the middle 50 percent of FES.

Measurements were made by determining the number of millimeters traveled by the kymograph pen from the baseline to the intersect of

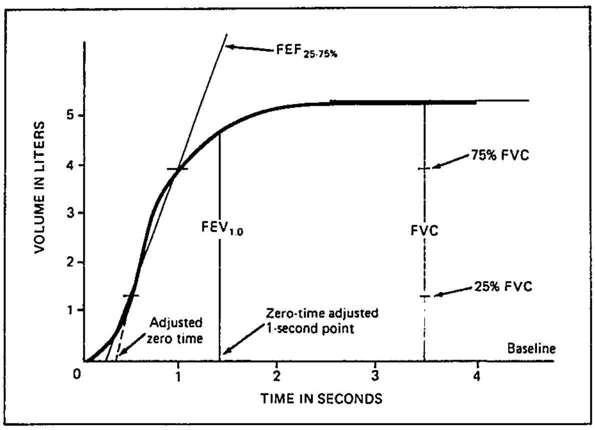

Figure 2. Forced expiratory spirogram illustrating measurements of FVC, $FEV_{1.0}$, and $FEF_{25\text{-}75\%}$ and identification of zero time

the volume line at defined points by use of a dividing caliper, and converting these distances to volume in milliliters by multiplying by the spirometer bell factor. For example, the $FEV_{1.0}$ is the distance in millimeters from the 1-second point on the baseline to the intersect of the volume curve (figure 2). The point from which the 1-second point is measured (zero time) is determined by extrapolating from the steepest part of the curve to a juncture of intersection on the baseline. This technique is used to approximate the point at which the spirogram would have begun if the expiratory effort had been devoid of hesitation and equipment inertia. The method, in fact, served to lend precision to the $FEV_{1.0}$ measurement, since it controls for those variables that cause the initiation of a spirometric signal to be slow in onset; that is, poor patient cooperation or poor comprehension of the test instructions. The FVC is measured from the baseline to the lowest point reached by the volume curve. Measurement of the $FEF_{25\text{-}75\%}$ is determined by the volume and time increment between 25 percent and 75 percent of FVC and is expressed as milliliters per second.

To eliminate errors in conversion and computation, the original direct measurements in millimeters were recorded and punched onto cards. These values then were converted automatically to volumes and flow rates, corrected to *b*ody *t*emperature and *p*ressure and *s*aturated with water vapor (BTPS), by a programed digital computer.

The findings are reported as FVC values from all of the 7,119 children examined in Cycle II weighted by their individual sampling weights to obtain the estimated national values (described in appendix). No recordings were obtained from 187 children; and, as described, the spirograms of 1,129 additional children were discarded as technically unsatisfactory. The missing FVC value for each of these children was imputed by multiple stepwise regression to preserve the individual sampling weights for all data. The rationale and method for imputing the missing data is discussed in the appendix.

As in all HES reports, age is basically defined as age attained at last birthday (verified from a copy of the birth certificate in 95 percent of Cycle II examinees). The mean age of each category, therefore, approximates the midpoint of the whole year; for instance, the 8-year-old male group consists of a 1-year cohort whose mean age is 8.51 years, while the corresponding female sample averages 8.49 years.

Race was recorded as "white," "Negro," and "other races." White children comprised 85.69 percent of the total; Negro children, 13.87 percent; and children of other races, only 0.45 percent. Because so few children of "other races" are included in a national probability sample, data from them cannot be analyzed separately. These data are included, however, when "total" is used, but are dropped when a white/Negro dichotomy is used. The differential response rate by age, sex, and race is discussed in the appendix.

RESULTS

Sex and Age

Mean FVC's by sex and by single year of age at last birthday show a monotonic increase with chronologic age which is almost straight through age 10.5 years, at which time both lines deflect upward (figures 3 and 4 and table 1). The two lines connecting the mean FVC's are generally parallel ($b_m = 206.3$, $b_f = 202.1$). The boys-versus-girls difference averages 146 milliliters (ml) over the 6 years. At age 6.5 years, it is 127 (ml), while at 11.5 years, it is 157 ml. Although there is a slight unexplainable dip in the boys' line at 10.5 years, it shows a commensurately greater increase to 11.5 years to regain the overall parallelism to the girls' line.

Race

The marked differences in mean FVC's between Negro and white children seen in figures 4 and 5 and table 1 are quite consistent. As with most HES data, when values for Negro children are examined separately, they fluctuate more than those of the white children because of the much smaller size of the sample (approximately 6.2:1).

The Negro girls' line is closer to the regression line for all girls than is that of the Negro boys as compared with that for all boys. The values for Negro girls also have the same upward deflection at 10½ years that is seen in the data for all boys and all girls.

The Negro boys' line, on the other hand, follows the slopes of the other lines for the first 3 years but then progressively falls away so that

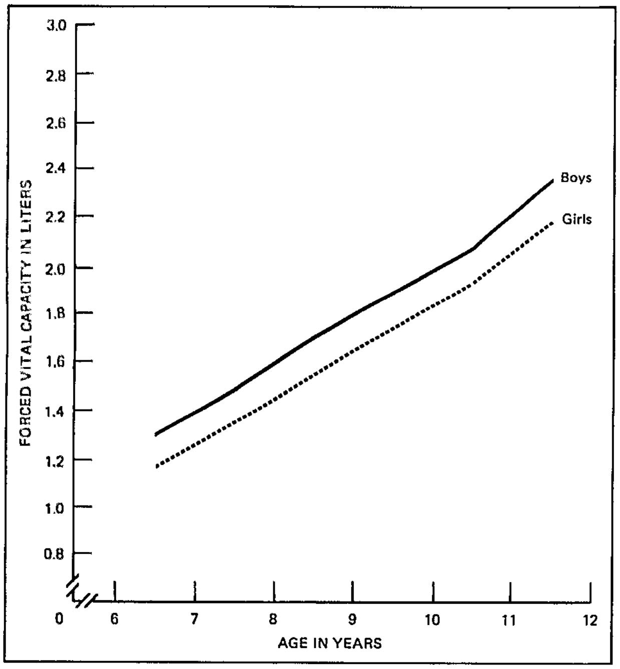

Figure 3. Mean forced vital capacity for children aged 6-11 years, by age and sex: Health Examination Survey, Cycle II, weighted results

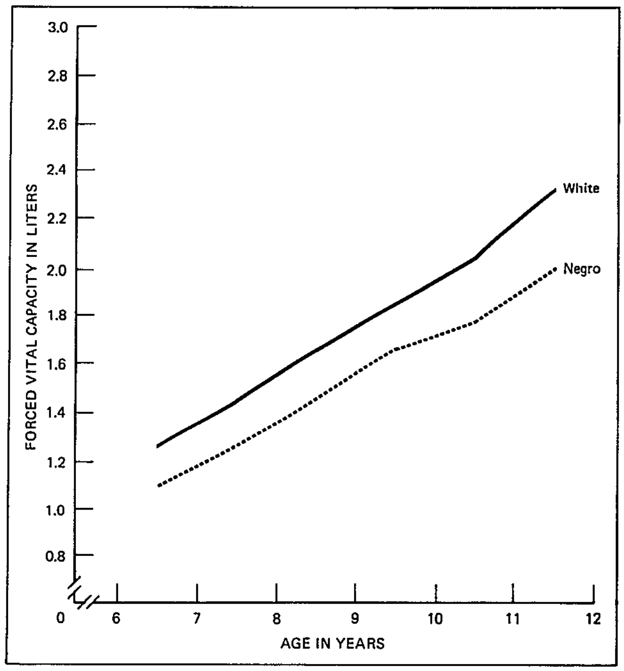

Figure 4. Mean forced vital capacity for children aged 6-11 years, by age and race: Health Examination Survey, Cycle II, weighted results

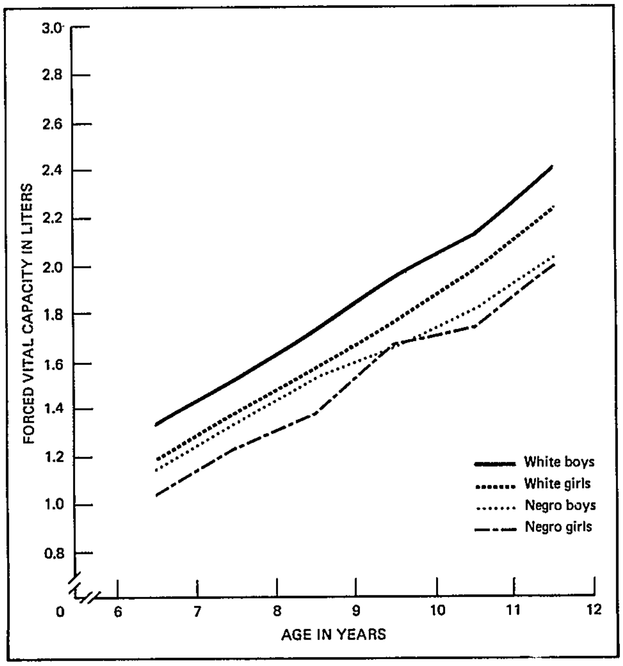

Figure 5. Mean forced vital capacity for children aged 6-11 years, by age, race, and sex: Health Examination Survey, Cycle II, weighted results

by age 11½ years the mean FVC for Negro boys is only 21 ml greater than is that of the Negro girls, whereas for the first 3 years it averages 129 ml greater.

From 6 years to 9 years of age, at least, the sex and race differences are both consistent and additive. All males during the 6-year age span (between 6 and 12 years) average 146 ml greater FVC than do all females; all white children during the 6-year age span average 226 ml greater FVC than do all Negro children; all white males average 263 ml greater than do Negro males and all white females average 186 ml greater than do Negro females.

In the age group 6-11 years there is a greater average difference when the data are grouped by race than when grouped by sex (i.e., 226 ml between white and Negro children, and 146 ml between all boys and girls).

FVC by Stature and by Sitting Height

When the mean FVC's of the children are examined, first by stature (figures 6 and 7 and table 2) and then by sitting height (figures 8 and

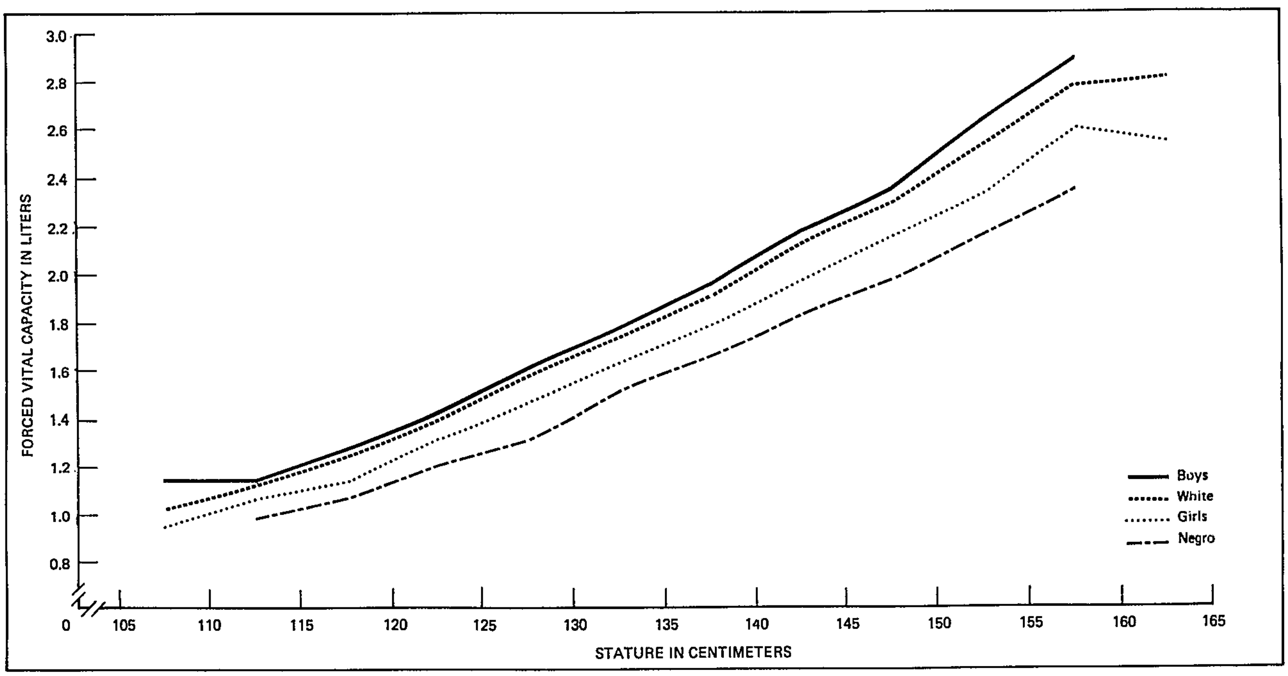

Figure 6. Mean forced vital capacity for children aged 6-11 years, by sex or race and stature: Health Examination Survey, Cycle II, weighted results

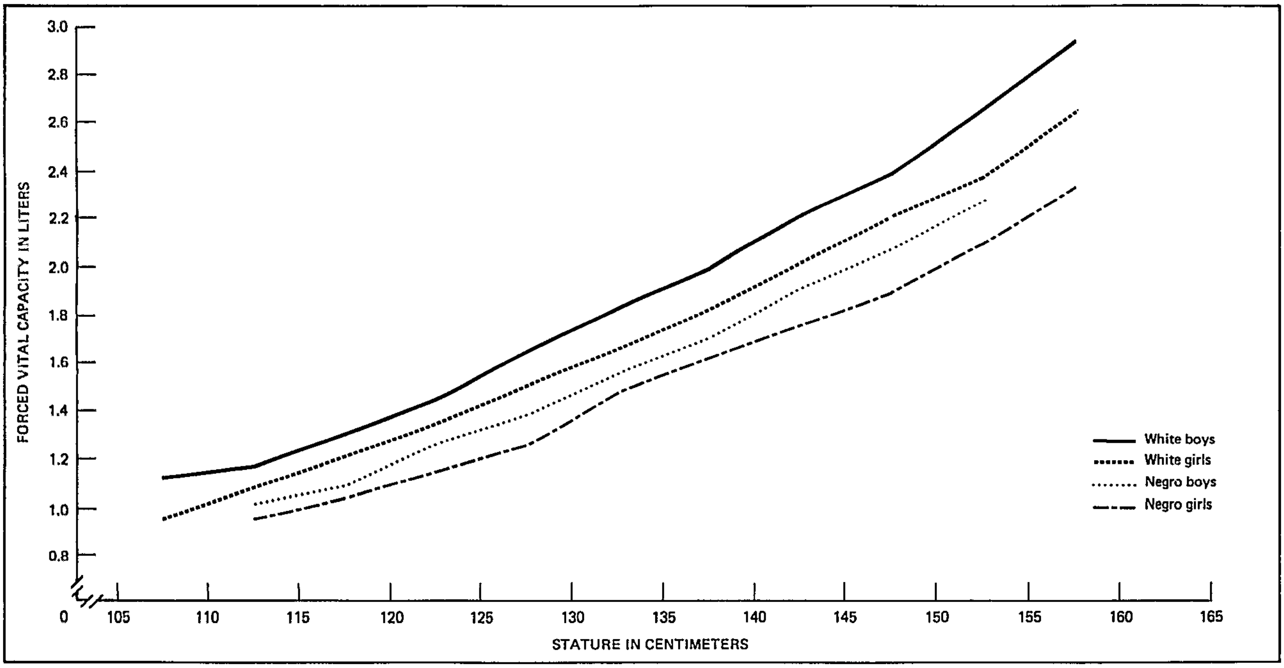

Figure 7. Mean forced vital capacity for children aged 6-11 years, by sex and race and stature: Health Examination Survey, Cycle II, weighted results

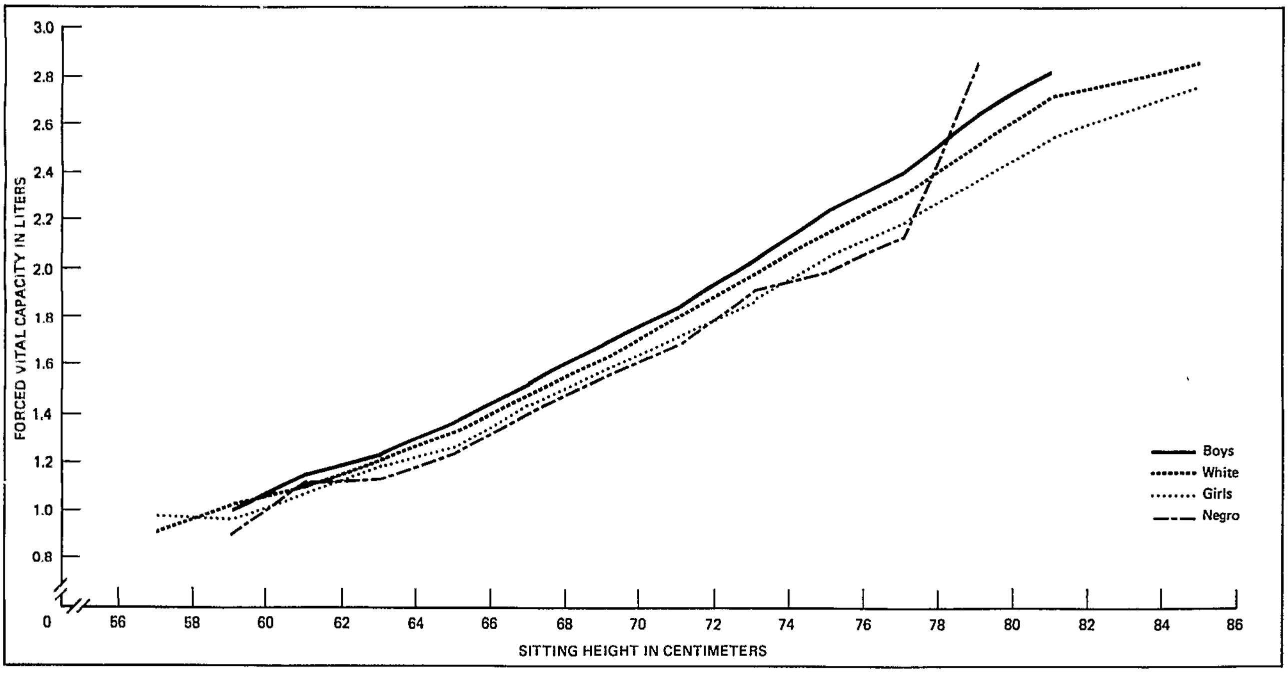

Figure 8. Mean forced vital capacity for children aged 6-11 years, by sex or race and sitting height: Health Examination Survey, Cycle II, weighted results

9 and table 3), several relationships become apparent.

When examined by stature, the lines connecting the mean FVC's show a general similarity to those data just examined by chronologic age. However, there are some small but notable differences.

The most striking change is that the four lines in figure 7 have a more consistent and a better balanced relationship to each other than did the four lines connecting mean FVC's by chronologic age in figure 5. The erratic upward hump plotted at 9½ years for Negro girls has been "replaced" by a smaller deflection at 132 ml; but more pronounced is the "correction" of the unexplainable general relative downward deflection of the Negro boys' line seen after 8½ years in figure 5. When grouped by increasing height rather than by chronologic age, the line of the Negro boys' mean FVC's maintains its relative position with the other three lines.

An important similar note, however, between figure 5 and figure 7, is the upward deflection of the lines at the far right of the graphs for most of the taller and older children (except the Negro boys).

When sitting height replaces stature as the classifying variable, even though the lines become more erratic (which will be considered in the section, "Discussion"), there is a more dramatic change than that seen between the figures for age and stature; the four lines move much closer together. Both girls' lines move a little closer to the lines of the two groups of boys, but the lines representing the FVC's of white and Negro children, which signify the mean racial difference in FVC, narrow the previously observed gap by approximately half. In fact, the mean FVC's of the Negro boys in figure 9 are now essentially equal to those of the white girls (when classified by sitting height, the overall means for all ages are: Negro boys, 1,557 ml; white girls, 1,542 ml).

Figures 6 and 8 contrasted with figures 3 and 5 summarize the changing relationship of FVC by sex and race when first classified by chronologic age, then by stature, and finally by sitting height. The original ordinal relationships still obtain (the mean FVC of white children is greater than that of Negro children and that of boys is greater than that of girls); but while the differences both by sex and by race have been

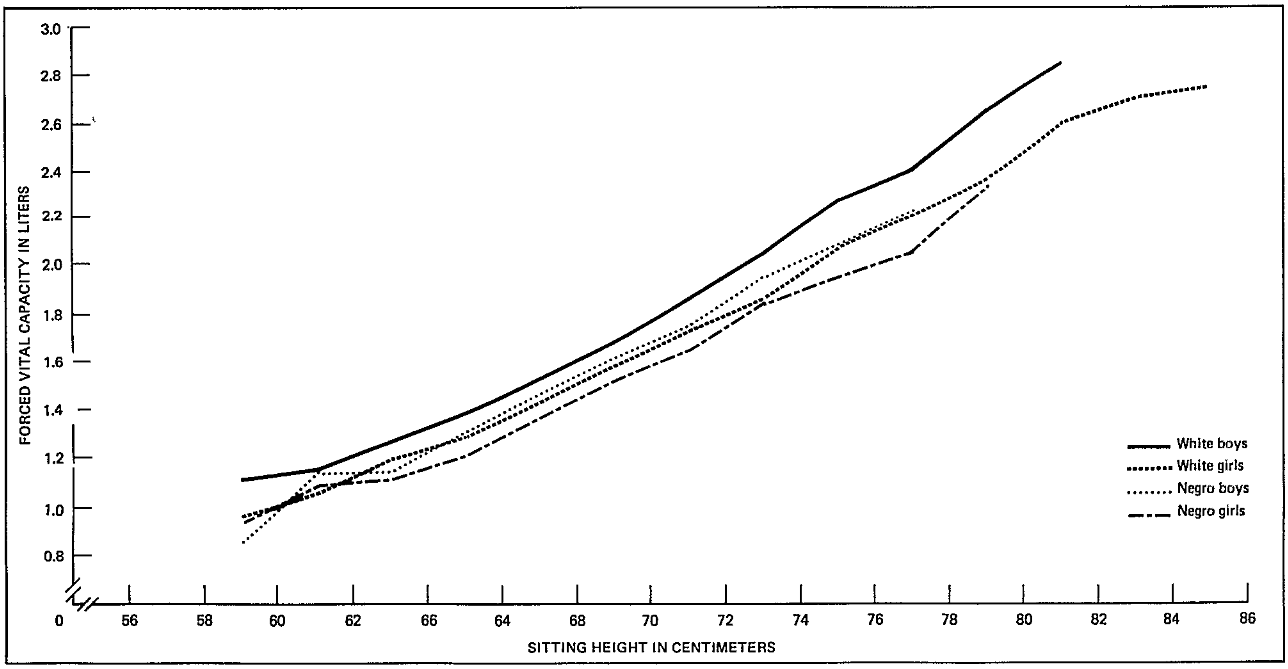

Figure 9. Mean forced vital capacity for children aged 6-11 years, by sex and race and sitting height: Health Examination Survey, Cycle II, weighted results

diminished by the consideration of sitting height differences, the magnitude of the difference by race has been reduced by a considerably greater margin.

DISCUSSION

Growth and Development

One of the most apparent and visibly dramatic changes from early childhood to adulthood among all normal people is the enormous increase in stature. Increase in stature was the parameter used in one of the earliest published accounts of a systematic study on human growth: A nobleman naturalist, Philibert Gueneau de Montbeillard, from 1759 to 1777, made serial height measurements every 6 months on his first-born son, which were later published by his encyclopedist friend, DeBuffon.[6] Since that time, stature has probably been used as a parameter of human growth as frequently as all other parameters combined because of its many conceptual and technical advantages: it lends itself to easily obtainable yet relatively accurate measurement; it is readily understood by almost all people; it is useful; and it is highly correlated both with the chronologic age of the growing child and most of his other physical, physiologic, and behavioral parameters. Also since de Montbeillard's time, the biologic mechanism of the elongation of the growing long bones has become rather well described and documented, and many of the factors controlling and influencing the rate of elongation have also been studied.

Although not as visible, nor as easily understood, nor as easy of accurate measurement, the increase in FVC, nevertheless, shares many of the characteristics of the increase in stature during these growing years of middle childhood.

From 6-10 years of age both mean FVC and mean stature display an almost linear increase with chronologic age, with a slight upward deflection from 11 to 12 years, especially among girls. The coefficient of correlation of chronologic age from 6 to 12 years with stature is 0.824 while with FVC it is 0.699. Dramatic as the increase in stature is, the proportionate increase in FVC is more than three times greater from 6 to 12 years: there is an average 24-percent increase in stature but an average 83.8-percent increase in FVC during these same 6 years. The proportionate increase in each of the parameters is approximately 10 percent greater in girls than in boys because, as a group, girls reach the adolescent growth spurt almost 2 years earlier than boys do. Even though the "growing," or increasing, FVC is as valid a parameter of human growth, as truly characteristic of the growing child as is the increase in stature, there does not seem to be much imminent danger of it replacing stature as the usual yardstick by which most people understand adolescent growth spurt.

The many physical, physiologic, and behavioral variables that systematically increase during the growing years in either dimension or quantity (and also in functional capacity) and that can usefully be considered as parameters of human growth and development are all, more or less, highly correlated statistically with chronologic age and, hence, by association with each other. Some of those growth changes, like skeletal maturation and developing intellectual capacity, are merely concomitants, or parallel developments, and are only very remotely, if at all, functionally related, while others, like the increase in stature and the increase in body weight, are very intimately related, both structurally and functionally. FVC is essentially a measure of physiologic or functional capacity, but it is much more than casually related to body size and structure. Both because it is measured as a volume (i.e., in milliliters, cubic centimeters, or liters) and because its upper limit at full inspiration (i.e., total lung capacity) and lower limit at full expiration (i.e., residual volume) require physiologic behavior and cannot be achieved passively, it should be considered an active or physiologic volume. As such, it has an intimate relationship to both the size and the shape of the growing musculoskeletal thorax.

It has long been known that FVC correlates very highly with stature; in fact, sex-specific stature represents the chief measured element in most prediction equations in adult's FVC. One would intuitively think that FVC would be most highly associated with the more anatomically specific part of the elongating body (the trunk segment) rather than simply overall stature. Two other related and well-established facts could give further promise to this line of reasoning. As stated by Damon in his review in 1966,[7] the literature for almost a hundred years has demonstrated the fact that Negro men have, on the average, 10 to 15 percent lower vital capacity than have white men of similar stature and age (and this is very well borne out in our even more accurate HES data on children). And another well-established, but perhaps lesser known fact is that Negroes, of both sexes and all ages, have longer legs and shorter trunks, proportionately, and thus, a shorter sitting height, than have corresponding white people.[8,9] Furthermore, with these HES data, the comparison of figure 6 with figure 8 (i.e., FVC grouped by sitting height rather than by stature) demonstrates that the mean differences in FVC between Negro and white children were reduced by approximately 50 percent when classified by sitting height rather than by stature.

Ratio of Sitting Height to Stature

To explore further the relationship of FVC with stature, we can examine the relationship of stature itself with its two most frequently measured component segments, sitting height and leg length. The relationship between sitting height and stature and age, race, and sex in growing children has been examined in three previous HES reports.[8-10] The data from all three reports can be brought together here and examined in a little more detail because the relationship to FVC might be so crucial and also because the relationships are complicated.

Figures 10-12 and table 4 present the data separately for Negro and white children, and over the whole age range from 6 to 18 years to give a better perspective. In comparing figures 10 and 11 it can readily be seen that there is a much greater difference in sitting height among these four race-and-sex groups than there is in stature.

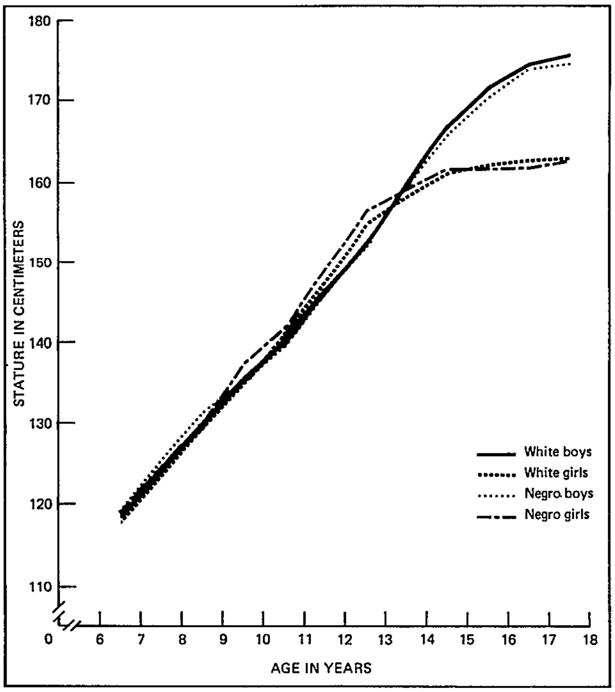

Figure 10. Stature of children and youths aged 6-17 years, by age, race, and sex: Health Examination Survey, Cycles II and III

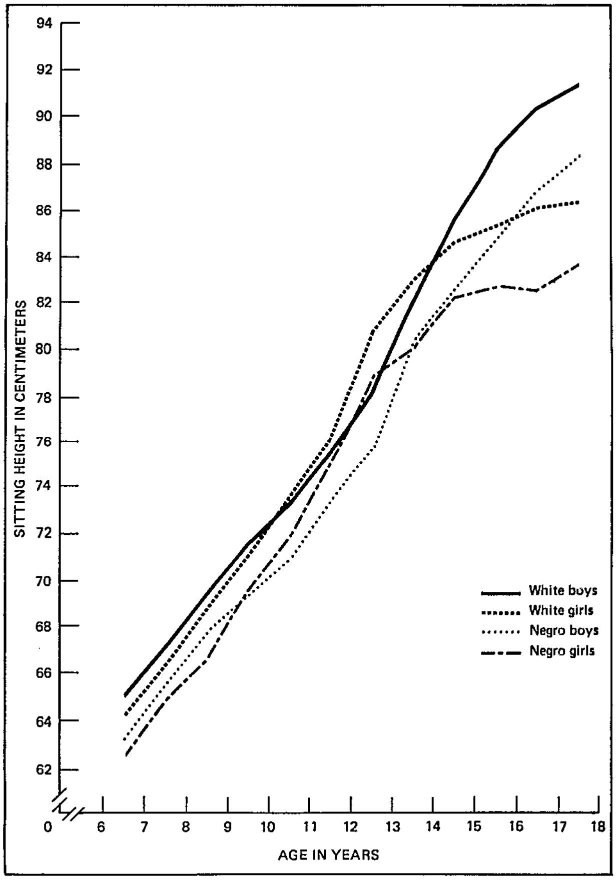

Figure 11. Sitting height of children and youths aged 6-17 years, by age at last birthday, race, and sex: Health Examination Survey, Cycles II and III

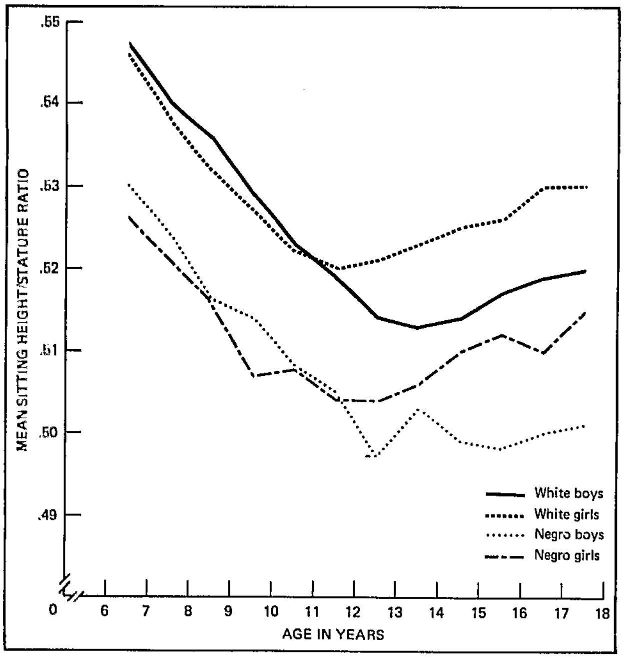

Figure 12. Mean ratio of sitting height to stature of children aged 6-17 years, by age, race, and sex: Health Examination Survey, Cycles II and III

To summarize the highlights of stature first: there is a more consistent racial difference between the two groups of girls over this 12-year age span than there is between the two groups of boys. The mean heights of the Negro girls are consistently greater than those of white girls from 7 until 14 years of age; from 14 until 17 years the mean heights for the white girls are slightly greater. The relationship between the two groups of boys is less clear (same height at 6 years of age; Negro boys slightly taller at 7-9 years; white boys slightly taller at 9-12 years; same height at 12-14 years. Then, from 14 to 17 years the mean heights of the white boys are slightly, but consistently, greater than those of their Negro counterparts). The overall mean from 6 to 14 years is essentially the same in the two groups of boys. In other words, the differences, though slight, are real, but they go in both directions so that they cancel each other out from 6 to 14 years of age. However, after age 14 there is enough consistency from 14-17 years to say that the white boys average very slightly taller over the entire 12-year span.

The difference in stature by sex is a little more consistent and a little more clear than by race. The boys start out slightly taller; the girls become taller at 9¼ years and remain so for the next 4 years until the boys rather dramatically pass the girls at 14¼ years and increasingly widen the gap for the remaining 4 years.

In contrast to stature, the data on sitting height display clear and consistent distinctions over the entire 12-year age span between the four age-sex groups. For the entire age span 6-18 years, white boys have distinctly and markedly greater sitting heights than Negro boys have, and the same is true of the relationship between white girls and Negro girls (the average difference of the means is 2.4 centimeters between the two groups of boys, and 2.0 centimeters between the two groups of girls over the 12-year span). In addition, there is a very marked, though not as consistent, difference between the two sexes. The sitting height of the boys is greater from 6 years to 9½ or 10 years of age, and becomes slightly less from 10 to 14 years (due to the earlier growth spurt in girls, as very vividly demonstrated for white children and youths in figure 13); but at age 14 the boys' sitting height becomes almost as distinctly greater than the girls' as was just seen for stature, but never by quite as much.

Figure 12 graphs the mean sitting height/stature ratios of the four age-sex groups from 6-17 years. When interpreting this figure it must be kept in mind that the ratios are dynamic in that at every age and for both sexes neither the numerator nor denominator ever decreases or remains constant from one period to the next; that is, from 6-17 years of age both the numerator and denominator at every single point are increasing, with the result that the ratios express the *relatively* greater increase of either the numerator or the denominator from one time to the next (obviously when the ratio is decreasing, as it does consistently from age 6 to 11½ in the girls and until about 13½ years in boys, it means that the legs are growing faster than the upper half of the body—trunk, neck, and head—but when the ratios start increasing again, although the legs are continuing to increase in length, the upper half of the body is increasing at an even faster rate). This figure clearly shows how much more discriminating, in growth differences among the four race-sex groups, sitting height is than is stature. Except for a little bit of sampling

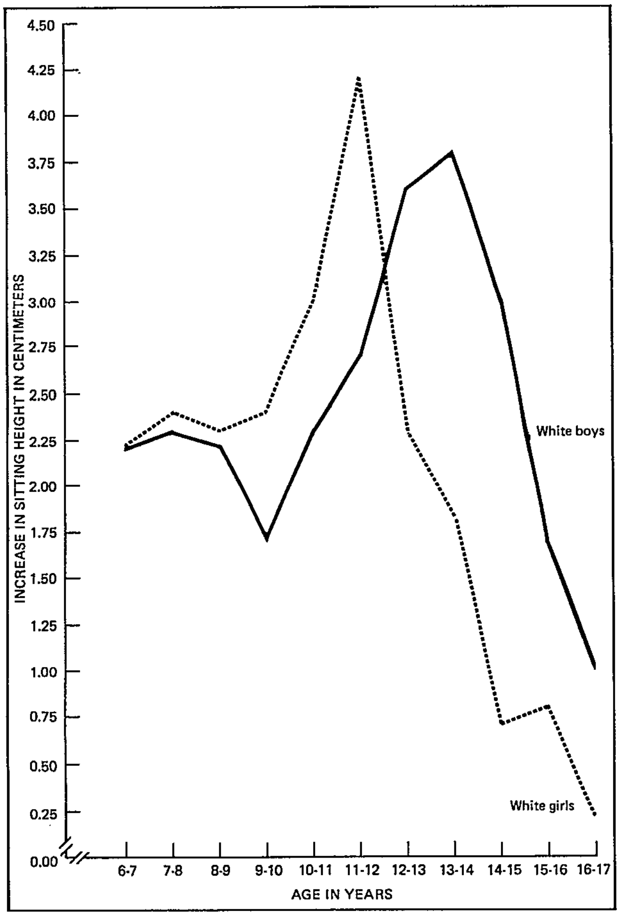

Figure 13. Increase in sitting height of white children and youths aged 6-17 years, by age, race, and sex: Health Examination Survey, Cycles II and III

"noise" in the much smaller Negro sample, the distinctions are extraordinarily consistent and quite marked. The sex difference, though relatively small, is completely consistent until 11 years of age (the boys' relative sitting height is greater than the girls', hence, the relative increase in their leg length is less), but the racial difference from 6 through 17 years is quite constant, with a slightly increasing gap at the upper ages. And also from 12 through 17 years of age, the differences between the two sexes becomes almost as marked as the differences between the two races. From 6-11 years, the average difference in sitting height/stature ratio between Negro and white children being so much greater than the average difference of that between boys and girls immediately explains the much greater relative reduction of the average difference in FVC by race than by sex when the data are grouped by sitting height rather than by stature.

Because of this distinct, and now understandable, reduction in the mean racial differences when FVC data are grouped by sitting height, and because there is a much closer anatomical relationship with sitting height than there is with leg length, one could be tempted to go a little further and say that sitting height "correlates" better with FVC and is a better predictor of FVC than is total stature. If one is expecting that, then, after examining the coefficients of correlation (table A), one would be quite surprised, and possibly disappointed. One

Table A. Zero-order and partial correlation coefficients for forced vital capacity (FVC) versus stature or sitting height, by race and sex: United States, 1963-65

Zero-order and partial correlation coefficients[1]	Total	White	Negro	White		Negro	
				Boys	Girls	Boys	Girls
Zero-order	Correlation						
FVC: stature	0.806	0.824	0.794	0.840	0.831	0.793	0.810
FVC: sitting height	0.817	0.817	0.807	0.828	0.825	0.795	0.825
Sitting height: stature	0.923	0.935	0.920	0.938	0.934	0.907	0.930
Partial[1]							
FVC: stature/sitting height	0.231	0.293	0.224	0.333	0.301	0.282	0.202
FVC: sitting height/stature	0.322	0.233	0.319	0.209	0.246	0.294	0.335
	Number						
Nonimputed cases	5,803	5,025	778	2,611	2,414	370	408

[1]A: B/C: A vs. B, C partialled out.

probably expected that the correlation coefficient of FVC would be higher not only by race- and sex-specific groups with sitting height than with stature but by an even greater magnitude in racially mixed groups, because sitting height has a much greater race specificity than has stature.

That none of these conditions obtained was the occasion of much of this detailed consideration of the relationship of stature with its component parts (especially sitting height). The relative contributions to differences in correlations by differential relative variances among and between the major body segments (with each other and also with FVC) and, in turn, the differential contributions to these variances made by true biologic variation versus that made by measurement error is discussed in detail in the appendix. There is a greater relative variance among the sitting heights than among the statures, as measured in Cycle II, but that, in itself, begs the question of biologic variability versus measurement error. A definite answer is not available at this writing. In Cycle II the only body segments directly measured were stature and sitting height; but data will be available from Cycle III on adolescents aged 12-17 years in which, in addition to stature and sitting height, measures of cervicale height (vertical distance from the floor up to the seventh cervical vertebra, or the bottom of the neck) were also obtained. Cervicale height, when subtracted from stature, gives the height of the neck-head segment of the body and trochanteric (lateral bony hip) height, which has a very high correlation with subischial height (leg length). These measures also were replicated on several occasions to give estimates of the technical error of measurement (or that amount of variation due to measurement error) so that when the FVC data are also available on this age group, the answer might become much clearer.

In the meantime, the best summary at the present time appears to be that although grouping by sitting height reduced by almost half the mean racial difference in FVC than when FVC is grouped by stature (and, intuitively, seems to be a much "closer relationship") in the present HES data, sitting height does *not* correlate any better with FVC than stature does, by either race or sex. Nor would sitting height predict FVC any better than would stature. In addition, although the racial differences in mean sitting height account for almost half of the observed differences in mean FVC, there are no additional anatomical measurements which seem capable of accounting for the residual mean difference.[b]

Another way of formulating the authors' present quandry is to restate Damon's questions of 1966[7] and then try to answer them with these data. In his study relating anthropometry to lung function, he states that, both from his own findings (when matching Negro and white soldiers of comparable age, sex, body size, smoking habits, and other attributes) and also from his summary of pulmonary function literature covering 100 years (in which the relationship has been found "without exception"), Negroes (children and adults) have 10 to 15 percent lower average FVC than comparable white persons have. As an eminently skilled anthropologist, he obtained multiple body measurements, including a grip-strength test (partly as an index of relative skeletal muscle mass and athletic ability and partly as an index of motivation), on these soldiers and tried partial correlations searching for his answers. He found that stature had a slightly higher partial correlation with FVC than sitting height had when he was trying to account for these differences. At the present time, HES data confirm the magnitude of the observed racial difference in FVC when matched by age, sex, and stature, and although we cannot "explain" Damon's dilemma, we can reduce his observed difference by more than 50 percent; namely, his observed mean difference in FVC between the two groups could have been reduced by approximately 50 percent if grouped by sitting height instead of by stature. However, the reduction is limited to the overall mean difference between the two groups. When trying to apply it on an individual level and ask, "Does sitting height correlate with, or predict, FVC much better than stature?", Damon concluded from his data and his analysis that it did not. In the present stage of the analysis of HES data, we have to reach a similar conclusion. In a future paper we hope to be able to distinguish whether the slightly greater relative variance in sitting height than in stat-

[b]Cubing the differences in sitting height, to approximate more closely a volumetric relationship, makes almost no difference.

ure is an inherent biologic relationship or is primarily a function of the differences in technical difficulty in measuring body segments.

Epidemiologic Implications

This rather detailed description and analysis of FVC, as a significant and measurable physiologic attribute of the growing child (with its similarities and differences between major age, sex, and race groupings and with its relationship to stature and to the components of stature) assumes greater significance when FVC is considered in the context of the total human lifespan. FVC, together with flow rates such as $FEV_{1.0}$ and $FEF_{25\text{-}75\%}$, are extremely important in estimating both the frequency of occurrence and the magnitude of disability from chronic obstructive pulmonary disease, which has become so prevalent among men after early middle age in most of the technologically developed countries. When these population estimates of FVC among young children are related to this medically useful parameter in later life and these descriptive estimates are considered as the leading edge, or the youngest chronologic ages, at which we can obtain population estimates on this parameter because of behavioral testing limitations, and when these data are considered as completing the picture of the natural history of this parameter, the effort takes on added meaning.

There are two facets to the natural history of a parameter such as FVC: (1) the description and understanding of its behavior as a physiologic variable in health and disease and (2) the consideration of it as a measuring or testing phenomenon. Because of the scarcity of well-developed disease entities in this young age group which can significantly affect FVC (which would have made it valuable as a clinical case-finding tool), the chief uses, epidemiologically, for these accurate HES population estimates are to look for predisposing factors (either host or environmental) which might impair FVC, either temporarily or permanently. This kind of search for incipient change, either in an individual or in population data, can sometimes yield valuable answers. Some of the questions to be asked of the data are: Is there a critical age of occurrence which would indicate greater age- or growth-related susceptibility? Among what special groups of children do any changes occur (and, of course, what are the changes and what may be some of the causes)? Is there any suggestion of a dose-response type of relationship? What are the eventual health consequences of these physiologic changes? Can anything be done to prevent the changes from occurring?

Population data such as these can be used epidemiologically in another way, too. Impairment in the rate of growth of children, especially in stature, is being used increasingly as one of the most sensitive indicators of adverse environmental factors, especially malnutrition.[11-13] By analogy, it is probable that alterations in the expected rate of growth of spirometric parameters in children might also be more sensitive indicators of environmental stress (such as air pollution) than is alteration in adult pulmonary function values. The Environmental Protection Agency, through its air pollution program, the Community Health and Environmental Surveillance System, is studying this premise by using children almost as miners used canary birds in the old days to detect poisonous gases. They will follow panels of children over time, in a variety of geographic sites, to correlate their changes in pulmonary function with data from its air-sampling network.

Testing Immaturity

Spirometric parameters do not arise suddenly and fully developed at about the age of 6. In fact, many of the ventilatory movements have been present since the last few months in utero. But because the testing of most of the commonly used spirometric parameters requires a high degree of cooperation and understanding on the subject's part, there are severe age limitations when considered as a populationwide testing phenomenon. A fairly reasonable FES is probably obtainable as early as age 2½ to 3 years on a very few precociously bright, imitative, and cooperative children who also have an unusually high degree of control over their voluntary physiologic functions. In fact, Luft, at the Lovelace Clinic in Albuquerque, is getting good FES data on children as young as 3 years of age and "most all of them by 5 or 6 years of age"[14] (the quality validated by comparable results from gas mixing and perfusion tests on the same subjects). However, these results are achieved in an optimal clinic setting: Luft has enormous experience, skill, and patience in spirometry with children; his staff has been with him for some 10 or 15 years and is similarly skilled; and there are no time pressures—the children can return if they become confused, tired, irritable, or just don't quite get the proper knack of it. In addition, they are self-selected by word-of-mouth contacts of friendly, interested, and cooperative families.

We will see, as this discussion of FVC considers "the natural history of FVC as a testing phenomenon," that when attempting to get total population estimates (which requires maximal participation by as many people as possible *without bias* among such major classifying variables as age, race, sex, socioeconomic level, intelligence, environmental region, schooling, etc.), there are distinct lower age limitations to accurate and reliable data. On *a total population level,* and in a survey setting, the testing problems are so numerous that at age 6 years, and probably even at 7 years of age, too many children are simply too immature behaviorally and socially to produce reliable and unbiased test data—even though many do produce good data. The very lengthy methodologic companion report[5] to this one describes several substudies and an enormous amount of data, argument, and analysis examining this point, which had become prominent when attempting to clarify and, if possible, to "adjust or correct" some of the inconsistencies found several years ago during analysis of these data. "Spirometric immaturity of a large proportion of 6- and 7-year-olds and an ever-decreasing proportion of 8-, 9-, 10- and 11-year-olds, *in a large survey setting such as HES,*" is one of the chief conclusions of that long and tortuous methodologic analysis. Figure 14 illustrates the age relationship to the proportion of children whose spirograms had to be discarded because of gross, observable errors. The almost asymptotic rise in those younger than 6½ years (compared with the 11½-year-olds) is readily seen.

The major substudy, which is the heart of the methodologic report,[5] was performed in Salt Lake City in May 1974, on a very select subpopulation under optimal testing conditions for children, which probably cannot be repeated and almost certainly cannot be applied in all regions of the country and to all segments of the population. As described in detail in the report, it was performed by an unusually experienced team, using very efficient and sensitive equipment on a self-selected population of highly motivated 6- and 7-year-old children almost totally from upper middle class, managerial, and professional families. The whole study was completed in a few short days before the enormous enthusiasm that had been generated could dissipate. These Salt Lake City data are used in this report and in the methodologic one as if they are optimal physiologic estimates, free of contamination from testing inadequacies. Even with these optimal testing circumstances, several of the subjects were finally judged to be too immature to perform properly a forced expiratory spirogram; their test results had to be discarded.

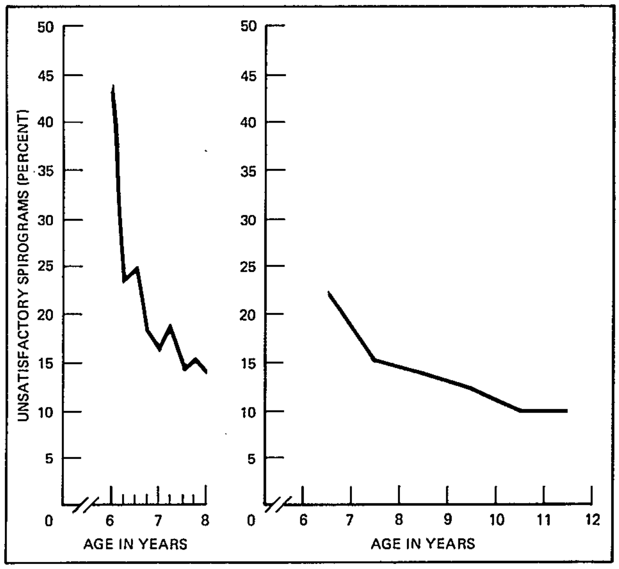

Figure 14. Percent of examinees with unsatisfactory spirograms, by whole year for ages 6-11 years and by quarter year for ages 6-8 years: Health Examination Survey, Cycle II

In all spirometry testing administered in a survey setting to broad populations of people of all ages there are always some people who are either incapable of or unwilling to perform a proper spirogram. Their data must be recognized and flagged so that it may be either adjusted or discarded. This general phenomenon is also certainly true in this young age group, but the chief epidemiologic problem encountered here is the additional one of immaturity—not physiologic immaturity but immaturity as a test subject. This testing immaturity is a behavioral-social phenomenon like a lack of "school readiness"; that is, the subjects would be unable to follow properly instructions like "Please sit down and be quiet," "Raise your hand when you want to speak," "Pick up your pencil and copy the picture and the words in your book," all of which require understanding and willingness and enough self-control to perform properly and effectively. In the absence of adverse factors, this immaturity is "outgrown" in a year or two in most children. We know that proficient testing, skillfully used motivational techniques, and plenty of patience can surmount the immaturity in some proportion of the youngsters (as is done by skillful kindergarten and first grade teachers). Apparently, this was accomplished in the Salt Lake City and Annapolis substudies[5] performed by HES and, as has been recently been reported,[16] by another group of investigators working independently, also in Salt Lake City.

In a substudy of 222 children reported by the pulmonary division of the Latter-day Saints Hospital (LDS), Salt Lake City, the findings[15,16] generally reinforce all HES findings, but the data are not sufficiently detailed to supply essential missing information. Specifically, as noted above, both they and the investigators in the HES Annapolis substudy achieved an approximate 10-percent improvement in FVC by a spirited group demonstration and instruction given prior to individual instructions. (The LDS group had to discard the data of 10 subjects as technically inadequate.)

Data Adjustments

The methodologic companion piece contains detailed rationale and discussion of the recommended adjustments. The resolution of many of the problems discussed in this report is being implemented in a current cycle of national data collection (1976 through 1980) on these same age groups: many refinements in testing procedures, hardware, and data handling have been instituted by HES over the past 8 years. When available, these new data will help substantiate the validity, or lack thereof, of the following recommended adjustments:

- Processing and refinement of original data set

    1. *No observed HES values have been adjusted or changed;* however, the imputation of FVC values for 18 percent of the 7,119 examined children to obtain weighted national population estimates slightly changed the overall mean data and the percentile distributions in the tables (as discussed in the methodologic report). The imputation procedure (described in detail in the appendix) employed multiple stepwise regression using a wealth of other variables. If it is assumed that most of the correlated attributes (sitting height, stature, chest breadth, race, sex, etc.) would be more closely associated with the true physiologic FVC capacity than with the testing behavior of the subject, then it would follow that the imputed values are reasonably fair and unbiased physiologic estimates.

    2. Except for reclassifying by quality (i.e., by culling and regrouping and then imputing), no other modifications of the original data set have been made. At one time it had been fully intended to adjust these observed HES values and append the adjusted values as the final section of this publication. However, repeated attempts failed[c] to obtain other population data on children to supplement those from the two methodologic studies which were undertaken (i.e., Salt Lake

[c]The only two exceptions have already been mentioned: (1) Dr. Luft, Lovelace Clinic, Albuquerque, New Mexico, who was very generous with advice and general conclusions, but, unfortunately, whose data have never been systematically analyzed and (2) Dr. C. DuWayne Schmidt, Chief of Pulmonary Division, LDS Hospital, Salt Lake City (published[15,16] and personal communications[17]).

City, 1974, and Annapolis, 1976); this ambitious project had to be abandoned because several pieces of key information are still missing.

- Recommended adjusting factors for clinical or epidemiologic comparisons: The following adjusting factors have been explained extensively both in this report and in the methodologic one, but they have not actually been applied to these data because they are incomplete.

1. The sex difference in median FVC reported in these HES data (table 1) is 9.8 percent at 6.5 years of age. Although Schmidt[17] observed even greater differences than these, he and we believe that these magnitudes overestimate the true physiologic difference and that some portion of the difference is due to attitudes and expectations on the part of *both* subjects and examiner. If this *testing difference* is overcome, we believe the residual physiologic difference will range from 3 to 6 percent at age 6.5 years.
2. Because almost all errors in performance of the FES result in underestimates and the effects are *additive*, it follows that almost all imperfect data are underestimates to varying degrees and that optimal data will be generally "maximal" data. The HES Salt Lake City substudy data are maximal (and optimal) with special attention to the problems of test instructions as they relate to testing immaturity, so a general adjustment could be made for the most immature children (i.e., the 6- and 7-year-olds). No comparable data are available for the older age groups, but it is assumed that among the 11-year-olds, the special age-related problem of immaturity (although there will always be a residual group of inadequate subjects in any population of people, as described earlier) is no longer operative so that, as the general population of children "outgrows" its testing immaturity (i.e., testing maturity would grow in a manner similar to the increase of FVC and stature and other "growth variables" in young children), the impact of its prevalence and severity decreases with age. Therefore, the mean FVC should be increased by approximately 20-25 percent at ages 6 and 7 years and by somewhere between 5 and 20 percent at ages 10 and 11 years (ages 8 and 9 to be interpolated linearly or curvilinearly).[d]
3. The shape of the distributions will change slightly when testing conditions more closely approach the optimal; that is, although the whole distribution would move up, by approximately 10-20 percent, the lower percentiles would move up proportionately more, thus somewhat narrowing the distance between the 5th and 95th percentile as reported in table 1.
4. The mean difference can be reduced by about 50 percent by standardizing for the racial differences in sitting height;[8,9] possibly a greater mean reduction would be obtained if thoracic height (i.e., from sitting position at table top up to the seventh cervical vertebra) can be partialled out. Can the residual difference be reduced somewhat more by overcoming attitude/expectation differences (as is predicted for girls in footnote d)? Because of the similarity of the estimated magnitude of difference with much more varied and extensive adult data, it is predicted that, even in an ideal testing situation, there will remain a residual mean FVC black-white difference, by stature, of 5-10 percent.

Five residual questions.—The following questions still remain:

1. Although classifying FVC by sitting height rather than by stature is intuitively more appealing and reduces the ob-

[d]By integrating the sex difference into the adjustments, it follows that HES girls' FVC is more underestimated than the boys'; therefore, whatever upward adjustments are made, the girls' data would require relatively greater accommodation.

served mean differences by sex and race (than when classified by stature or chronologic age) by as much as 50 percent, why doesn't FVC *correlate* better with sitting height than with stature? Is the slightly greater variance in HES Cycle II sitting-height data than that in the stature data primarily due to greater biological variability (especially because sitting height includes both thoracic height *and* head-neck height) or is it due to greater measurement error? (Because of more detailed and better replicated anthropometric data this probably can be answered using data from HES Cycle III.)

2. What is the earliest age at which a reliable FES can be performed in a survey setting by enough children to get valid population estimates by race, sex, socioeconomic, cultural, and regional classifications? There are many interesting subsidiary questions that could be studied by behaviorists; for example, What factors comprise testing immaturity (how similar is this phenomenon to school "readiness") and how are they best overcome? How much extra skill, time, patience, sensitive equipment, and sophisticated milieu are required to obtain reasonably good population estimates on the youngest possible age group? (a practical cost/benefit survey question).

3. Looking at FVC as a physiologic parameter of the growing child, and assuming better testing conditions and quality control than obtained in HES Cycle II, what regression line would most accurately describe FVC and chronologic age and/or stature (or sitting height)?

4. What are the *true physiologic differences* in FVC between boys and girls and between Negro and white children?[e]

5. What are the best estimated *test differences* obtained under optimal conditions? And what factors contribute to these differences?[e]

In other words, how much of the 5-20-percent differences in these population subgroupings (i.e., sex and race), which have been almost universally found in the past, are due to true physiologic capacity and how much are due to attitudes and expectations on the part of both the examinee and the subject?

Final Note

Because of the technical limitations of these spirometry data in children, they are *not recommended to be used as clinical standards.* In most laboratories, with skill and patience and time, and opportunity to have the subject return another day (when necessary) researchers can expect to get mean FVC values approximately 150 ml higher than these HES values among 6-8-year-olds and perhaps 100 ml higher among 9-11-year-olds.

These data have been presented as population distributions with subgroup comparisons for their epidemiologic value.

This is epidemiologically useful both as a measurable physiologic parameter of the growing child and by filling in as the youngest ages in the natural history of a parameter that assumes clinical importance in adults, especially for the detection and measurement of chronic obstructive lung disease. Although the absolute values are underestimates by approximately 10-20 percent, it is considered that the *comparative* values by age, race, and sex are reasonably accurate (although the observed sex difference requires more study), and that the population distribution of values by percentiles has some merit as a measure of population variability, especially because of their pioneering nature.

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[e]Questions 4 and 5 are related and are perhaps the most interesting because of their extraphysiologic implications.

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LIST OF DETAILED TABLES

Table 1. Forced vital capacity of children 6-11 years, by age, sex, and race—sample sizes, standard deviation, standard error of the mean, mean, and selected percentiles: United States, 1963-65

Age, sex, and race	n	N	SD	$SE_{\bar{X}}$	$\bar{X}$	Percentile						
						5th	10th	25th	50th	75th	90th	95th
			Milliliters									
Total[1]												
6-11 years	7,119	23,784	488	11.3	1,726	1,009	1,127	1,371	1,684	2,035	2,391	2,595
6 years	1,111	4,098	279	12.4	1,240	807	907	1,048	1,232	1,412	1,584	1,711
7 years	1,241	4,084	286	11.9	1,429	974	1,074	1,228	1,424	1,624	1,795	1,901
8 years	1,231	3,986	307	11.0	1,628	1,120	1,228	1,426	1,621	1,829	2,022	2,138
9 years	1,184	3,957	354	15.6	1,829	1,294	1,385	1,588	1,812	2,049	2,301	2,435
10 years	1,160	3,867	379	19.1	2,012	1,404	1,543	1,742	1,988	2,266	2,515	2,641
11 years	1,192	3,792	430	16.3	2,279	1,613	1,745	1,982	2,254	2,552	2,803	2,992
Boys												
6-11 years	3,632	12,081	491	14.5	1,798	1,068	1,202	1,441	1,758	2,113	2,464	2,653
6 years	575	2,082	271	14.3	1,302	878	955	1,112	1,313	1,474	1,628	1,745
7 years	632	2,074	287	16.5	1,498	1,058	1,143	1,300	1,494	1,689	1,840	1,935
8 years	618	2,026	299	13.8	1,703	1,218	1,330	1,505	1,701	1,908	2,082	2,194
9 years	603	2,012	367	25.9	1,908	1,340	1,462	1,664	1,898	2,136	2,381	2,555
10 years	576	1,963	377	22.3	2,080	1,475	1,614	1,834	2,066	2,337	2,568	2,708
11 years	628	1,924	433	22.9	2,356	1,709	1,846	2,056	2,337	2,619	2,894	3,078
Girls												
6-11 years	3,487	11,703	474	9.8	1,652	961	1,078	1,302	1,611	1,948	2,298	2,505
6 years	536	2,016	272	15.6	1,175	744	856	1,002	1,159	1,340	1,495	1,641
7 years	609	2,010	267	10.6	1,357	917	1,023	1,173	1,347	1,521	1,707	1,817
8 years	613	1,960	295	14.7	1,550	1,078	1,158	1,340	1,553	1,754	1,898	2,044
9 years	581	1,945	322	15.7	1,747	1,217	1,336	1,534	1,734	1,946	2,161	2,288
10 years	584	1,904	368	21.7	1,942	1,365	1,507	1,690	1,927	2,190	2,427	2,567
11 years	564	1,868	412	13.9	2,199	1,548	1,681	1,898	2,179	2,466	2,717	2,901
White												
6-11 years	6,100	20,403	488	12.0	1,757	1,039	1,155	1,401	1,712	2,072	2,419	2,618
6 years	950	3,509	272	13.6	1,261	862	933	1,073	1,254	1,425	1,593	1,720
7 years	1,063	3,497	283	13.6	1,454	1,018	1,104	1,259	1,447	1,651	1,812	1,916
8 years	1,035	3,413	301	12.1	1,657	1,158	1,273	1,465	1,647	1,851	2,039	2,161
9 years	1,019	3,393	351	16.2	1,857	1,316	1,424	1,624	1,833	2,079	2,323	2,458
10 years	1,014	3,324	368	18.6	2,048	1,470	1,585	1,793	2,035	2,298	2,530	2,655
11 years	1,019	3,267	421	17.6	2,320	1,673	1,792	2,025	2,301	2,585	2,846	3,028
Negro												
6-11 years	987	3,272	440	11.0	1,531	860	988	1,207	1,505	1,822	2,093	2,280
6 years	156	570	276	17.5	1,098	642	747	905	1,100	1,269	1,436	1,588
7 years	172	570	254	20.2	1,273	876	941	1,090	1,248	1,457	1,621	1,718
8 years	192	560	283	21.9	1,448	1,028	1,092	1,242	1,438	1,627	1,833	1,956
9 years	158	534	319	18.4	1,656	1,158	1,303	1,430	1,638	1,866	2,065	2,183
10 years	142	530	362	33.7	1,779	1,146	1,307	1,571	1,780	1,944	2,201	2,403
11 years	167	507	391	29.5	2,010	1,348	1,523	1,785	1,989	2,236	2,523	2,681

[1]Includes other races.

Table 1. Forced vital capacity of children 6-11 years, by age, sex, and race—sample sizes, standard deviation, standard error of the mean, mean, and selected percentiles: United States, 1963-65—Con.

Age, sex, and race	n	N	SD	$SE_{\bar{X}}$	$\bar{X}$	Percentile 5th	10th	25th	50th	75th	90th	95th
			Milliliters									
White boys												
6-11 years	3,153	10,391	492	15.6	1,833	1,104	1,244	1,475	1,793	2,155	2,496	2,690
6 years	489	1,787	263	17.2	1,326	912	994	1,132	1,329	1,497	1,640	1,764
7 years	551	1,781	282	19.2	1,524	1,088	1,182	1,332	1,519	1,707	1,858	1,946
8 years	537	1,739	296	14.3	1,732	1,263	1,359	1,536	1,736	1,932	2,105	2,216
9 years	525	1,730	358	26.9	1,947	1,385	1,518	1,700	1,927	2,170	2,397	2,586
10 years	509	1,692	364	21.6	2,122	1,519	1,646	1,874	2,119	2,373	2,580	2,724
11 years	542	1,662	419	24.1	2,406	1,767	1,903	2,119	2,388	2,645	2,930	3,119
White girls												
6-11 years	2,947	10,012	472	9.8	1,678	992	1,101	1,330	1,637	1,974	2,328	2,527
6 years	461	1,722	266	16.2	1,194	790	900	1,025	1,178	1,354	1,510	1,640
7 years	512	1,716	265	12.1	1,382	967	1,058	1,202	1,377	1,540	1,733	1,846
8 years	498	1,674	286	17.4	1,579	1,104	1,189	1,403	1,577	1,768	1,910	2,059
9 years	494	1,663	317	15.6	1,763	1,236	1,356	1,556	1,747	1,953	2,169	2,290
10 years	505	1,632	356	21.8	1,972	1,414	1,543	1,716	1,954	2,212	2,448	2,575
11 years	477	1,605	404	15.9	2,230	1,615	1,716	1,945	2,206	2,487	2,738	2,915
Negro boys												
6-11 years	464	1,642	419	15.2	1,570	924	1,053	1,279	1,559	1,845	2,110	2,237
6 years	84	289	275	38.6	1,153	641	803	973	1,160	1,367	1,458	1,617
7 years	79	286	262	24.9	1,331	921	1,006	1,124	1,321	1,519	1,685	1,791
8 years	79	279	265	34.4	1,528	1,075	1,214	1,347	1,527	1,704	1,890	2,029
9 years	74	269	309	35.2	1,651	1,158	1,309	1,430	1,632	1,829	2,063	2,146
10 years	65	264	347	50.5	1,812	1,130	1,346	1,654	1,799	1,948	2,187	2,346
11 years	83	255	366	44.8	2,021	1,483	1,573	1,805	1,991	2,219	2,492	2,701
Negro girls												
6-11 years	523	1,629	456	15.4	1,492	828	939	1,163	1,442	1,799	2,080	2,348
6 years	72	281	266	24.4	1,040	642	726	836	1,021	1,197	1,344	1,482
7 years	93	284	232	26.8	1,215	860	912	1,041	1,202	1,370	1,534	1,607
8 years	113	281	278	22.3	1,370	982	1,066	1,165	1,318	1,555	1,771	1,913
9 years	84	265	328	26.8	1,661	1,099	1,286	1,429	1,648	1,917	2,068	2,243
10 years	77	266	373	39.0	1,746	1,221	1,286	1,491	1,750	1,940	2,213	2,404
11 years	84	253	415	37.1	2,000	1,323	1,473	1,760	1,984	2,282	2,550	2,667

NOTE: n = sample size; N = estimated number of children in population in thousands; SD = standard deviation; $SE_{\bar{X}}$ = standard error of the mean; $\bar{X}$ = mean.

Table 2. Mean forced vital capacity of children 6-11 years, by sex, race, and stature—sample size: United States, 1963-65

Sex and race	n	Stature in centimeters											
		105-110	110-115	115-120	120-125	125-130	130-135	135-140	140-145	145-150	150-155	155-160	160-165
		Mean forced vital capacity in milliliters											
Total[1]	7,119	1,026	1,106	1,230	1,381	1,549	1,711	1,885	2,090	2,247	2,470	2,714	2,627
Boys	3,632	1,148	1,147	1,281	1,433	1,618	1,782	1,961	2,180	2,348	2,614	2,887	(2)
Girls	3,487	956	1,068	1,183	1,326	1,474	1,633	1,796	1,985	2,151	2,323	2,594	2,544
White	6,100	1,020	1,124	1,256	1,407	1,588	1,745	1,912	2,131	2,295	2,522	2,783	2,805
Negro	987	(1)	994	1,068	1,207	1,318	1,518	1,656	1,827	1,970	2,164	2,357	(2)
White boys	3,153	1,137	1,167	1,314	1,455	1,651	1,825	1,992	2,217	2,391	2,659	2,931	(2)
White girls	2,949	953	1,082	1,204	1,355	1,514	1,659	1,818	2,026	2,201	2,375	2,662	(2)
Negro boys	464	(1)	1,024	1,090	1,265	1,381	1,552	1,697	1,908	2,072	2,277	(2)	(2)
Negro girls	523	(1)	967	1,045	1,156	1,266	1,481	1,617	1,747	1,885	2,082	2,338	(2)

[1]Includes other races.
[2]Sample size less than 14.

NOTE: n = sample size.

Table 3. Mean forced vital capacity of children 6-11 years, by sex, race, and sitting height—sample size: United States, 1963-65

Sex and race	n	Sitting height in centimeters														
		56-58	58-60	60-62	62-64	64-66	66-68	68-70	70-72	72-74	74-76	76-78	78-80	80-82	82-84	84-86
		Mean forced vital capacity in milliliters														
Total[1]	7,119	942	978	1,110	1,204	1,318	1,474	1,629	1,792	1,972	2,145	2,307	2,509	2,673	2,745	2,861
Boys	3,632	(1)	1,000	1,157	1,235	1,368	1,522	1,684	1,855	2,045	2,224	2,403	2,651	2,828	(2)	(2)
Girls	3,487	977	964	1,077	1,183	1,265	1,420	1,573	1,720	1,877	2,054	2,195	2,372	2,559	2,666	2,752
White	6,100	911	1,023	1,108	1,226	1,332	1,483	1,638	1,803	1,979	2,160	2,319	2,525	2,720	2,792	2,861
Negro	987	(1)	909	1,118	1,125	1,249	1,428	1,566	1,702	1,919	1,994	2,129	2,875	(2)	(2)	(2)
White boys	3,153	(1)	1,112	1,158	1,264	1,380	1,531	1,692	1,867	2,056	2,238	2,410	2,664	2,856	(2)	(2)
White girls	2,947	(1)	975	1,072	1,200	1,280	1,431	1,582	1,727	1,877	2,070	2,209	2,374	2,606	2,704	2,752
Negro boys	464	(1)	864	1,156	1,144	1,302	1,479	1,623	1,752	1,958	2,073	2,223	(2)	(2)	(2)	(2)
Negro girls	523	(1)	949	1,090	1,109	1,203	1,365	1,521	1,656	1,872	1,920	2,064	2,355	(2)	(2)	(2)

[1]Includes other races.
[2]Sample size less than 14.

NOTE: n = sample size.

Table 4. Stature, sitting height, and sitting height/stature ratio for children 6-11 years, by race, sex, and age—sample size, mean, and standard deviation: United States, 1963-65

Race, sex, and age	N	Stature (centimeters)		Sitting height (centimeters)		Sitting height/ stature (percent)	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
White boys							
6 years	1,787	118.5	5.15	65.0	2.68	54.8	1.33
7 years	1,781	124.5	5.52	67.2	2.74	54.0	1.34
8 years	1,739	129.8	5.70	69.5	2.94	53.6	1.20
9 years	1,730	135.5	6.77	71.6	3.15	52.9	1.66
10 years	1,692	140.3	6.62	73.3	3.07	52.3	1.41
11 years	1,662	145.7	6.69	75.6	3.10	51.9	1.36
White girls							
6 years	1,722	117.7	5.47	64.2	3.00	54.6	1.54
7 years	1,716	123.4	5.86	66.4	2.99	53.8	1.51
8 years	1,674	129.4	6.19	68.8	2.89	53.2	1.79
9 years	1,663	135.1	6.72	71.1	3.19	52.7	1.45
10 years	1,632	140.8	7.00	73.5	3.39	52.2	1.28
11 years	1,605	147.3	7.89	76.5	3.96	52.0	1.92
Negro boys							
6 years	289	119.1	5.11	63.2	2.48	53.0	1.39
7 years	286	125.2	5.50	65.6	2.58	52.4	1.19
8 years	279	131.3	5.33	67.8	2.81	51.6	1.24
9 years	269	135.0	6.46	69.3	3.69	51.4	1.51
10 years	264	139.6	7.92	70.9	3.54	50.8	2.26
11 years	255	145.7	8.08	73.4	3.36	50.5	2.35
Negro girls							
6 years	281	118.5	5.75	62.3	2.78	52.6	1.23
7 years	284	124.6	5.55	64.9	3.05	52.1	1.18
8 years	281	129.4	6.69	66.6	3.50	51.6	1.52
9 years	265	137.5	7.80	69.6	3.43	50.7	1.49
10 years	266	141.8	9.85	71.9	3.77	50.8	2.77
11 years	253	149.2	7.42	75.1	4.08	50.4	1.23

NOTES: N = estimated number of children in population in thousands; $\bar{X}$ = mean; SD = standard deviation.
Comparable data for children 12-17 years can be found in Series 11, No. 126 of *Vital and Health Statistics*.

APPENDIX

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APPENDIX

STATISTICAL NOTES

The Survey Design

The sampling plan of the second cycle of the Health Examination Survey (HES) followed a highly stratified, multistage probability design in which a sample of the U.S. population (including Alaska and Hawaii) from the ages of 6 through 11 years, inclusive, was selected. Excluded were those children confined to an institution or residing upon any of the reservation lands set up for the American Indians.

In the first stage of this design, the nearly 2,000 primary sampling units (PSU's), geographic units into which the United States was divided, were grouped into 357 strata for use in the Health Interview Survey and the Current Population Survey of the U.S. Bureau of the Census and were then further grouped into 40 superstrata for use in Cycle II of HES.

The average size of each Cycle II stratum was 4.5 million persons, and all strata fell between the limits of 3.5 and 5.5 million persons. Grouping into 40 strata was done in a way that maximized homogeneity of the PSU's included in each stratum, particularly with regard to the degree of urbanization, geographic proximity, and degree of industrialization. The 40 strata were classified into 4 broad geographic regions (each with 10 strata) of approximately equal population and cross-classified into 4 broad population density groups (each having 10 strata). Each of the resultant 16 cells contained either 2 or 3 strata. A single stratum might include only one PSU (or only part of a PSU as, for example, New York City, which represented two strata) or several score PSU's.

To take account of the possible effect that the rate of population change between the 1950 and the 1960 census might have had on health, the 10 strata within each region were further classified into 4 classes ranging from those with no increase to those with the greatest relative increase. Each such class contained 2 or 3 strata.

One PSU was then selected from each of the 40 strata. A controlled selection technique was used in which the probability of selection of a particular PSU was proportional to its 1960 population. In the controlled selection an attempt was also made to maximize the spread of the PSU's among the States. While not every one of the 64 cells in the 4X4X4 grid contributed a PSU to the sample of 40 PSU's, the controlled selection technique ensured the sample's matching the marginal distributions in all 3 dimensions and being closely representative of all cross-classifications.

Generally, within a particular PSU, 20 census enumeration districts (ED's) were selected with the probability of selection of a particular ED proportional to its population in the age group 5-9 years in the 1960 census, which by 1963 roughly approximated the population in the target age group for Cycle II. A similar method was used for selecting one segment (cluster of households) in each ED. Each of the resultant 20 segments was either a bounded area or a cluster of households (or addresses). All of the children in the age range properly resident at the address visited were eligible children (EC's). Operational considerations made it necessary to reduce the number of prospective examinees at any one location to a maximum of 200. The EC's to be excluded for this reason from the sample child (SC) group were determined by systematic subsampling. If one of the sample children had a twin who was not a sample child, this other twin was brought in for examination, and while the results were recorded for use in a special substudy of twins, this twin was not included in the 7,119 children under the present analysis.

The total sample included 7,417 children 6-11 years of age of whom 96 percent were finally examined. These 7,119 examined children represented the roughly 24 million children in the United States who met the general criteria for inclusion in the sampling universe as of mid-1964.

All data presented in this publication are based on "weighted" observations; that is, data recorded for each sample child are inflated in the estimation process to characterize the larger universe of which the sample child is representative. The weights used in this inflation process are a product of the reciprocal of the probability of selecting the child, an adjustment for nonresponse cases, and a poststratified ratio adjustment which increases precision by bringing survey results into closer alinement with known U.S. population figures by race and sex for single years of age group 6-11.

In the second cycle of HES, the sample was the result of three stages of selection—the single PSU from each stratum, the 20 segments from each sample PSU, and the sample children from the eligible children. The probability of selecting an individual child is the product of the probabilities of selection at each stage.

Since the strata are roughly equal in population size and a nearly equal number of sample children were examined in each of the sample PSU's, the sample design is essentially self-weighting with respect to the target population; that is, each child 6-11 years old had about the same probability of being drawn into the sample.

The adjustment upward for nonresponse is intended to minimize the impact of nonresponse on final estimates by imputing to nonrespondents the characteristics of "similar" respondents. Here, "similar" respondents were judged to be examined children in a sample PSU having the same age (in years) and sex as children not examined in that sample PSU.

The poststratified ratio adjustment used in the second cycle achieved most of the gains in precision which would have been attained if the sample had been drawn from a population stratified by age, race, and sex and made the final sample estimates of population agree exactly with independent controls prepared by the U.S. Bureau of the Census for the noninstitutional population of the United States as of August 1, 1964 (approximate midsurvey point), by race and sex for each single year of age 6-11. The weights of every responding sample child in each of the 24 age, race, and sex classes are adjusted upward or downward so that the weighted total within the class equals the independent population control.

A more detailed description of the sampling plan and estimation procedures is included in earlier reports of the *Vital and Health Statistics* series. Series 11, No. 1[2] described the techniques used in Cycle I, which are similar to those of Cycle II.

Notes on Response Rates

There were 7,417 children aged 6-11 years selected for examination. Of these, 7,119 were actually examined, which made an overall response rate of just under 96 percent. The response rate by sex and 1-year age groups is shown in table I. It can be seen that only at age 8 years was the response rate for girls better than that for boys.

A similar analysis can be done by sex, race, and age as shown in table II where a striking difference in response is readily seen. Negro children responded better than their white counterparts at every age group, and 9-year-old Negro girls had an extraordinary 100-percent response rate.

Table I. Response rates for children 6-11 years, by sex and age: United States, 1963-65

Age	Boys	Girls
	Percent	
Total	96.5	95.5
6 years	96.5	94.9
7 years	96.5	95.5
8 years	95.2	97.0
9 years	97.6	94.8
10 years	97.0	95.1
11 years	96.2	95.6

Table II. Response rates for children 6-11 years, by sex, race, and age: United States, 1963-65

Age	Boys		Girls	
	Negro	White	Negro	White
	Percent			
Total	98.1	96.2	98.7	94.9
6 years	97.7	96.3	97.3	94.7
7 years	97.5	96.3	98.9	94.8
8 years	97.5	95.0	99.1	96.5
9 years	98.7	97.4	100.0	93.9
10 years	98.5	96.8	97.5	94.7
11 years	98.8	95.8	98.8	95.0

Parameter and Variance Estimation

As each of the 7,119 sample children has an assigned statistical weight, all estimates of population parameters presented in HES publications are computed taking this weight into consideration. Thus, $\overline{X}$, the estimate of a population mean μ is computed as follows:

$$\overline{X} = \frac{\sum_{i=1}^{n} W_i X_i}{\sum W_i}$$

where X_i is the observation or measurement taken on the ith person and W_i is the statistical weight assigned to that person.

The Health Examination Survey has an extremely complex sampling plan, and obviously the estimation procedure is, by the very nature of the sample, complex as well. A method is required for estimating the reliability of findings that "reflects both the losses from clustering sample cases at two stages and the gains from stratification, ratio estimation, and poststratification."[2]

The method for estimating variances in HES is the half-sample replication technique. The method was developed at the U.S. Bureau of the Census prior to 1957 and has at times been given limited use in the estimation of the reliability of results from the Current Population Survey. This half-sample replication technique is particularly well suited to HES because the sample, although complex in design, is relatively small (7,119 cases) and is based on but 40 strata. This feature permitted the development of a variance estimation computer program that produces tables containing desired estimates of aggregates, means, or distributions, together with a table identical in format but with the estimated variances instead of the estimated statistics. The computations required by the method are simple, and the internal storage requirements are well within the limitation of the IBM 360-50 computer system used at the National Center for Health Statistics.

Variance estimates computed for this report were based on 20 balanced half-sample replications. A half sample was formed by choosing one sample PSU from each of 20 pairs of sample PSU's. The composition of the 20 half samples was determined by an orthogonal plan. To compute the variance of any statistic, this statistic is computed for each of the 20 half samples. Using the mean as an example, this is denoted $\overline{X}_i$. Then, the weighted mean of the entire, undivided sample ($\overline{\overline{X}}$) is computed. The variance of the mean is the mean square deviation of each of the 20 half-sample means about the overall mean. Symbolically,

$$\text{Var}(\overline{X}) = \frac{\sum_{i=1}^{20} (\overline{X}_i - \overline{\overline{X}})^2}{20}$$

and the standard error of the mean is the square root of this. In a similar manner, the standard error of any statistic may be computed.

A detailed description of this replication process has been published.[18]

Imputation

As described earlier, the 7,119 spirograms collected by means of the HES varied greatly in quality. Since the HES is a weighted survey, intended to represent the 6-11-year-old population of the United States, spirometric values are necessary for every examined subject. It is important, then, to determine (1) for which subjects values should be imputed and (2) which method of imputation is most satisfactory.

Distributions of FVC's and FEV_1's were computed by age, race, and sex for each quality group (reference 5, tables 1 and 2), along with distributions of a variety of other physical and demographic characteristics (reference 5, tables 4-7). Inspection of these tables led the authors to collapse groups IA-IE into a group called "acceptables" and the other groups into a group called "unacceptables." Groups IA-IE (n = 5,803) comprised approximately 82 percent of the examined subjects, and their distributions of spirometric parameters and physical and demographic variables were sufficiently similar to treat them as one group.

Several methods of imputation were considered, but multiple stepwise regression was chosen as the most appropriate for the following reasons: (1) the percent of "unacceptables" was too high to permit simple substitution of age-race-sex specific means or random assignment of the values listed for a similar respondent case; (2) the percent of "unacceptables" was too high to permit simply dropping the unknown cases and distributing the accompanying sampling weights; and (3) relevant information was available for each unacceptable case, making possible a more accurate prediction than could be obtained by any of the other methods, particularly for those cases evidencing some unusual physiological or demographic characteristics. Thus, the 5,803 cases of groups IA-IE became the data set from which equations to predict spirometric parameters for the 1,316 "unacceptables" were generated.

The authors determined that, among the many physical and demographic variables available as regressors, 37 of these (see list that follows) might manifest significant correlations with the spirometric variables. The 37 independent variables submitted for multiple stepwise regression equations were:

Race	Elbow-elbow breadth	Muscle circumference	Ponderal index
Sex	Sitting height	Shoulder/hip ratio	WISC I.Q.
Age	Stature	Weight	Oral health index
North Region	Subischial length	Right-grip strength	Number of decayed, missing, filled teeth
Midwest Region	Biacromial breadth	Left-grip strength	Asthma
South Region	Chest breadth	Systolic blood pressure	Restricted activity
West Region	Chest depth	Diastolic blood pressure	Heart abnormality
Size of place	Bicristal breadth		Birthweight
Family income	Chest girth		
Parental education	Waist girth		
Seat breadth	Hip girth		

The computer was fed the values for these 37 possible regressors and the two dependent variables (FVC and FEV_1) for the 5,803 "acceptable" cases, and the following equations to predict FVC and FEV_1 for the 1,316 "unacceptables" were the result.

$$\begin{aligned} FVC = & -2982.5 - 141.7 \times \text{race} - 69.3 \times \text{sex} \\ & + 22.4 \times \text{age} + 24.7 \times \text{sitting height} \\ & + 11.8 \times \text{stature} + 33.7 \times \text{chest breadth} \\ & + 11.6 \times \text{chest girth} - 7.5 \times \text{hip girth} \\ & + 15.0 \times \text{left grip strength} + 2.0 \times \text{WISC I.Q.} \end{aligned}$$

$r = 0.8689 \qquad r^2 = 0.7550 \qquad \sigma_Y = 238.3$

$$\begin{aligned} FEV_1 = & -2624.0 - 95.8 \times \text{race} - 35.8 \times \text{sex} \\ & + 19.7 \times \text{age} + 20.3 \times \text{sitting height} \\ & + 10.6 \times \text{stature} + 27.7 \times \text{chest breadth} \\ & + 15.7 \times \text{chest depth} + 8.6 \times \text{chest girth} \\ & - 7.4 \times \text{hip girth} + 10.7 \times \text{left grip strength} \\ & + 1.5 \times \text{WISC I.Q.} + 167.5 \times \text{restricted activity} \end{aligned}$$

$r = 0.8279 \qquad r^2 = 0.6854 \qquad \sigma_Y = 236.3$

The reader should be forewarned about making unwarranted conclusions from these equations. The absence of a particular independent variable (e.g., chest girth) does not imply that it is not related to the dependent variable; it simply means that some other variable or combination of variables that *is* in the equation has accounted for the effect of the absent variable. Also, the resultant equation may not necessarily be the best predictor—as the number of dependent variables goes up, the number of possible multiple regression equations increases at a rate that makes the computation of every possible equation a prohibitive effort. The stepwise technique is a compromise in which the loss of predictive power is usually negligible.

The values for the independent variables in the two equations were then collected for the 1,316 "unacceptable" cases. The nominal variables, such as region, were recoded into "0-1" dichotomies, and all the data were edited. The spirometric values for each case were predicted, and to each value was added a random error calculated from the standard error of estimate of the appropriate regression equation and the IBM-written, random deviate generator. This last step is necessary to provide a parametrically normal dispersion of predicted values for any given set of regressor values; that is, to prevent an improper lumping of values at or near the population mean that would speciously reduce the standard error of that mean.

The validity of the prediction scheme was verified several ways. Distributions of the predicted values by age, race, and sex were computed and compared with the same distributions for the "acceptables" population. No significant difference was shown by the Sign Test at the 5-percent level. When these distributions were further crossed by sitting height (the first variable to be included in both the FVC and FEV_1 equations), again the Sign Test revealed no significant difference. Visual inspection showed that the relationship by age, race, and sex of FVC and FEV_1 was very similar in the "acceptables" and "unacceptables" classes. Finally, combining the groups resulted in values that were very near those of the original respondent group. Generally, the values for summary age, race, or sex groups were reduced somewhat, while there was no consistent increase or decrease of age-race-sex specific values. This was expected, since younger children, females, and Negroes (all of whom tend to have lower values than their respective complements) were overrepresented in the "unacceptables" class.

Correlations of Sitting Height Versus FVC and Stature Versus FVC

The problem of determining the exact relationships of FVC with stature or sitting height when race is a qualifier has stubbornly eluded solution. Graphs of these relationships (see figures 6 and 8) show clearly that there is a race effect and that nearly half of the FVC difference between Negro and white people can be accounted for by the shorter trunk lengths of Negroes. This suggests that race-specific product-moment correlations between FVC and sitting height should be greater than correlations that are not race specific. Also, since only the upper part of the body is significantly involved in the performance of an FES, it seems reasonable that correlations between FVC and sitting height should be greater than those of FVC and stature. Subsequent analysis was unable to substantiate any of this conjecture (see table A in text).

Not only are none of the race-specific correlations significantly better than the total correlations, but they also vary erratically. Also, the correlation between FVC and sitting height is only slightly greater than that between FVC and stature, where a large difference was anticipated.

One explanation for these unexpected results may lie in the relatively larger technical error (t.e.) associated with sitting height. This statistic, calculated from the formula

$$\text{t.e.} = \sqrt{\sum_{i=1}^{n} d_i^2 / 2n}$$

where d_i is the difference between repeated measurements on an examinee, reflects the reproducibility of a given measurement and is nearly twice as large (relatively) for sitting height as for stature.[8] It is mathematically and empirically demonstrable that increasing the technical error of a variable decreases its correlation with other variables. However, no replicate studies were done on Cycle II measurements. So it was not possible to calculate t.e.'s for these data or to quantify their relative effects, except to say that if the t.e. for sitting height had been as low (relatively) as that for stature, then the correlation between sitting height and FVC would have been greater. Also, due to the lack of t.e.'s on sitting height and stature, estimating what proportion of the total variability of each is due to real biologic variation and what proportion is due to examiner error is impossible. If these estimates had been available, the variances and covariances could have been adjusted to reflect equal t.e.'s, and the pseudocorrelations calculated from these estimates would have been a better description of the relationships between the three variables.

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