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Effect of body build on weight-training-induced adaptations in body composition and muscular strength

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ABSTRACT

VAN ETTEN, L. M. L. A., F. T. J. VERSTAPPEN, and K. R. WESTERTERP. Effect of body build on weight-training-induced adaptations in body composition and muscular strength. *Med. Sci. Sports Exerc.* Vol. 26, No. 4, pp. 515–521, 1994. The aim of the present study was to investigate whether weight-training-induced adaptations in body composition and isokinetic strength differ as a function of body build. Body build of a subject was characterized as the extent to which a person's fat-free mass index (FFMI = fat-free mass·height^{-2}; kg·m^{-2}) differs from the regression of FFMI over fat mass index (FMI = fat mass·height^{-2}; kg·m^{-2}) as derived from a sedentary male population (N = 77). From this population two groups with either a slender (N = 10) or a solid (N = 11) body build were selected. For 12 wk the subjects performed a weight-training program twice a week. Training induced a significant ($P < 0.05$) increase in fat-free mass (FFM) in the solid group (1.6 kg, 2.3%) in contrast with the slender group, which showed no significant change in FFM. Both groups showed comparable decreases in fat mass (FM; slender: −1.7 kg, −10.8% versus solid: −2.4 kg, −11.3%) and increases in strength (on average 13.8%). In conclusion, the increase in FFM due to a weight-training program is modified by body build. This modification, however, is restricted to a larger increase in the solidly built group.

BODY COMPOSITION, FAT-FREE MASS INDEX, FAT MASS INDEX, ISOKINETIC STRENGTH

Muscle, fat, and bone are the three major structural components that model the human body build. Visual differences in body dimensions among individuals are readily apparent, including differences in height, weight, and regional fat distribution (e.g., waist/hip ratio). Body composition differences, namely differences in fat-free mass (FFM) and fat mass (FM), may be less apparent. The actual body build of a subject is determined, in part, by genotype and physical activity. Leading a more active lifestyle, including both occupational and leisure time activities, positively increases the FFM/FM ratio (22,23,26). Furthermore, specific types of physical training lead to specific changes in body composition. Weight training mainly increases FFM whereas endurance-type activities mainly decrease FM (11). The relative contribution of genetics and the environment to body build are not well studied or quantified. In healthy individuals, the size of the skeleton and therefore height, can presumed to be mainly genetically determined.

Like body build, the ability to achieve a high level of sports performances is determined, in part, by genetic factors and physical training. Despite quality training, wide variability still exists in physical performance among elite athletes. Thus, coaches and sports medicine scientists are interested in the connection between body build and physical performance. Previous research (10) has reported the biometrical benefits of height, muscle mass (absolute quantity), and proportional body dimensions for a variety of sports. The benefit of using proportional dimensions is the possibility to compare individuals or groups irrespective of differences in height. Proportional dimensions mostly express the size of body parts relative to other bodily dimensions within a person, e.g., body mass index (BMI), which expresses weight relative to height (kg·m^{-2}). Sometimes bodily dimensions are also compared with reference values based on a large number of subjects. The somatogram introduced by Behnke and Wilmore (1) and the somatotype originated by Sheldon and modified by Heath and Carter (8) are examples of methods to describe body build by using proportional bodily dimensions relative to other dimensions as well as reference values.

The influence of body build is relevant to consider when the effect of different training programs, training methods, or equipment are compared. The response to the intervention may be biased by differences in initial body build of the experimental population. This can lead

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TABLE 1. Initial anthropometric characteristics of the different subject categories (recruited population, slender-group, solid-group) and the absolute differences between the slender- and solid-group (| dif Sl – So |)

Variables	Recruited ($N = 77$)	Slender ($N = 10$)	Solid ($N = 11$)	| dif Sl – So |
Age (yr)	34 ± 4.8	38 ± 3.4	34 ± 4.7	4.0*
Weight (kg)	83.9 ± 11.5	74.1 ± 7.9	90.2 ± 9.7	16.1**
Height (m)	1.79 ± 0.07	1.80 ± 0.04	1.77 ± 0.06	0.03
BMI ($kg \cdot m^{-2}$)	26.1 ± 3.2	22.6 ± 3.7	28.8 ± 2.1	6.2**
Fat (%)	24.0 ± 5.6[a,b]	24.2 ± 4.8[b]	23.0 ± 4.2[b]	1.2
FFM (kg)	63.4 ± 7.0	55.9 ± 4.1	69.2 ± 5.7	13.3**
FM (kg)	20.5 ± 6.5	18.2 ± 5.1	21.0 ± 5.5	2.8
FFMI ($kg\ FFM \cdot m^{-2}$)	19.7 ± 1.7	17.1 ± 1.2	22.1 ± 1.0	5.0**
FMI ($kg\ FM \cdot m^{-2}$)	6.4 ± 2.1	5.5 ± 1.4	6.7 ± 1.6	1.2
$FFMI\text{-}FFMI_{predicted}$ ($kg\ FFM \cdot m^{-2}$)	0 ± 1.5	-2.3 ± 1.2	2.3 ± 1.0	4.6**

Values are means ± SD (level of significance: * $P < 0.05$, ** $P < 0.01$).
Body composition was measured using skinfold thickness ([a]) or hydrostatic weighing ([b]).

to an over- or underestimation of the studied independent variables and thus to false conclusions.

The aim of the present study was to investigate whether weight-training-induced changes in body composition and strength are a function of initial body build. Additionally, attention is paid to a possible relation between changes in bodily dimensions and physical performance. For this study two groups of healthy untrained sedentary males were selected with a contrasting body build described as the height-normalized quantity of FFM corrected for FM. Subsequently subjects trained two times a week for 12 wk. The response was measured by comparing body composition and strength before and after the intervention.

METHODS

Subjects. Subjects were healthy clerks recruited from various offices. The recruitment criteria were male sex, age between 25 and 45 yr, a sedentary lifestyle and not participating in a regular training program for at least 2 yr prior to the study. Seventy-seven subjects met these criteria and gave their written informed consent. Body composition, FFM and FM, were calculated from skinfold thickness (3) and body mass (Table 1). From this recruited group two experimental groups (slender and solid group) were selected with contrasting body build.

Body build. The description of body build was based on a two-compartment model of body composition in which body weight is divided into FFM and FM. The active component FFM was used to describe body build. To allow comparisons between individuals, FFM was corrected for height and FM. FFM and FM relative to height were in analogy with the body mass index (BMI) expressed as fat-free mass index ($FFMI = FFM \cdot height^{-2}$; $kg\ FFM \cdot m^{-2}$) and fat mass index ($FMI = FM \cdot height^{-2}$; $kg\ FM \cdot m^{-2}$) (24,26). In addition, BMI is equal to the sum of FFMI and FMI. To quantify the relationship between FFMI and FMI (6), FFMI was plotted as a function of FMI (Fig. 1). The regression equation expresses the quantitative relationship between FFMI and FMI ($FFMI_{predicted} = 17.566 + 0.335(FMI)$; $r = 0.409$; $P < 0.001$). Individual body build was characterized on an interval scale by subtracting $FFMI_{predicted}$ from the actual FFMI. The 60% prediction interval of FFMI given FMI (Fig. 1) was used to ensure a clear contrast in body build. After verifying body composition with the hydrostatic weighing technique, subjects beyond this prediction interval were assigned to either the slender group ($N = 10$; actual $FFMI < FFMI_{predicted}$) or solid group ($N = 11$; actual $FFMI > FFMI_{predicted}$). Three subjects were excluded because of a FMI not within two standard deviations of the mean. For interpretation of the applied concept, examples of body build are given in Figure 2.

Body composition. After the selection procedure all measurements concerning body composition were taken the morning after a controlled overnight stay at the laboratory where the subjects abstained from eating and drinking for 14 h.

Body mass was measured after emptying the bladder to an accuracy of ±5 g on an electronic scale (Mettler, E1200). Body density was measured using the hydrostatic weighing technique with simultaneous measure-

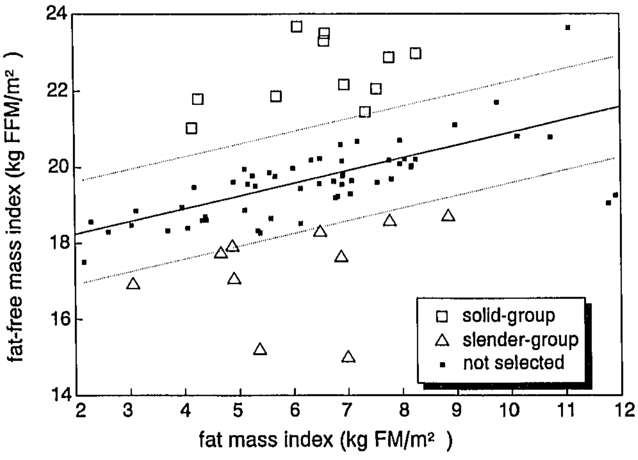
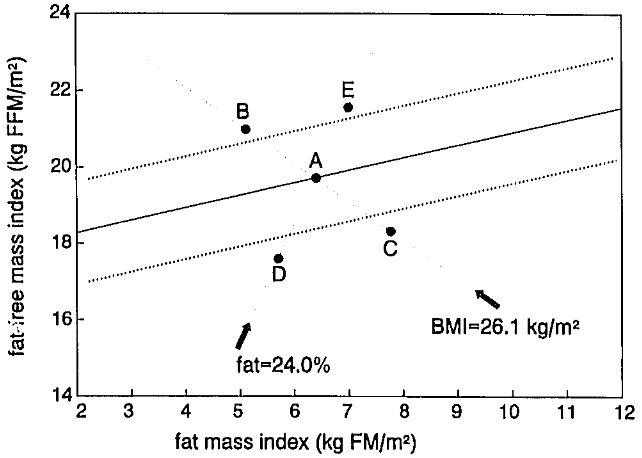


Figure 1—Fat-free mass index plotted as a function of fat mass index of the recruited population ($N = 77$; $FFMI_{predicted} = 17.566 + 0.335 * FMI$; $r = 0.409$; $P < 0.001$). The dotted lines are the borderlines of the 60% prediction interval of FFMI given FMI. Subjects beyond this interval were assigned to either the slender group ($N = 10$) or solid group ($N = 11$).



Subject	Weight	Height (BMI)	%Fat
A	83.8	1.793 (26.1)	24.0
B	83.8	1.793 (26.1)	*19.5*
C	83.8	1.793 (26.1)	*29.8*
D	*74.9*	1.793 (23.3)	24.0
E	*91.6*	1.793 (28.5)	24.0
D	83.8	*1.896* (23.3)	24.0
E	83.8	*1.714* (28.5)	24.0

Figure 2—The effect of changes in weight, height, or %fat on the body build of subject A representing the mean anthropometric characteristics of the recruited group. Changes are printed in italics.

ment of residual lung volume with the helium dilution technique (Volugraph 200, Mijnhardt). Water density was corrected for temperature. Percent fat was calculated from body density assuming a FFM and FM density of 1.097 and 0.901 kg·l^{-1}, respectively. This resulted in the following equation for percentage of fat:

$$FAT(\%) = \left(\frac{504.28}{body\ density} - 459.69\right).$$

Muscular strength. Muscular strength in the upper thigh and shoulder/arm was measured using an isokinetic dynamometer (Cybex II) at several angular velocities: knee flexion and extension at 1.047, 3.142, and 4.189 rad·s^{-1} (60, 180, and 240°·s^{-1}, respectively); shoulder/arm during a bench press movement at 1.047 and 2.094 rad·s^{-1} (60 and 120°·s^{-1}, respectively). Subjects performed one set of five repetitions at each velocity from which the peak torque was noted as parameter for maximal strength.

Training program. The subjects trained independently, twice a week, on nonconsecutive days for 12 wk, using an individually prescribed training program based on the subject's weight and baseline performance at the respective exercises. The program consisted of 10 min warming up (cycling), 14 strength exercises using free weights and machine gym equipment (Table 2) and 5 min of cooling down (cycling) completed with stretching exercises. In weeks 2 and 3 the initial single set of 15 repetitions (reps) per exercise was doubled and tripled, respectively, without changing the training weight. Throughout weeks 4, 5, and 6, training weight was adjusted as strength levels increased provided that the subjects were able to perform three sets of 15 reps. Thus, during the first 6 wk the nature of the training program changed from familiarizing and skill development to more serious resistance training. From week 7 the design of the training program was furthermore adjusted for seven exercises (marked with a diamond (♦) in Table 2). The one repetition maximum (1RM) of the exercise was measured to adjust the training weights to 65–70% of 1RM (14). The number of repetitions per set was changed from 15 to 10 repetitions in the first two sets and an all-out effort in the third set (18). This all out effort was used as criterion to further adjustment of the training weight: less than seven reps the training weight was lowered and more than 13 reps the training weight was increased with one unit of weight (2.5, 5 or 10 kg, depending on the apparatus and muscle group used). In case of the unmarked exercises (Table 2), the adjustment procedure of the first 6 wk was continued. The training program was regularly supervised by a fitness instructor to guide and encourage the subjects and to control the use of correct techniques. Maximal aerobic power was meas-

TABLE 2. Training protocol from weeks 1–12. Subjects trained independently, two times a week on nonconsecutive days

Exercise	Week 1	Week 2	Week 3	Week 4–6	Week 7–12
Flys	1 set of 15 reps	2 sets of 15 reps	3 sets of 15 reps	3 sets of 15 reps + load increment if possible	3 sets of 15 reps + load increment if possible
Seated lats pulley					
♦ Leg press					2 sets of 10 reps + third set maximal reps if reps >13 then load increment
♦ Butterfly					
♦ Triceps pushdown					
Sit ups					3 sets of max reps
Calf raises					3 sets of 15 reps + load increment if possible
Leg curl					
♦ Chest press					2 sets of 10 reps + third set maximal reps if reps >13 then load increment
♦ Leg extension					
♦ Over head lats pulley					
♦ Shoulder raises					
Preacher bench curl					3 sets of 15 reps + load increment if possible
Leg raises					

reps = repetitions.

ured before and after the training period with a progressive cycling test to consider the specificity of the training.

Statistical analysis. Unpaired and paired *t*-tests were used to analyze the differences between the groups and changes within a group, respectively. When comparing more than two population means, analysis of variance and the Student-Neuman-Keuls *post-hoc* test was used. A probability value of $P < 0.05$ was considered significant.

RESULTS

In Table 3 the mean changes (Δ) on body composition are presented for: all subjects ($N = 21$), the slender group (Sl; $N = 10$), the solid group (So; $N = 11$), and the absolute differences between the slender and solid group (dif | Sl – So |). Changes (%) relative to initial values are also presented because of initial differences in body composition and physical performance between the groups.

The entire group showed a significant change in body weight (−1.1 ± 2.1 kg, −1.3 ± 2.5%), FFM (0.9 ± 1.3 kg, 1.5 ± 2.0%) and FM (−2.1 ± 1.7 kg, −10.9 ± 8.4%). An additional way to compare the changes in body composition is a comparison of the changes in body build. This method combines changes in FMI and FFMI and hence changes in FM and FFM since height remains the same. The entire group became a more solid body build after 12 wk of weight training. Regarding the subgroups, most of the within group changes were also significant except the changes in weight within the solid group and the changes in FFM within the slender group. Comparing the size of the changes between both subgroups, there is a significantly larger increase in FFM for the solid group (1.6 ± 1.4 kg vs 0.3 ± 0.9 kg and 2.3 ± 2.0% vs 0.5 ± 1.7%; $P < 0.05$). The solid group also showed a significantly larger change in body build (0.75 ± 0.45 $\text{kg}\cdot\text{m}^{-2}$ vs 0.26 ± 0.30 $\text{kg}\cdot\text{m}^{-2}$; $P < 0.05$).

Before the training period, strength (maximal torque) differed significantly between the groups (Fig. 3), whereas strength relative to FFM ($\text{Nm}\cdot\text{kg}^{-1}$ FFM) was similar at all movements tested. Strength, absolute as well as relative to FFM, significantly increased in both subgroups at all angular velocities and movements tested (Fig. 3). No significant difference in Δstrength between both subgroups has been found. The relative (%) increase in strength in the knee extensor is significantly lower than the increase in the knee flexor and shoulder/arm muscles (8.8 ± 7.0% vs 15.3 ± 11.2% and 17.1 ± 9.9%). There was no significant correlation between initial strength and absolute Δstrength. Despite a highly significant correlation between initial FFM and the parameters of strength (r = 0.73, 0.59, and 0.85 for knee extension, knee flexion and shoulder/arm muscles, respectively: $P <$

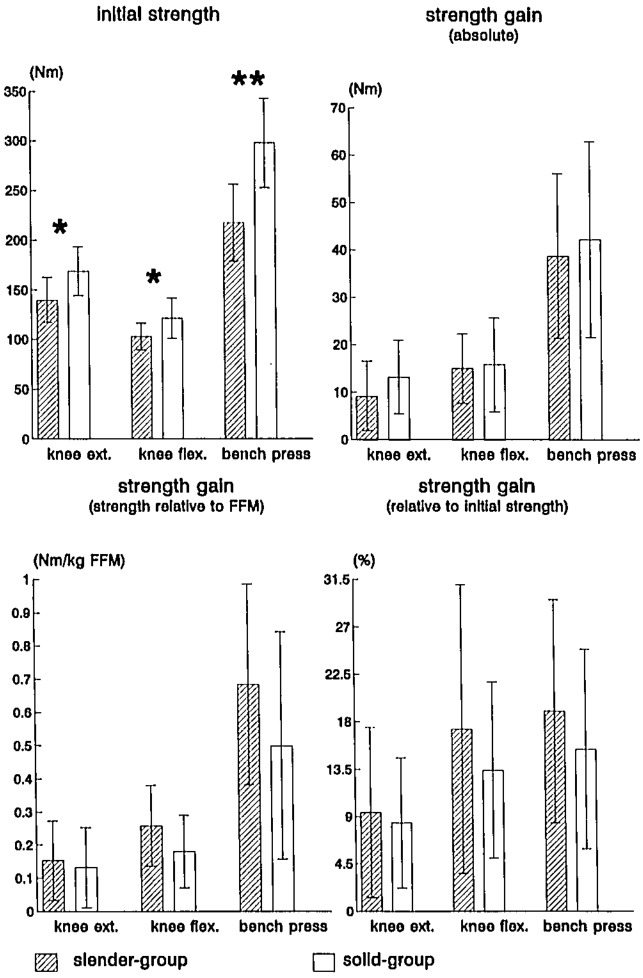


Figure 3—Initial data and changes (mean ± SD) in strength at the three movements tested. The initial data differed between both group (*$P < 0.05$, **$P < 0.01$). Strength was significantly increased ($P < 0.001$) in both subgroups but did not significantly differ between the slender and solid group. The knee extensor muscles showed a smaller strength gain than the knee flexor and arm/shoulder muscles ($P < 0.01$).

TABLE 3. Changes in weight, fat-free mass (FFM), fat mass (FM), and body build after 12 wk of weight training

	All Subjects ($N = 21$)	Slender ($N = 10$)	Solid ($N = 11$)	| dir Sl – So |
Absolute changes				
Δ weight (kg)	−1.1* ± 2.1	−1.5* ± 1.7	−0.8 ± 2.5	0.7
Δ FFM (kg)	0.9** ± 1.3	0.3 ± 0.9	1.6** ± 1.4	1.3*
Δ FM (kg)	−2.1** ± 1.7	−1.7** ± 1.4	−2.4** ± 1.9	0.7
Changes relative to pretraining values				
Δ weight (%)	−1.3* ± 2.5	−1.9* ± 2.3	−0.9 ± 2.6	1.0
Δ FFM (%)	1.5** ± 2.0	0.5 ± 1.7	2.3** ± 2.0	1.8*
Δ FM (%)	−10.9** ± 8.4	−10.5** ± 8.4	−11.3** ± 8.8	0.8
Δ body-build (kg FFM/m^2)	0.52** ± 0.5	0.26* ± 0.3	0.75** ± 0.5	0.49**

Values are means ± SD (level of significance: * $P < 0.05$, ** $P < 0.01$).

0.001), there was no significant correlation between ΔFFM and Δstrength. Maximal aerobic power was not influenced by weight training.

Training compliance was similar in the slender and the solid group (97.1 ± 4.4% and 92.4 ± 7.4%, respectively). The mean absolute training load during the last 6 wk of the training program differed significantly between the slender and solid group (43.0 ± 7.4 kg vs 51.3 ± 9.5 kg; $P < 0.05$, respectively). However, training load relative to FFM was comparable (0.76 ± 0.1 $\text{kg}\cdot\text{kg}^{-1}$ FFM vs 0.73 ± 0.1 $\text{kg}\cdot\text{kg}^{-1}$ FFM). There was no significant correlation between mean absolute training load and ΔFFM or Δstrength (absolute and relative to pretraining values).

DISCUSSION

The aim of the present study was to investigate the effect of body build on weight-training-induced adaptations in body composition and strength. The physical adaptation in two groups with different body build were compared. The solid group showed a significant absolute and relative increase in FFM ($P < 0.05$). The slender group showed no significant change in FFM. Both groups showed comparable decreases in FM and increases in strength and no change in maximal aerobic power.

The mean increase in FFM for the entire group (+0.9 kg) is in agreement with findings of other weight-training studies. A review of the literature did not provide any information on the effect of initial differences in FFM on the training response. The few studies that did include initial differences in FFM in their experimental design were primarily focused on differences between sexes. These studies revealed no influence of the initial amount of FFM. In general, men had a larger absolute increase in FFM and strength but percentage increases were similar in both sexes (2,9). The use of different sexes, however, makes these studies less appropriate as data for comparison.

The mean decrease in FM for the entire group (−2.1 kg) was somewhat larger then usually found in comparable weight-training studies (on average 1 kg). It cannot be excluded that the training-induced changes in FM and/or FFM were partly be due to changes of energy intake (5,15). However, the poor reliability of methods to measure dietary intake accurately (27) made it little meaningful to record eventual changes in energy intake in the present study. The similar ΔFM in both groups suggests that an eventual change in dietary intake could only have had a minor contribution to the measured difference in ΔFFM between the groups. Furthermore, it is not likely that a change of eating habits would only occur in one of the groups.

Body weight decreased significantly in the slender group as a consequence of a larger discrepancy between the increase in FFM and a decrease in FM (−1.5 ± 1.7 kg) compared with the solid group (−0.8 ± 2.5 kg). The large standard deviation indicates the interindividual variation in Δweight. These data demonstrate the limited validity of Δweight as a parameter to evaluate dietary or training interventions since it masks adaptation in FFM and FM.

At the beginning of the program the solid group was stronger than the slender group. The initial amount of FFM correlated significantly with strength ($P = 0.001$). This is in agreement with other studies showing that strength is primarily determined by the quantity of FFM and the physiological cross-section of the muscle (13,19,28). In spite of this relationship, no significant correlation was found between the increase in FFM and the increase in strength. Surprisingly, the slender group had a comparable increase in strength without a change in FFM. This discrepancy between Δstrength and ΔFFM may partly be attributed to the process of neural adaptation to training (20). In the beginning of a training program neural adaptation, if compared with muscular adaptation (hypertrophy), accounts for the larger proportion of the strength increment (14,16). The contribution of muscle hypertrophy increases slowly during the training period and after 3–6 wk becomes the dominant factor. The magnitude of the contribution of neural factors depends on the familiarity with the performed movement or test protocol. The difference in strength gain between the everyday knee extension movement (8.8 ± 7.0%) and the atypical knee flexion (15.3 ± 11.2%) and bench press (17.1 ± 9.9%) movement is in concordance with this latter finding. Another factor that might partly explain the discrepancy found between ΔFFM and Δstrength is the specificity of the strength tests. Each test measures Δstrength in the muscle groups involved in contrast with the increase in FFM which was presumably distributed all over the body. The interindividual variation in the contribution of neural adaptation and ΔFFM to the increase in strength might explain the lack of a significant correlation between ΔFFM and Δstrength.

This study applied a nearly unknown method to describe body build. The reason for not using a more commonly used method to classify humans by their physical shape lies in the fact that these methods use skinfolds and girths (1,8). These descriptions mostly fit the visual perception but do not make a clear distinction between FFM and FM. Furthermore, studies revealed the limited accuracy of girths to estimate the total amount of or changes in FFM (28). The reliability of the present method to describe body build is restricted to the precision in the determination of body composition and the measurement of height. The application of the height-normalized index FFMI appeared to be an appropriate method to eliminate differences in height (correlation FFM and height: $r = 0.65$, $P < 0.001$; correlation FFMI and height: $r = -0.1$, $P = 0.19$; $N = 77$). Further, the quantitative relationship in this study between FFM and FM was in agreement with findings of other studies. Dietary intervention studies revealed that FFM contributes for a quarter to a third to changes in body weight (7). The classification of body build by the extent to which a person's FFMI differs from the regression of FFMI over FMI seems a workable method to distinguish between individuals with different height-normalized quantities of FFM and FM. The difference in FFM between the slender and solid group was 13.3 kg FFM. However, this method is only usable if a valid reference regression equation of FFMI over FMI is available.

This study used several exclusion criteria in combination with a specific definition of body build to eliminate well-known determinants of a training response like age (12,17,21), sex (25), absolute quantity of fat mass (6), and the initial level of training (21). The training stimulus as determinant differed, with respect to the mean training load, between the groups. This was mainly the consequence of the intergroup difference in FFM. The mean absolute training load, however, was not significantly correlated with ΔFFM. Therefore, it seems plausible that the difference in ΔFFM between both groups is due to the initial difference in body build. The data of the present study, however, do not explain the underlying mechanism responsible for this difference in ΔFFM. A genetic determined potential to increase FFM seems a possible explanation which also could explain the initial differences in body build. Some investigators reported a preferential hypertrophy of type II fibers (4) in weight-trained subjects, suggesting a fiber-type composition modified adaptation to weight training. Another possible explanation lies not so much in the capacity to produce FFM, which refers to the final amount of FFM, but in a difference in adaptation speeds. This hypothesis can be tested by prolonged weight-training studies with several intermediate measurements.

In conclusion, the data of the present study indicate that body build, defined as the initial quantity of fat-free mass corrected for fat mass and height, modifies the weight-training-induced changes in FFM. After 12 wk of weight training, individuals with a solid body build increased their FFM whereas slenderly built individuals did not show a significant change in FFM. The data confirm earlier studies that weight training is an appropriate method to increase muscular strength and to decrease FM. Additional research over a longer period is needed to confirm and extend these findings and to study the mechanism responsible for differences in weight-training-induced changes in FFM. Reference values for various populations (e.g., males/females, trained/sedentary or age groups) based on large numbers of subjects should be determined to enable other investigator to utilize and implement FFMI and FMI in describing their study subjects.

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CORRIGENDUM

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