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Association of Dominant Somatotype of Men With Body Structure, Function During Exercise, and Nutritional Assessment

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ABSTRACT This study examined the hypothesis that somatotype determines body structure, functional responses at peak exercise, and nutritional status of 63 men ages 18–40 years who lived under controlled conditions. Data were grouped by dominant somatotype to emphasize differences in body types. Dominant ectomorphs (n = 19) had less ($P < 0.05$) body weight, fat weight, and percent body fat than endomorphs (n = 14) and mesomorphs (n = 30). Fat-free weight (FFW), total body potassium (TBK), and body cell mass (BCM), normalized for stature, were lower ($P < 0.05$) in the ectomorphs than in the endomorphs and mesomorphs. Comparisons between measured and predicted FFW and TBK showed that only the ectomorphs had less ($P < 0.05$) FFW and TBK than expected. Although all groups had the same peak power output, the ectomorphs had different functional responses during peak exercise. Ectomorphs had the greatest respiratory exchange ratio ($P < 0.05$), ventilatory equivalent for oxygen, and end-exercise plasma lactate concentrations ($P < 0.05$), and lowest peak oxygen uptake (L/min; $P < 0.05$). Nutrient intakes and blood biochemical markers of nutritional status were within the range of normal values in all groups. Correlations between measures of body structure, function, and nutritional status and dominant somatotype components were calculated after controlling for the effects of the other two somatotype components. Partial correlations were variable, with significant correlations ranging from –0.30 to 0.87. These data indicate that ectomorphs, as compared to endomorphs and mesomorphs, have deficits in FFW and BCM which are associated with differences in functional capacity. Am. J. Hum. Biol. 12:167–180, 2000.

Humans with different somatotypes demonstrate unique performance capacities during exercise and physical training (Cozens, 1930; Cureton, 1941; Sills, 1950; Sills and Michem, 1957; Tanner et al., 1960). Anthropological studies of Olympic athletes consistently show that individuals competing in the same athletic event have similar somatotypes regardless of their geographical, cultural, or economic backgrounds,

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whereas athletes participating in different athletic activities have different somatotypes (Carter, 1970, 1984; de Garay et al., 1974). These studies characterized the typical somatotype associated with performance in specific athletic events and concluded that significantly different somatotypes were associated with each event.

Sheldon et al.'s (1940) procedure for determining the somatotype of an individual did not require body measurements, although measurements from cadaver studies were used to establish morphological characteristics. But subsequently developed methods to more objectively estimate the somatotype of an individual (Parnell, 1958; Heath and Carter, 1967) utilized body measurements and many of those measurements were similar to measurements utilized to anthropometrically determine body composition. It is not surprising, then, that many studies have attempted to relate body composition variables and somatotype (Tanner et al., 1960; Bulbulian, 1984; Slaughter and Lohman, 1976; Dupertius et al., 1951; Bolonchuk et al., 1989). These studies have found that, on average, endomorphs were heavier, taller, and fatter than mesomorphs or ectomorphs, that mesomorphs had greater fat-free weights and were shorter than endomorphs or ectomorphs, and that ectomorphs had less fat and lower body weights than mesomorphs or endomorphs. Thus, these findings suggest a general association between body structure and somatotype and infer that performance is dependent on somatotype. However, because performance is an indirect measure of physiological function, an association between somatotype and function has only been implied, not demonstrated. Furthermore, it is well established that diet and mineral nutriture influence physical performance (Lukaski et al., 1996). Few studies have explored the interactions between body structure, physiological function at peak exercise, and nutritional status.

There is evidence of an association between physique and nutritional status. Tanner et al. (1960) and Gordon et al. (1987) demonstrated a relationship between total serum cholesterol and somatotype. Both studies revealed that endomorphs had the highest, whereas ectomorphs had the lowest, serum cholesterol concentrations; men, but not women, exhibited this relationship. Allard and Goulet (1968) also reported increased serum cholesterol concentrations as a function of body build, classified by height and weight. Although these studies categorize one measure of nutritional status according to body type, they failed to include an assessment of diet in the association between somatotype and serum cholesterol.

There are limited data evaluating differences in functional responses to exercise in relation to somatotype. Schreiber (1973) found that ectomorphs, as compared to endomorphs and mesomorphs, demonstrated an increased dependence on glycolytic metabolism during a standardized test of anaerobic function. No physiological explanation for this finding was provided.

This study examines the association between body structure and functional response at peak exercise and the concomitant role of nutrition in males exhibiting somatotype dominance. We report that ectomorphs exhibit different metabolic responses at peak power and that these differences in response may be explained by deficits in fat-free weight (FFW) and body cell mass (BCM).

METHODS

Subjects

Eighty-five men, ages 18–40 years, who had been recruited for participation in studies to determine mineral nutrient requirements at the USDA, ARS Grand Forks Human Nutrition Research Center, participated in this study. The studies were approved by the Institutional Review Board of the University of North Dakota and the Human Studies Review Committee of the U.S. Department of Agriculture. The research subjects gave written consent after receiving written and oral explanations of the purpose and procedures of the study.

Inclusion of the data in the present study was dependent on somatotype dominance. Only those subjects (n = 63; age = 28.5 years ± 0.96, mean ± SE) who demonstrated somatotype dominance, defined as a somatotype component rating at least 0.5 points higher than either of the other two component ratings, were selected. This criterion eliminated all subjects with equal ratings for the highest somatotype component. The mean ages for the dominant endomorphs, mesomorphs, and ectomorphs was 28.9 ± 1.4, 29.4 ± 1.8, and 26.7 ± 1.1

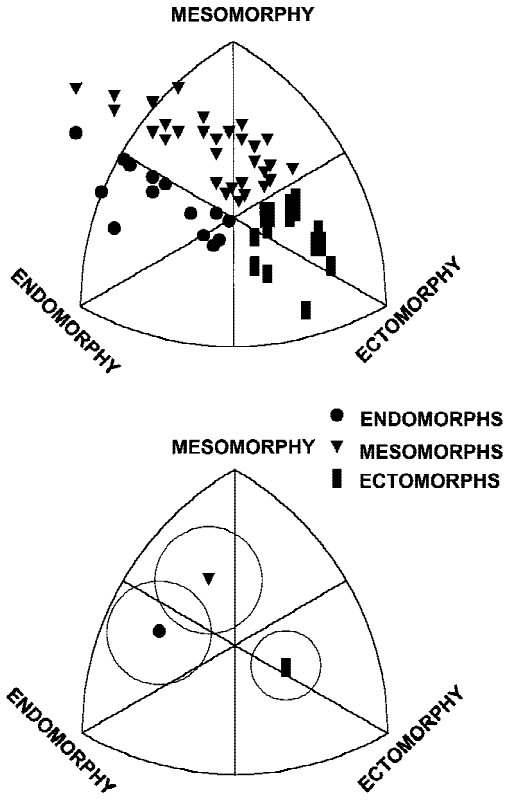

Fig. 1. Distribution of somatotypes. The upper somatochart represents the distribution for the sample of n = 63 while the lower somatochart depicts the mean somatotypes, and standard dispersion index, of the three dominant somatotype groups.

years, respectively. The upper somatochart in Figure 1 depicts the dispersion of individual volunteers, while the lower somatochart shows the mean somatotype for each of the dominant somatotype groups; the circle around each mean represents the somatotype dispersion index (SDI) for that group. The SDI is the mean of the individual somatotype distances from the mean somatotype (Carter, 1975).

Procedures

The anthropometric, compositional, biochemical, and physiological measurements were collected in the first 2 weeks of an initial control period during which the diet provided nutrients in amounts consistent with optimal function and health (NRC, 1989). All tests were administered as early in the control period as possible to optimize the effect of the self-selected dietary intake of the volunteers.

Body structure

Somatotype by anthropometry was computed according to the procedure of Carter (1975) and endomorphy was corrected for standing height (Carter and Heath, 1990). The Holtain skinfold caliper, Harpenden anthropometer, and a Toledo scale (Model 2831) were the test instruments and a trained anthropometrist administered all tests. The technical errors of the anthropometric measurement (<0.2 somatotype units) were only a fraction of the sample variance, coefficents of variation ranged from 3–7% and intraclass correlations for repeated measurements were greater than 0.98.

Total body potassium (TBK), which is found almost exclusively in the fat-free body, was determined by counting the gamma ray emissions from ^{40}K in the body by using sodium iodide detectors in a whole body counter with the methods and procedures described by Lykken et al. (1980). The precision of this method was 2%. Body cell mass (BCM) was calculated from determinations of TBK by using the formula (Moore et al., 1963): BCM = TBK · (0.00833) in which BCM is in kg and TBK is in milliequivalents. This approach assumes that the predominance (>97%) of TBK is located in muscle and viscera, with only minimal amounts (<3%) in bone, collagen, and adipose tissue (Moore et al., 1963).

Body density was determined by hydrodensitometry with a system similar to that described by Akers and Buskirk (1969). Measurement variability was less than 1% for body fat (Mendez and Lukaski, 1981). Residual lung volume was measured simultaneously with the underwater weighing by an open circuit technique for nitrogen washout of the lungs (Darling et al., 1940). Percent body fat was estimated from body density as described by Brozek et al. (1963). Fat weight was computed as the product of percent fat and body weight. FFW was computed as the difference between fat weight and body weight.

Because standing height is a significant predictor of FFW, and somatotype ratings are influenced by standing height, differences in FFW and TBK among dominant somatotypes were evaluated not only in absolute terms but also in comparison to predic-

tions based on nonathletic populations. This approach attempts to discriminate differences in the energy-producing component of the body by using prediction models for TBK (TBK_E) and FFW (FFW_S):

$$TBK_E = (5.52 \cdot 0.014\ A)\ X\ (W)^{0.5} \cdot (S)^2$$

in which TBK_E is in grams, A is age in years, W is body weight in kilograms, and S is standing height in meters (Ellis et al., 1974); and,

$$FFW_S = 0.00199\ (S)^2 + 1.67$$

in which FFW_S is in kilograms and S is standing height in meters (Slaughter and Christ, 1995).

Function during exercise

The physical work capacity (PWC) of the men was measured during a progressive, continuous, maximal exercise test on a cycle ergometer (Monark 868; Varberg, Sweden). The PWC protocol required a pedaling rate of 50 rpm beginning at a resistance of 1.0 kilopond (kp). Pedaling resistance was increased by 1.0 kp after each 3 min of exercise. All subjects pedaled to voluntary maximum. Tests were administered between 6:00 and 8:00 am and before breakfast.

Exhaled gas was analyzed continuously for oxygen and carbon dioxide concentrations, expired volume, and other selected variables of pulmonary function. Measurements were recorded at 60-sec intervals for 5 min of pre-exercise and during each minute of exercise. The Beckman Metabolic Measurement Cart (MMC), as described by Wilmore et al. (1976), or the MMC Horizon (Anaheim, CA) were the test instruments; subjects were randomly assigned to one instrument for all physical work capacity tests. Both instruments were calibrated before each test by analysis of a certified reference gas. The volume measurement was calibrated by a syringe with a known volume. Test-retest reproducibility was within 5%.

The electrocardiogram and heart rate were monitored with a Quinton electrocardiograph monitoring system (Model 630A; Quinton Instruments Co., Seattle, WA) using a bipolar CM_5 ECG lead.

A sample of whole blood was obtained from an antecubital vein before and at the end of each physical work capacity test for the determination of plasma lactate concentrations according to the method of Henry (1964).

Nutritional status assessment

Nutrient intakes were estimated by use of self-reported, 7-day dietary recall records of food and beverage consumption before entering the metabolic unit studies. The records were reviewed and interviews were conducted with an experienced dietician to clarify items and quantities that may have been unclear. The dietary records were analyzed for nutrient intake values by the methods described by Lukaski et al. (1990).

A fasting sample of whole blood was obtained from an antecubital vein during the first week of the control period and analyzed to yield estimates of nutritional status. Hematocrit, hemoglobin, plasma copper (Cu), iron (Fe), magnesium (Mg), and zinc (Zn), plasma total cholesterol (TCHOL), high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, very-low-density lipoprotein (VLDL) cholesterol, triglyceride (TG), and ferritin concentrations, total iron binding capacity (TIBC), ceruloplasmin, and superoxide dismutase (SOD) were the nutritional variables selected for this study.

Hematocrit and hemoglobin were measured with a Coulter Model S+4 (Coulter Electronics, Hialeah, FL). Plasma metals and TIBC were analyzed by the atomic absorption spectroscopy methods of Fernandez and Kahn (1971). Analyses of serum ferritin, an iron-containing protein which is the primary storage compound by which iron is mobilized to the transferrin-bound plasma pool, were performed by a procedure which utilized a competitive double binding assay (Abbott Laboratories, Abbott Park, IL). Ceruloplasmin, the principal copper-containing protein in the plasma, was determined by a colormetric copper oxidase reaction (Sunderman and Nomoto, 1970). SOD was assayed in red blood cells by the method described by Winterbourn et al. (1975). Serum cholesterol was measured enzymatically (Cobas Fara, Nutley, NJ) and the LDL and VLDL fractions were determined according to the procedures described by Friedwald et al. (1972).

Statistics

A somatochart was developed to show the dispersion of the somatotypes (Fig. 1). Three

TABLE 1. Anthropometric dimensions (mean ± standard error) of the subjects

	Endomorphs	Mesomorphs	Ectomorphs	
	n = 14	n = 30	n = 19	n = 63
Skinfolds, mm				
triceps	11.9^{b} ± 1.20	9.3^{b} ± 0.76	6.9^{a} ± 0.76	9.1 ± 0.55
subscapular	17.0^{c} ± 1.64	12.0^{b} ± 0.97	7.7^{a} ± 0.37	12.0 ± 0.75
suprailiac	19.1^{c} ± 1.60	8.1^{b} ± 0.96	6.5^{a} ± 0.62	10.1 ± 0.86
sum of three	48.9^{c} ± 3.69	29.3^{b} ± 2.47	21.1^{a} ± 1.37	31.2 ± 1.95
Height, cm	182.2^{b} ± 1.95	174.8^{a} ± 1.23	180.5^{b} ± 1.65	178.1 ± 0.97
Humerus width, cm	6.6 ± 0.16	6.7 ± 0.09	6.5 ± 0.07	6.6 ± 0.06
Femur width, cm	9.5 ± 0.14	9.2 ± 0.12	9.0 ± 0.14	9.2 ± 0.08
Circumferences, cm				
biceps	30.3^{b} ± 0.52	31.2^{b} ± 0.60	27.4^{a} ± 0.35	29.8 ± 0.38
calf	37.5^{b} ± 0.61	36.0^{b} ± 0.61	33.2^{a} ± 0.52	35.5 ± 0.41
Weight, kg	87.7^{b} ± 2.3	78.0^{b} ± 2.9	67.3^{a} ± 1.8	76.9 ± 1.80
Ponderal index*	41.1^{a} ± 0.42	41.1^{a} ± 0.35	44.5^{b} ± 0.19	42.1 ± 0.28

*Ponderal index = height, cm/(body weight, kg)$^{0.33}$
^{a,b,c}Different superscripts indicate statistically different ($P < 0.05$) means among dominant somatotypes.

distinct groups emerged with 14 dominant endomorphs, 30 dominant mesomorphs, and 19 dominant ectomorphs. The data were grouped by dominant somatotype and descriptive statistics were expressed as mean ± SE. The hypothesis that somatotype impacted structural, functional, and nutritional variables was tested for significance at the $\alpha = 0.05$ level by using one-way analysis of variance. In the presence of a significant main effect, Tukey's contrasts (SAS, 1997) were used post-hoc to compare means for each variable. Differences between measured and predicted TBK and FFW were evaluated for significant ($P < 0.05$) differences from 0 by using the paired *t*-test (SAS Institute, Cary, NC).

Because the somatotype of an individual reflects a composite estimate of physique, we also used partial correlation coefficients (Kleinbaum and Kupper, 1978) to discern associations between a specific somatotype component and various dependent variables (body structure, functional measures, and nutrition variables) after statistically adjusting for the other two somatotype components (SAS, 1997). Thus, the reported partial correlation coefficients describe relationships between the residual scores of each somatotype component and the individual compositional, functional, and nutritional variables after the effects of the other two somatotype components were statistically removed.

RESULTS

Body structure

The anthropometric dimensions (Table 1) showed a unique description for each dominant somatotype group. Skinfold measurements differed significantly by dominant somatotype except for the triceps measurement, which was not different between endomorphs and mesomorphs. Dominant endomorphs and ectomorphs were significantly taller than mesomorphs. Girth measurements and body weights were significantly greater for dominant endomorphs and mesomorphs than for ectomorphs. Humerus and femur widths were not significantly different by dominant somatotype. The Ponderal Index was significantly higher, and the body mass index (BMI) (Table 2) was significantly lower, for dominant ectomorphs than for endomorphs and mesomorphs.

The value for the somatotype component that represented the dominant somatotype was statistically greater than the value for the other components of somatotype in each dominant somatotype group (Table 2). This finding indicates clear dominance for each of the three somatotype groups (Fig. 1). Three men were rated as extreme endomorphic mesomorphs and one man was rated as an extreme mesomorphic endomorph. Body composition components also differed significantly as a function of somatotype dominance (Table 2). Dominant endomorphs had more fat, FFW, and BCM than ectomorphs. Dominant mesomorphs had more FFW than ectomorphs. Dominant ectomorphs had the least FFW and BCM.

Because standing height is highly correlated with FFW and TBK or BCM, and these relationships are not linear, we examined the influence of somatotype on these components of body composition by compar-

TABLE 2. Somatotype ratings and body composition (mean ± standard error) of the subjects

	Endomorphs	Mesomorphs	Ectomorphs	n = 63
Endomorphy	$4.8^{c} \pm 0.33$	$2.9^{b} \pm 0.24$	$2.1^{a} \pm 0.15$	3.1 ± 0.19
Mesomorphy	$3.7^{b} \pm 0.34$	$4.6^{c} \pm 0.23$	$2.3^{a} \pm 0.16$	3.7 ± 0.19
Ectomorphy	$1.7^{a} \pm 0.21$	$1.8^{a} \pm 0.17$	$3.9^{b} \pm 0.14$	2.4 ± 0.16
BMI, kg/m^2	$26.4^{b} \pm 0.7$	$25.5^{b} \pm 0.8$	$20.6^{a} \pm 0.3$	24.2 ± 0.5
Fat-free weight, kg	$63.9^{b} \pm 1.8$	$62.0^{b} \pm 1.9$	$56.5^{a} \pm 1.5$	60.4 ± 1.1
Fat weight, kg	$20.8^{b} \pm 2.2$	$14.6^{a,b} \pm 1.2$	$9.4^{a} \pm 0.6$	13.8 ± 0.8
Body fat, %	$24.4^{b} \pm 2.0$	$17.8^{a,b} \pm 0.9$	$14.0^{a} \pm 0.8$	17.5 ± 1.1
Total body potassium, g	$155^{a} \pm 24$	$144^{b} \pm 16$	$127^{a} \pm 18$	138 ± 22
Body cell mass, kg	$33.2^{b} \pm 5.2$	$31.2^{b} \pm 3.5$	$27.1^{a} \pm 3.0$	29.5 ± 4.6
Body cell mass, g/cm	$0.18^{b} \pm 0.01$	$0.18^{b} \pm 0.01$	$0.15^{a} \pm 0.01$	0.16 ± 0.01

[a,b,c]Different superscripts indicate statistically different ($P < 0.05$) means among dominant somatotypes.

ing measured and predicted values. Dominant somatotype impacted the measured and predicted FFW data differently (Fig. 2). Dominant endomorphs and mesomorphs had similar FFW values measured with hydrodensitometry which were significantly greater than values observed in the ectomorphs. In contrast, predicted FFW values were greater than observed values in the dominant endomorphs and ectomorphs, as compared to the mesomorphs. The difference between measured and predicted FFW values were significantly different than 0 only in the dominant ectomorphs. Measured TBK values were less than predicted in all three dominant somatotype groups of healthy adults (Ellis et al., 1974) but only significantly different in the ectomorphs (Fig. 3).

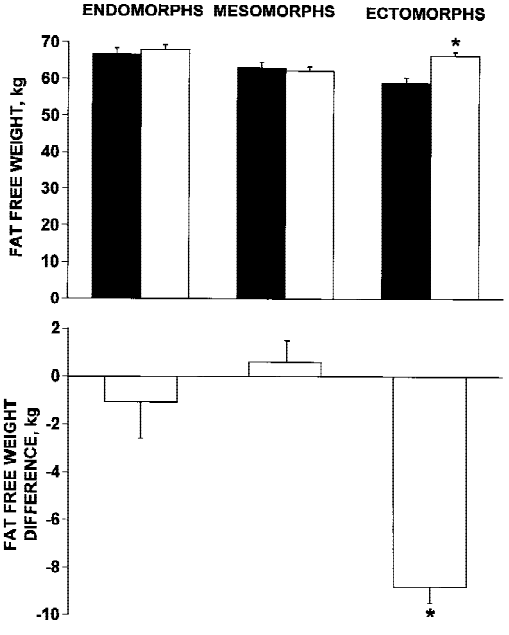

Fig. 2. Comparison of densitometrically determined (filled bars) and predicted (open bars; Slaughter and Christ, 1995) fat-free weight in upper panel and differences between predicted and measured fat-free weight in men with dominant somatotypes. Asterisks indicate significant ($P < 0.05$) differences from 0. Values are mean ± SE.

Function at peak exercise

All groups produced statistically similar peak power output, ventilatory rate, heart rate, and gross peak carbon dioxide output and oxygen uptake (Table 3). Peak oxygen consumption, normalized for body weight, in the dominant ectomorphs was significantly greater than in the endomorphs, but similar to that in the mesomorphs during the physical work capacity test (Table 3). The dominant ectomorphs also had the greatest respiratory exchange ratio (RER) at peak exercise. The dominant endomorphs had lower mean oxygen consumption per unit body weight and lower mean RER at peak exercise than the ectomorphs; neither were significantly different than the values obtained from the mesomorphs. The dominant ectomorphs had an increased ventilatory equivalent for oxygen (V_E/VO_2) over endomorphs and ectomorphs and a ventilatory equivalent for carbon dioxide (V_E/VCO_2) greater than mesomorphs but similar to that measured in the endomorphs. Pre-exercise blood lactate concentration was similar among the somatotype groups but end-exercise lactate concentration was significantly greater in the ectomorphs than the other somatotypes.

Nutritional status assessment

Blood biochemical indices of iron, zinc, and magnesium nutritional status were not affected by dominant somatotype (Table 4). Dominant endomorphs had significantly reduced copper status as measured by de-

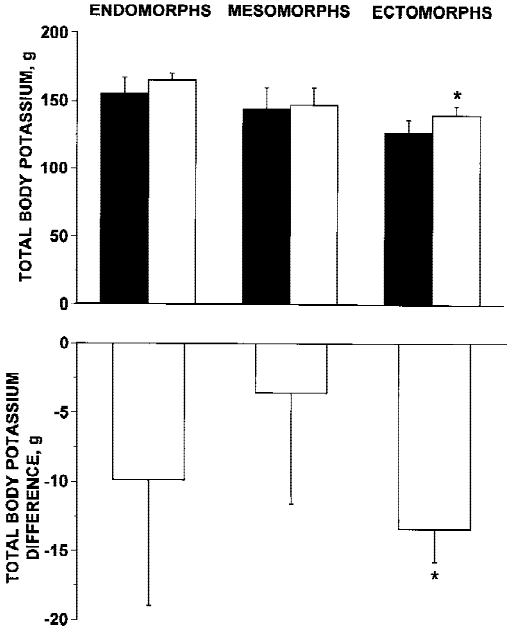

Fig. 3. Comparison of measured (filled bars) and predicted (Ellis et al., 1974) total body potassium in upper panel and differences between predicted and measured total body potassium in men with dominant somatotypes. Asterisks indicate significant ($P < 0.05$) differences from 0. Values are mean ± SE.

creased superoxide dismutase and ceruloplasmin, two copper-containing proteins, as compared to mesomorphs and ectomorphs.

Body type impacted some measurements of circulating lipid concentrations. Total plasma cholesterol concentrations were similar among the groups. Dominant endomorphs had significantly lower HDL-cholesterol than compared to the mesomorphs and ectomorphs; they also had the highest TG, LDL-, and VLDL-cholesterol concentrations, although the differences were not statistically significant.

Dietary intake

Energy and macronutrient (protein, fat, and carbohydrate) intakes (Table 5) were statistically similar among dominant somatotype groups. The dominant endomorphs had significantly lower copper and magnesium intakes; these values were at the low end of the recommended amount of intakes. While zinc intakes were not significantly different among the dominant somatotypes, the mean intakes by dominant endomorphs and ectomorphs were lower than the recommended amount of intake. Iron intakes did not differ significantly among the dominant somatotypes and, on average, iron intakes exceeded recommendations for the U.S. male population.

Somatotype and body structure, function, and nutritional variables

Dominant somatotype, statistically adjusted for the contributions of the other two somatotype components, was significantly related to some measures of body structure, physiological responses to exercise, and nutritional status indicators (Table 6). The magnitude of the correlation coefficients, however, was variable, with numerous significant relationships identified. Endomorphy was directly related to all measures of body habitus and composition. In contrast, ectomorphy was inversely related to most determinations of body size and composition, except stature and FFW. Mesomorphy was significantly correlated only with BMI.

Certain somatotypes were significantly related to some cardiorespiratory and cardiovascular responses during peak exercise (Table 6). Endomorphy was positively related to the ventilatory equivalent for carbon dioxide. Mesomorphy, however, was positively associated with peak power, rate of ventilation, and oxygen uptake. Similarly, ectomorphy was positively correlated with power output, ventilatory rate, oxygen consumption, heart rate, and ventilatory equivalents for oxygen and carbon dioxide. Lactate accumulation during exercise, however, was positively related to ectomorphy.

Somatotype was also correlated significantly with some nutritional status indicators. In general, all somatotypes were very strongly correlated with ceruloplasmin ($r \geq 0.75$) and plasma magnesium ($r \geq 0.33$). Endomorphy was correlated with copper markers (directly with plasma copper but inversely with SOD activity). Mesomorphy was positively related to plasma zinc and serum ferritin, but negatively with hematocrit. Ectomorphy was positively related with plasma zinc.

Somatotype was significantly associated with circulating lipid and lipoprotein concentrations (Table 6). All somatotypes were positively correlated with total cholesterol, triglycerides, LDL-, and VLDL-cholesterol fractions. The HDL fraction was inversely

TABLE 3. Function (mean ± standard error) at peak ergocycle exercise by dominant somatotype component

	Endomorphs	Mesomorphs	Ectomorphs
Peak power, W	202 ± 11	210 ± 7	209 ± 9
$\dot{V}_E$, L/min	110 ± 11	101 ± 10	108 ± 6
$\dot{V}O_2$, mL/kg/min	34.2[a] ± 3	39.2[a,b] ± 2	41.6[b] ± 2
$\dot{V}O_2$, mL/min	2,989 ± 227	2,999 ± 121	2,827 ± 165
$\dot{V}CO_2$, mL/min	3,249 ± 268	3,414 ± 131	3,300 ± 196
RER	1.09[a] ± 0.02	1.11[a] ± 0.02	1.17[b] ± 0.03
Heart rate, bpm	179 ± 6	180 ± 4	184 ± 2
$\dot{V}_E/\dot{V}O_2$	34.8[a] ± 1.4	33.5[a] ± 0.9	38.4[b] ± 1.3
$\dot{V}_E/\dot{V}CO_2$	33.2[b] ± 1.4	29.3[a] ± 0.6	32.9[b] ± 1.2
Blood lactate, mM/L			
Pre-exercise	0.6 ± 0.07	0.7 ± 0.05	0.7 ± 0.05
Peak exercise	4.8[a] ± 0.7	5.9[a] ± 0.3	6.6[b] ± 0.3

[a,b]Different superscripts indicate statistically different ($P < 0.05$) means among dominant somatotypes.

TABLE 4. Nutritional assessment (mean ± standard error) by dominant somatotype component

	Endomorphs	Mesomorphs	Ectomorphs	Range of normal values*
Hematocrit, %	45.4 ± 0.6	45.2 ± 0.6	44.8 ± 0.7	37–52
Hemoglobin, g/L	155 ± 22	157 ± 30	154 ± 31	120–180
Plasma Cu, μg/dL	91[a] ± 6.2	78[b] ± 2.2	82[a,b] ± 3.1	70–140
Plasma Mg, mg/dL	1.70 ± 0.03	1.73 ± 0.05	1.80 ± 0.04	1.6–3.0
Plasma Zn, μg/dL	88 ± 2.9	85 ± 1.8	88 ± 2.7	65–115
Plasma Fe, μg/dL	122 ± 7.1	116 ± 5.9	124 ± 9.6	50–150
Ferritin, μg/L	51.0 ± 10.7	93.0 ± 11.2	80.0 ± 18.5	36–255
TIBC, μg/dL	301 ± 13.8	281 ± 9.2	285 ± 10.5	250–500
Ceruloplasmin, mg/dL	29.8[a] ± 0.5	35.1[b] ± 3.1	34.2[b] ± 2.1	
SOD, U	2,654[a] ± 102	3,298[b] ± 127	3,479[b] ± 192	2,500–3,500
TCHOL, mg/dL	179 ± 10	169 ± 6	175 ± 8	<220
Triglycerides, mg/dL	111 ± 10	97 ± 8	91 ± 8	40–197
HDL, mg/dL	40.3[a] ± 4.2	49.7[b] ± 2.4	56.8[b] ± 3.2	29–80
LDL, mg/dL	117 ± 10	101 ± 6	100 ± 7	
VLDL, mg/dL	22.3 ± 2.8	19.0 ± 1.6	18 ± 1.6	

*Reference data from Grand Forks Human Nutrition Research Center.
[a,b]Different superscripts indicate different ($P < 0.05$) means among dominant somatotypes.

TABLE 5. Mean daily dietary intake (mean ± standard error) by dominant somatotype component

	Endomorphs	Mesomorphs	Ectomorphs	RDA or ESADD1*
Energy, kcal	2,866 ± 356	3,391 ± 287	2,828 ± 258	
Protein, g	115 ± 11.2	123 ± 13.2	117 ± 13.8	
Fat, g	106 ± 15.0	144 ± 17.4	100 ± 11.1	
Carbohydrate, g	364 ± 44.8	392 ± 35.6	335 ± 24.8	
Cu, mg	1.6 ± 0.2[a]	2.4 ± 0.3[b]	2.1 ± 0.3[b]	1–3
Fe, mg	19.0 ± 2.1	24.0 ± 4.5	19.0 ± 2.1	12
Mg, mg	335 ± 26[a]	432 ± 55[b]	405 ± 74[b]	350
Zn, mg	13.4 ± 1.3	15.8 ± 1.7	13.3 ± 2.2	15

*NRC (1989).
[a,b]Different superscripts indicate statistically different ($P < 0.05$) means among dominant somatotypes.

related to somatotype; this relationship was significant only in the mesomorphs.

Correlations between individual somatotypes and nutrient intakes were generally weak, with only a few significant relationships identified (Table 6). Endomorphy was inversely related ($r \leq -0.25$) to carbohydrate, copper, iron, and magnesium intakes. In contrast, mesomorphy was directly correlated with fat and magnesium intakes. No significant relationships were found between ectomorphy and nutrient intake.

DISCUSSION

The findings of this study demonstrate that dominant somatotype affects the body structure, functional response at peak exercise, and selected measurements of nutritional status of men. They also provide evidence that the influence of body physique on physiological function at peak exercise may be explained by a decrease of the energy-producing component of the body, fat-free mass, or body cell mass.

TABLE 6. Summary of partial correlations relating somatotype components and body structural, functional, and nutritional variables

	Endomorphs	Mesomorphs	Ectomorphs
Body structure			
Height, cm	0.544[d]	–0.173	0.350[c]
Weight, kg	0.657[d]	0.152	–0.014
BMI, kg/m^2	0.653[d]	0.410[c]	–0.470[d]
Fat-free weight, kg	0.352[b]	0.182	0.054
Fat weight, kg	0.687[d]	0.020	–0.100
Body fat, %	0.872[d]	–0.142	–0.303[a]
Body cell mass, kg	–0.016	–0.127	–0.454[d]
Functional responses			
Peak power, W	0.075	0.252[a]	0.239[a]
V_E, L/min	0.180	0.247[a]	0.270[a]
VO_2, L/min	0.114	0.226	0.152
VO_2, mL/kg/min	–0.229	0.261[a]	0.256[a]
VCO_2, L/min	0.044	0.244	0.183
RER	–0.215	0.133	0.147
Heart rate, bpm	0.053	0.239	0.258[a]
V_E/VO_2	0.106	0.147	0.285[a]
V_E/VCO_2	0.246[a]	0.100	0.245[a]
Blood lactate, nmol/L			
Pre-exercise	–0.206	0.081	–0.063
Post-exercise	–0.218	0.187	0.251[a]
Blood biochemical variables			
Hematocrit, %	–0.009	–0.262[a]	–0.221
Hemoglobin, g/L	0.001	–0.125	–0.092
Plasma Cu, μg/dL	0.468[c]	–0.057	0.175
Plasma Mg, mg/dL	0.331[a]	0.401[b]	0.445[b]
Plasma Zn, μg/dL	0.173	0.300[a]	0.276[a]
Plasma Fe, μg/dL	–0.163	–0.001	–0.004
Ferritin, μg/L	–0.171	0.291[a]	0.051
TIBC, μg/dL	0.275	–0.012	0.121
Ceruloplasmin, mg/dL	0.757[d]	0.826[d]	0.833[d]
SOD, U	–0.439[c]	0.204	0.160
TCHOL, mg/dL	0.393[a]	0.353[a]	0.356[a]
Triglycerides, mg/dL	0.517[b]	0.625[d]	0.448[b]
HDL, mg/dL	–0.111	–0.493[b]	–0.203
LDL, mg/dL	0.411[c]	0.484[c]	0.416[c]
VLDL, mg/dL	0.516[c]	0.624[d]	0.446[c]
Dietary variables			
Energy, kcal/d	–0.229	0.218	–0.003
Protein, g/d	–0.063	0.108	0.043
Fat, g/d	–0.069	0.286[a]	0.067
Carbohydrate, g/d	–0.294[a]	0.078	–0.104
Cu, mg/d	–0.361[a]	0.053	–0.208
Fe, mg/d	–0.284[a]	0.160	–0.072
Mg, mg/d	–0.246[a]	0.321[a]	0.101
Zn, mg/d	–0.128	0.101	–0.067

[a]$P < 0.05$.
[b]$P < 0.01$.
[c]$P < 0.001$.
[d]$P < 0.0001$.

Somatotype has been described as the overview of physique which is independent of size (Parnell, 1958). Parnell noted that Sheldon et al.'s (1940) somatotypes concentrated on body shape, not body size, and they seemingly deliberately avoided size by placing height as the denominator in a series of body proportions by which he classified physique in terms of three components.

The structural dimensions associated with the dominant somatotype groups in this study identified standing height as a dependent variable in the determination of somatotype. A high value for standing height, associated with heavy body weight, high skinfold fat, and large girth dimensions, was characteristic of the dominant endomorphs. A similarly high standing height, but in combination with the least of body weight, skinfold fat, and girth, was characteristic of the dominant ectomorphic group. The dominant mesomorphs demonstrated another unique combination: lowest standing height with weight and skinfold

fat less than the dominant endomorphs but greater than the dominant ectomorphs, and with girths greater than dominant ectomorphs but not significantly different from those of dominant endomorphs. Height apparently is a significant dimension in determining somatotype but only in combination with other variables.

These findings agree with Boileau and Lohman (1977) in that physique is characterized by three distinct and complementary components, including body size, structure, and composition. Body size refers to the physical magnitude of the body and its segments. Body structure alludes to the distribution of body parts expressed as ratios of stature. Composition is the amount of the various chemical components of the body. Although there is recurrent interest in describing the relationship between physique and physical performance (Cureton, 1941; Carter, 1970), only generalizations are available. As expressed by Sheldon et al. (1940), Tanner (1964), and de Garay et al. (1974), individuals with relatively homogenous somatotypes participate in specific sporting activities. Explanations for this finding remain tenuous.

One speculation is that somatotype reflects differences in body composition. This hypothesis rests on observed correlations between body composition determinations and somatotype ratings. Dupertius et al. (1951) found a significant negative correlation between specific gravity and endomorphy and nonsignificant correlations between specific gravity, mesomorphy, and ectomorphy. Wilmore (1970) evaluated the hypothesis that the endomorphic and mesomorphic components represent the degree of fatness and FFW, respectively. Because of low correlations ($r = 0.16$ and 0.41 for females and males, respectively) between FFW and mesomorphy, Wilmore questioned the validity of considering the mesomorphic component as the fat-free body. Wilmore observed greater correlation coefficients between percent body fat and the endomorphic component among women and men ($r = 0.58$ and 0.72, respectively).

Slaughter and Lohman (1976) reported significant correlations between percent body fat and endomorphy, mesomorphy, and ectomorphy ($r = 0.74$, 0.45, and –0.66, respectively). Correlation coefficients relating FFW and the somatotype components were not significant ($P > 0.05$; $r = 0.25$, 0.20, and -0.34, respectively). Participants in these studies only included college students.

Bolonchuk et al. (1989) reported similar findings in samples of men ($n = 220$) and women ($n = 200$) ranging in age from 17–74 years. Endomorphy was significantly correlated with densitometrically determined percent fat in men and women $r = 0.80$ and 0.87, respectively. Ectomorphy was negatively correlated with percent body fat $r = –0.56$ and –0.68 for men and women. FFW correlated significantly with mesomorphy $r = 0.36$ and ectomorphy $r = –0.62$ only in men.

Generalizations regarding the specificity of somatotypic ratings with body composition measurements should be restricted. In previous studies (Dupertius et al., 1951; Wilmore, 1970; Slaughter and Lohman, 1976; Bolonchuk et al., 1989), the highest component of the somatotype rating was clear. These somatotypes, however, tended toward midline ratings, not extremes or dominant somatotypes. Moreover, the dominance of the rating was modified by a second component. Thus, the relationship of the dominant component to a body composition variable may be diminished by the association of the modifying component to the same variable. Bulbulian (1984) demonstrated a significant correlation between endomorphy and percent body fat among individuals with extreme endomorphic ratings. Bolonchuk et al. (1990) discussed this effect of the modified somatotype on body composition.

In the present study, the impact of dominant somatotype, after statistically adjusting for the modifying somatotype components, on body composition was investigated. Dominant endomorphy was significantly correlated with body fatness and fat weight, $r = 0.872$ and 0.687, respectively; it also was significantly related to FFW, $r = 0.352$. No significant relationships were identified for mesomorphy and FFW. Ectomorphy, however, was significantly and inversely correlated with BCM and body fatness, $r = –0.454$ and –0.303, respectively. Thus, only endomorphy and ectomorphy are strong predictors of body composition.

Another consideration in the relationship between somatotype and body composition is the impact of stature on this relationship. Stature is one discriminating factor among individuals with different somatotypes. Me-

somorphs generally are shorter than endomorphs and ectomorphs. Because the relationship between somatotype and function may depend on fat-free weight, or more importantly muscle weight, it is important to normalize body composition data for stature. Van Itallie et al. (1990) recommended the fat-free weight index, fat-free weight/height^2, as an indicator of nutritional status. A limitation of the use of this ratio is that a linear relationship between stature and FFW is assumed. Because this assumption of linearity is considered weak (Slaughter and Christ, 1995), a regression of FFW vs. height^x has been derived to characterize physique while controlling for differences in stature in athletic and nonathletic populations (Slaughter and Lohman, 1980; Slaughter et al., 1987). Slaughter and Christ (1995) used this approach to find that participants in some activities have significantly greater than expected FFW (i.e., professional and collegiate football players, judoists, ice hockey players, weight lifters) and other participants (cyclists and long distance runners) have similar or significantly less than expected FFW.

We employed this approach to examine the influence of dominant somatotypes on FFW independently of stature. Dominant endomorphs and mesomorphs had similar measured and predicted FFW values. In contrast, dominant ectomorphs had significantly less FFW than anticipated.

Because energy production depends on the amount of BCM, we compared the measured and predicted TBK (Ellis et al., 1974). Dominant ectomorphs had significantly less TBK than predicted on the basis of sex, age, body weight, and stature. This difference was, on average, 12 g. Dominant endomorphs also had a dearth of about 10 g, but this difference was quite variable because of interindividual differences between measured and predicted values.

Dominant ectomorphs had different physiological responses during an ergocycle work capacity test. Although all groups had similar peak power outputs and gross oxygen consumption during the standardized exercise test, the ectomorphs demonstrated an increased dependence on glycolytic metabolism, as shown by a significantly increased respiratory exchange ratio and post-exercise lactate concentration. This finding is consistent with Schreiber's (1973) report of greater anaerobic component in ectomorphic, as compared to endomorphic and mesomorphic, athletes during a standardized test of anaerobic function.

The dominant ectomorphs also had a significantly altered respiratory response. Peak ventilatory rate was similar among all groups. The ventilatory equivalent for oxygen, however, was significantly higher in the ectomorphs. This observation indicates an increased rate of ventilation per unit of oxygen uptake. Somatotype also impacted the peak ventilatory equivalent for carbon dioxide; dominant endomorphs and ectomorphs had significantly greater values than the mesomorphs. The altered elimination of carbon dioxide is a characteristic of over-fat individuals during exercise and is related to altered pulmonary function associated with decreased chest wall compliance (Babb et al., 1991). In the dominant ectomorphs, the increased ventilatory equivalent for carbon dioxide presumably reflects the heightened anaerobic demand of the ergocycle work. This finding is consistent with the reported increased peak respiratory exchange ratio and post-exercise lactate concentration.

Blood biochemical measures of nutritional status were within the ranges of normal values. Copper status, however, was impacted by somatotype. Dominant endomorphs had significantly decreased superoxide dismutase activity and ceruloplasmin protein concentration, which are two indicators of copper nutritional status (Milne, 1998). Plasma copper, a less sensitive indicator of marginal copper status (Milne, 1998), was significantly lower in the dominant mesomorphs than in the endomorphs, who had a value similar to the that seen in the ectomorphs. These measures of copper nutriture may be explained by a significantly reduced dietary intake of copper by the dominant endomorphs. Similarly, magnesium intake was significantly less among the endomorphs. Mean dietary copper and magnesium were at the minimal amounts recommended for the U.S. population (NRC, 1989).

Somatotype affected some measures of circulating lipids. Although total cholesterol and triglyceride concentrations were similar among the somatotype groups, dominant endomorphs had significantly decreased high density lipoprotein cholesterol. This finding is consistent with the observation of Gordon et al. (1987) that endomorphs have

decreased high-density cholesterol. The failure to detect hypercholesterolemia in the dominant endomorphs contrasts with previous reports (Tanner et al., 1960; Allard and Goulet, 1968; Gordon et al., 1987; Malina et al., 1997). This difference may be attributed to the lack of evaluation of dietary fat intake, a key factor in explaining serum lipid concentrations in healthy people (Lukaski et al., 1984), in previous reports. This finding suggests that somatotype per se is not an independent predictor of total cholesterol concentration.

Because an individual's physique is influenced not only by the dominant somatotype rating but also by contributions from the other somatotype components, we examined relationships between dominant somatotype components, controlled for the influences of the other components, and measures of body structure, function, and nutrition. This analysis provided some interesting parallels with the previous findings. Endomorphs had significant and positive partial correlations with all measures of body composition, whereas the ectomorphs had inverse relationships. These observations confirm the generalization of increased fat and FFW among endomorphs and diminished fat and BCM among ectomorphs.

Some important relationships were identified between somatotype and functional responses during peak ergocycle work. Interestingly, endomorphy and ectomorphy were significantly correlated with the ventilatory equivalent for carbon dioxide; these somatotypes also demonstrated significantly greater ventilatory equivalents for carbon dioxide than did the mesomorphs (Table 3). Furthermore, ectomorphy was significantly correlated with end-exercise lactate, suggesting an exaggerated anaerobic metabolism during graded, progressive work in ectomorphs.

Somatotype apparently did not discriminate serum lipid and lipoprotein concentrations. Total cholesterol, triglycerides, LDL and VLDL concentrations were significantly and directly related to each somatotype rating. HDL concentration, however, was only significantly and inversely correlated with mesomorphy. This finding suggests that somatotype affects blood lipid and lipoprotein concentrations. It extends the report of Malina et al. (1997), who showed an inverse, significant relationship between somatotype, specifically mesomorphy and ectomorphy, and blood lipids (triglycerides and cholesterol) among men ages 40–49 years, but not men ages 30–39 years, who had nonsignificant relationships with blood lipids. These authors also found that in women ages 40–49 years, mesomorphy was directly and significantly related to blood lipids and lipoproteins. HDL cholesterol was inversely correlated with all somatotypes in men and women ages 30–39 years, and women and male endomorphs ages 40–49 years. This finding is consistent with the observations in the present study.

Some insights into these relationships may be found in the nutrient intake data. Dietary fat was significantly and directly related to mesomorphy. Carbohydrate intake was inversely correlated with endomorphy. Copper, iron, and magnesium intakes were significantly and inversely correlated with endomorphy, whereas magnesium intake was significantly and positively related to mesomorphy. Because nutrient intake was similar and consistent with recommended amounts, the impact of the relationships on measured lipid variables is unclear. It is noteworthy that endomorphs demonstrated a negative relationship with mineral intakes, and suggest that a long-term consumption pattern of minimal dietary copper and magnesium may be conducive to development of elevated circulating lipids and lipoproteins conducive to future increased risk of ischemic heart disease.

The findings of this study were limited by the magnitude of the dominant somatotypes for the groups: 4.8, 4.6, and 3.9 for the dominant endomorphs, mesomorphs, and ectomorphs, respectively. Although these values clearly indicate component dominance, they are not extreme values. The endomorphic group, for example, had a mean somatotype of 4.8–2.9–2.1, which is substantially different than an extreme somatotype rating of 7–1–1. Similarly, the mean somatotypes of the dominant mesomorph and ectomorph groups are quite different than their extreme counterparts. Because there was an association among many of the variables tested, it would seem likely that selection of more somatotypes would yield more extreme values.

In summary, the relationship between dominant somatotype and body composition was limited to endomorphy as an indicator of body fatness in men. The interaction be-

tween somatotype and nutritional status suggests that endomorphs may be at risk of copper depletion because of marginal dietary intakes of copper. Similarly, dietary magnesium may be a limiting nutrient. Somatotype per se did not impact measures of circulating lipids. This finding apparently is related to a lack of difference in dietary fat intake among the groups. Ectomorphy was associated with increased dependence on glycolytic metabolism during progressive, maximal exercise on a cycle ergometer. This functional characteristic of ectomorphy, as compared to mesomorphy and endomorphy, may be explained by the deficit in fat-free weight and body cell mass.

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LITERATURE CITED

Akers R, Buskirk ER. 1969. An underwater weighing system utilizing force cube transducers. J Appl Physiol 26:649–652.

Allard C, Goulet C. 1968. Serum lipids: an epidemiological study of an active Montreal population. Can Med Assoc J 98:627–637.

Babb TG, Korzick D, Meador M, Hodgson JL, Buskirk ER. 1991. Ventilatory response of moderately obese women to submaximal exercise. Int J Obes 15:59–65.

Boileau RA, Lohman TG. 1977. The measurement of human physique and its effect on physical performance. Orthop Clin North Am 8:33:563–581.

Bolonchuk WW, Hall CB, Lukaski HC, Siders WA. 1989. Relationship between body composition and the components of somatotype. Am J Hum Biol 1:239–248.

Bolonchuk WW, Lukaski HC, Siders WA, Hall CB. 1990. The body composition of dominant and modified somatotypes. In: Dotson CO, Humphrey JH, editors. Exercise physiology: current selected research. New York: AMS Press. p 145–157.

Brozek J, Grande F, Anderson JT, Keys A. 1963. A densitometric analysis of body composition: revision of some quantitative assumptions. Ann NY Acad Sci 110:113–140.

Bulbulian R. 1984. The influence of somatotype on anthropometric prediction of body composition in young women. Med Sci Sport Exerc 16:389–397.

Carter JEL. 1970. The somatotype of athletes — a review. Hum Biol 42:535–569.

Carter JEL. 1975. The Heath-Carter somatotype method. San Diego: San Diego State University Press.

Carter JEL. 1984. Physical structure of Olympic athletes. II. Kinanthropometry of Olympic athletes. Med Sci 18, Basel: Karger.

Carter JEL, Heath IH. 1990. Somatotyping: development and applications. New York: Cambridge University Press.

Cozens FW. 1930. A study of stature in relation to physical performance. Res Q 1:38–45.

Cureton TK. 1941. Body build as a framework of reference for interpreting physical fitness and athletic performance. Res Q Suppl 12:302–330.

Darling C, Conrand H, Richards DW. 1940. Studies on the intrapulmonary mixture of gasses. III. An open circuit method for measuring residual air. J Clin Invest 19:609–618.

de Garay AL, Levine L, Carter JEL. 1974. Genetic and anthropological studies of Olympic athletes. New York: Academic Press.

Dupertius CW, Pitts GC, Osserman EF, Welham WC, Behnke AR. 1951. Relation of specific gravity to body build in a group of healthy men. J Appl Physiol 3:676–680.

Ellis KJ, Shukla KK, Cohn SH, Pierson RN Jr. 1974. A predictor for total body potassium in man based on height, weight, sex and age: applications in metabolic disorders. J Lab Clin Med 83:716–727.

Fernandez FJ, Kahn HC. 1971. Clinical methods for atomic absorption spectroscopy. Clin Chem Newsl 3: 24.

Friedwald WT, Leny RI, Fredrickson DS. 1972. Estimation of the concentration of low-density lipoprotein cholesterol in plasma without use of the preparative ultracentrifuge. Clin Chem 18:499–502.

Gordon E, Tobias PV, Mendelsohn D, Seftel H, Howson A. 1987. The relationship between somatotype and serum lipids in male and female young adults. Hum Biol 59:459–465.

Heath BH, Carter JEL. 1967. A modified somatotype method. Am J Phys Anthropol 27:57–74.

Henry J. 1964. Determination of lactic acid. Clin Chem Prin Tech, New York: Harper and Row. p 715–719.

Kleinbaum DG, Kupper LL. 1978. Applied regression analysis and other multivariable methods. North Scituate, MA: Duxbury Press.

Lukaski HC, Bolonchuk WW, Klevay LM, Mahalko JR, Milne DB, Sandstead HH. 1984. Influence of type and amount of dietary lipid on plasma lipid concentrations in endurance athletes. Am J Clin Nutr 39:35–44.

Lukaski HC, Hoverson BS, Gallagher SK, Bolonchuk WW. 1990. Physical training and copper, iron, and zinc status of swimmers. Am J Clin Nutr 51:1093–1099.

Lukaski HC, Siders WA, Hoverson BS, Gallagher SK. 1996. Iron, copper, magnesium and zinc status as predictors of swimming performance. Int J Sports Med 17:535–540.

Lykken GI, Jacob RA, Munoz JM, Sandstead HH. 1980. A mathematical model of creatine metabolism in normal males — comparison between theory and experiment. Am J Clin Nutr 33:2674–2685.

Malina RM, Katzmarzyk PT, Song TMK, Theriault G, Bouchard C. 1997. Somatotype and cardiovascular risk factors in healthy adults. Am J Hum Biol 9:11–19.

Mendez J, Lukaski HC. 1981. Variability of body density in ambulatory subjects measured at different days. Am J Clin Nutr 34:78–81.

Milne DB. 1998. Copper intake and assessment of copper status. Am J Clin Nutr 67:1041S–1045S.

Moore FD, Olesen KH, McMurrey JD, Parker HV, Ball R, Boyden CM. 1963. The body cell mass and its supporting environment: body composition in health and disease. Philadelphia: Saunders.

Parnell RW. 1958. Behavior and physique. London: Edward Arnold.

NRC (National Research Council) Committee on Dietary Allowances, Food and Nutrition Board. 1989.

Recommended dietary allowances, 9th ed. Washington, DC: National Academy Press.
SAS. 1997. SAS/STAT software: changes and enhancements through release 6.12, version 6.12. Cary, NC: SAS Institute.
Schreiber ML. 1973. Anaerobic capacity as a function of somatotype and participation in varsity athletics. Res Q 44:197–205.
Sheldon WH, Stevens SS, Tucker WB. 1940. The varieties of human physique. New York: Harper Bros.
Sills FD. 1950. A factor analysis of somatotypes and their relationship to achievement in motor skills. Res Q 21:424–427.
Sills FD, Michem J. 1957. Prediction of performance on physical fitness tests by means of somatotype ratings. Res Q 28:64–71.
Slaughter MH, Christ CB. 1995. The role of body physique assessment in sports science. In: Davies PSW, Cole TJ, editors. Body composition techniques in health and disease. Cambridge: Cambridge University Press. p 166–194.
Slaughter MH, Lohman TG. 1976. Relationship of body composition to somatotype. Am J Phys Anthropol 44: 237–244.
Slaughter MH, Lohman TG. 1980. An objective method for measurement of musculo-skeletal size to characterize body physique with application to athletic population. Med Sci Sports Exerc 12:170–174.
Slaughter MH, Lohman TG, Christ CB, Boileau RA. 1987. An objective method for the measurement of musculo-skeletal size in children and youth. J Sports Med Phys Fit 27:461–472.
Sunderman FW, Nomoto S. 1970. Measurement of human serum ceruloplasmin by its p-phenylenediamine oxidase activity. Clin Chem 16:903–910.
Tanner JM. 1964. The physique of the Olympic athlete. London: George Allen and Unwin.
Tanner JM, Israelson WJ, Whitehouse RH. 1960. Physique and body composition as factors affecting success in different athletic events. J Sports Med Phys Fit 14:397–411.
Van Itallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. 1990. Height normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. Am J Clin Nutr 52: 953–959.
Wilmore JH. 1970. Validation of the first and second components of the Heath-Carter modified somatotype method. Am J Phys Anthropol 32:369–372.
Wilmore JW, Davis JA, Morton AC. 1976. An automated system for assessing metabolic and respiratory function during exercise. J Appl Physiol 40:619–624.
Winterbourn CC, Hawkins RE, Brain M, Carrell RW. 1975. The estimation of red cell superoxide dismutase activity. J Lab Clin Med 85:337–341.