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# PHYSICAL ACTIVITY AND BODY COMPOSITION*

The purpose of the present study was to examine the differences in body composition of two groups of middle-aged men who exhibited long-standing differences in the amount of habitual physical exercise. The subjects were drawn from a larger sample of business and professional men living in a metropolitan Midwestern community.

## INTRODUCTION

Data on the composition of the living, human body are of fundamental importance for characterization of individuals – an important task for the Sciences of Man. Body composition is one of the focal points of human biology. Methodologically, it represents crossroads of anatomy, physical anthropology, biophysics (including radiology), and biochemistry. The data, in turn, are of importance in several contexts, theoretical and applied.

In the Laboratory of Physiological Hygiene, University of Minnesota, we became interested in the methods for the description of body composition as an approach to a quantitative evaluation of nutritional status (nutriture, BROŽEK, 1). In the 1944–1946 study of the effects of prolonged caloric deficiency and subsequent nutritional rehabilitation (KEYS et al., 2), the gross body weight was separated into the fat and fat–free (»lean«) fraction, following the methods developed by Behnke and his collaborators and based on the determination of specific gravity of the whole body. The body volume was obtained by weighing the subjects in air and under water, applying a correction for residual air. The fat–free body weight was broken down into bone mineral (estimated as a fraction of the standard weight for given height), extracellular fluid (measured by the thiocyanate dilution method) and the remaining »active« tissue mass.

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The mineralization of bones – which, surprisingly enough, showed no changes during semistarvation – was evaluated radiologically (MACK, TRAPP and BROWN, 3).

In a reversal of the starvation experiment, involving a prolonged excess intake of calories, the classical anthropometric measurements of lengths, diameters, and circumferences were supplemented by the evaluation of subcutaneous fat (measurements of skinfold thickness). In the biochemical sector, determination of the total body water by the antipyrine dilution method was added to the measurement of plasma volume and of extracellular fluid. The study yielded badly needed information on changes in body composition resulting from overeating. The methodological implications of these data have been taken into consideration in the present study.

In a long–term study in aging carried on in the Laboratory of Physiological Hygiene since 1948, the data on body composition are on interest for their own sake, as new gerontological facts, as well as a reference point for metabolic processes and physiological functions. In a special study on cardiac function and body composition (TAYLOR et al., 4), it was shown that the basal cardiac output was related more closely to »lean body mass« (r = 0.75) than to the surface area (r = 0.60) or gross body weight (r = 0.52). The arteriovenous oxygen difference showed a low but statistically significant correlation with the estimated percentage of fat in the body (r = 0.35). This may represent a protective mechanism in obesity, contributing to a reduction of cardiac work load.

Changes in body composition were examined in the course of a study on the effects of the rice–fruit diet in male patients with well–established, moderately severe hypertension (CHAPMAN et al., 5). The average loss of weight (– 8.6 kg) in these experiments, carried on for 23 to 46 days, could be accounted for largely on the basis of the loss of fat (– 4.6 kg) and extracellular fluid (– 1.9, calculated as 0.7 of the thiocyanate space times the density of 1.002). The balance of the weight loss was probably due to body protein, insofar as such precise calculations are at all permissible with the given methods. Any significant amount of demineralization is unlikely to have taken place.

Behnke's initial concern (6) with methods promising a useful description of body build was related to his studies of man's adaptation to varied atmospheric pressures, whether these were the high pressures impinging on the deep–sea diver and caisson worker or the low pressures to which the aviator is exposed at high altitudes. Gaseous nitrogen is considerably more soluble in fat than in the body fluids, with nitrogen solubility coefficients of 52 cc/kg and 9 cc/kg, respectively. On reducing drastically the atmospheric pressure, the nitrogen dissolved in the tissues becomes available for the formation bubbles of nitrogen, resulting in the »decompression sickness«. Behnke has shown that the determination of gaseous nitrogen, eliminated from the body tissues by prolonged breathing of pure oxygen and partitioned according to its solubility in body fat and body fluids, can be used for the estimation of the fat content of the living human organism (cf. BEHNKE, 7).

Historically, Kohlrausch (8,9) became interested in indirect methods for the study of body composition, including body density, as means for the analysis of the effects of exercise. While Kohlrausch worked with dogs, one of Behnke's early studies was concerned with professional football players (WELHAM and BEHNKE, 10). Strangely enough, the inviting and broad field of research on physical activity and the composition of the body remained largely unexplored by the new methods. It has been recognized that specific sports are associated with recognizable patterns of body build and anthropometric investigations of groups of athletes have not been lacking (cf. ŠKERLJ, 11). However, longitudinal investigations which alone can provide clearcut answers, not complicated by the problem of selection, haven been rare (TANNER, 12).

The present study is concerned with differences in body composition of middle-aged individuals differing in the habitual amount of physical exercise. While the differences in the mode of life in the two groups, labelled as physically »active« and »inactive«, are not dramatic – we do not deal with professional athletes versus bad–bound patients – they were present over a period of several decades. Personally, all of the individuals involved in the study would resent being called »inactive« and in a questionnaire their answers to the dichotomy active-inactive would be totally misleading, even if the emphasis were placed clearly on physical activity. All of the subjects were employed and a good number of them occupied responsible positions in a Mid–western metropolitan community of the U. S. A.

## *Subjects*

The subjects were drawn from a larger group (N about 300) of business and professional men, enrolled in a long–term study of the aging process, with emphasis on the cardiovascular system. Their habitual leve of physical activity was appraised by Dr. A. Henschel (cf. 13) on the basis of special activity questionnaires, interviews with the men and, in some instances, the information provided by physical–activites directors of local »athletic« clubs. While there were no professional athletes in the group, the men differed considerably in the amount of physical exercise. The men labelled as »physically active« had participated for years in recreational activities involving a fair amount of physical exertion and kept up the habit. By contrast, the »physically inactive« men had always maintained a rather sedentary mode of life.

Because of the marked changes in body composition during maturity (Brožek, 14), the groups were closely matched with reference to age; the match (see Table 1) is satisfactory both with reference to the means and to standard deviations. The second characteristic which was considered in the process of matching was the subjects' height, considered as an index of the bony structure. Here again the two groups were matched very closely.

Table 1

*General characteristics of the physically »active« and »inactive« men*

| Group | Active (N = 29) |  | Inactive (N = 27) |  |
|---|---|---|---|---|
|  | M | SD | M | SD |
| Age, years | 52,9 | 3,2 | 52,2 | 2,9 |
| Height, cm. | 176,1 | 6,3 | 176,2 | 5,0 |
| Gross body, wt., kg. | 81,5 | 9,2 | 78,3 | 12,3 |
| Relative body weight (actual as °/o of standard) | 106,2 | 11,9 | 102,2 | 13,6 |
| Residual air, liters | 1,972 | 0,461 | 2,073 | 0,557 |

## *Methods*

In the last decade a variety of methods for the study of body composition *in vivo* have been developed or improved and applied to man. The advances have come from radiological studies (analysis of tissue masses – Stuart et al., 15; Reynolds, 16; bone density – Mack et al., 17; Brown and Birtley, 18), evaluation of specific gravity (Behnke et al., 19; Rathbun and Pace, 20), and the measurement of the fluid compartments of the body (Pace and Rathbun, 21; Pace et al., 22; McCance and Widdowson, 23). For reviews of the methods cf. Brožek and Keys (24), McCance and Widdowson (25), Edelman et al. (26) and Behnke et al. (27). A comprehensive methodological analysis was undertaken by Keys and Brožek (28).

In the present study the principal tool was the determination of body volume by the technique of underwater weighing. The apparent weight of the body during submersion ($M'_W$) was corrected with reference to the volume of residual air ($V_R$), determined by the nitrogen-dilution method (cf. Brožek et al., 29) at the end of maximal exhalation. It was at this moment that the apparent underwater weight ($M'_W$) was read.

The ratio of body weight (in air, $M_A$) and of body volume ($V_B$) yields body density, $D_B$. The ratio of body density to the density of water ($D_W$), at a specified temperature, represents the specific gravity of the body. Obviously, body density is a simper concept. Historically, Behnke (6), Behnke et al. (19) and Welham and Behnke (10) introduced specific gravity as an »index of obesity« and the formula for estimating the fat content of the body, provided by Rathbun and Pace (20), is based on specific gravity:

$$\text{(1)} \qquad {}^0/_0 \text{ fat} = 100\left(\frac{5{,}548}{\text{sp. gr.}} - 5{,}044\right)$$

This formula was derived by separating the human body into a »fat-free« fraction of a relatively constant composition and the density of 1,10, and the variable amount of body fat, with an assumed density of 0,918 Having determined the mass and the density of the body ($D_B$) and knowing the densities of the 2 components ($F$, fat; $N$, non-fat), the proportional mass of $F$ can be calculated from equation (2); for the mathematics cf. Keys and Brožek (28):

$$\text{(2)} \qquad F = \frac{1}{D_B} \times \frac{D_N D_F}{(D_N - D_F)} - \frac{D_F}{(D_N - D_F)}$$

Using the values of $D_F = 0{,}918$ and $D_N = 1{,}10$, one arrives at the Rathbun-Pace formula. Obviously, the authors used 1 for the density of water, so that specific gravity ($= D_B / D_W$) was numerically equivalent to body density. This in an unacceptable simplification. In the range of temperatures suitable for underwater weighing the absolute density of water is significantly smaller than one (0,997 at 25° C, 0,994 at 35° to 36° C; it was at the latter water temperature that our measurements were made). At higher water temperatures the specific gravity of the human body, which retains its own temperature within narrow limits, rises as the result of a lowered density of the water in the tank. Thus a body density of 1,0653 gm/cc. corresponds to a specific gravity of 1,0686 at 25,6° C (78° F) and to 1,0719 at 35,5° C. Using these »specific granties« in the Rathbun-Pace equation one would arrive at the fat values of 16,4, 14,8, and 13,2 percent, respectively.

There are several other dificiencies in the system developed by Behnke and his collaborators, which become apparent on a more detailed consideration of the assumptions and the numerical constants. Thus the value for the density of body fat is definitely too high. The original determination (JAECKLE, 30) was made at 15° C whereas the average temperature of the fat in the human body is not far below 37° C. At this temperature the density of human fat (ether extract of subcutaneous and intra-abdominal adipose tissue) is 0,900 gm/cc. (FIDANZA et al., 31), with a mean density increment of 0,00074 gm/cc. for a decrement of 1° C in the temperature of the fat.

In Behnke's system the value of the density of the non-fat portion lacks empirical validation and the concept itself is fuzzy, sometimes including (»lean body mass«), at other times excluding the so-called essential lipids

(»fat-free body«). While animal studies suggest a relatively small interindividual variability in the composition (and, consequently, in the density) of the fat-free fraction of the body. We are aware of no data on the density of man's fat-free body. Investigations on adult man indicate that increases of weight – even without altering one's mode of life and the level of physical activity – do not represent a simple addition of »fat«, defined as ether extract. In 10 men, studied for six months at the Laboratory of Physiological Hygiene, the body weight rose on the average from 69.834 to 81.275 kg (Keys, et al., 32). The density of the gain was $D_G = 0{,}9478$ gm/cc. Of the 11.441 kg of the mass gained by the men, 1.601 kg was accounted for by the increment in the extracellular fluid, estimated from measurements of the thiocyanate space. The »dry« gain had an average mass of 9.840 kg and a volume of 10.473 liters, yielding a density of 0,9395 gm/cc.

Inserting the density values for fat (0,9007 at 36° C) and for »cells« (1,057) in equation (2), we determine that »fat« accounts for 72 per cent, »cells« for 28 per cent of the dry gain. In reference to the total weight gain, 14 per cent is accounted for by extracellular fluid, 62 by fat, and 24 by cells.

These data provide the basis for a new densitometric approach to the analysis of body composition, which has been elsewhere described in detail (Keys and Brožek, 28). In a brief summary, the body weight is divided into a »normal« fraction, of standard composition, and the »gain« (G) with a density of 0,9478. The density of a »standard« body, 1,0629 gm/cc., was obtained as the mean value for a group of 25 clinically normal men, with a mean age of 25 years (range 23 to 29) and body weight equal to standard weight for age and height (Association, 33); the data were reported by Brožek (14).

Following equation (3),

$$(3)\qquad G = \frac{1}{D_B}\,\frac{D_S\,D_G}{(D_S - D_G)} - \frac{D_G}{(D_S - D_G)}$$

the proportional mass of the excess (or deficit), $G$, superimposed on a tissue mass of standard (»normal«) density and composition, $S$, is obtained as

$$(4)\qquad G = \frac{8{,}753}{D_B} - 8{,}235$$

The formula for »excess fat« ($\Delta F$, where $\Delta F = 0{,}62\,G$) is

$$\Delta F = \frac{5{,}427}{D} - 5{,}106$$

On the basis of meager data in the literature on the fat content of the adult human body and, more importantly, by taking into account the values for other estimated or measured components of the body of normal young men, we have arrived at the approximate value of 14 per cent of fat in our »standard« body (KEYS and BROŽEK, 28). Considering the total body weight as equal to one ($M = 1$), the mass of the tissue of »standard« density is $S = 1 - G$, where $G$ refers to »gained« tissue. Thus total fat may be calculated from the equation

$$F = 0{,}14 + \Delta F \tag{5}$$

With $S = 1 - G$ and $\Delta F = 0{,}62\ G$,

$$F = 0{,}48\ G + 0{,}14 \tag{6}$$

Using equation (4), we obtain

$$F = \frac{4.201}{D_B} - 3{,}813 \tag{7}$$

The densitometric analysis was supplemented by anthropometric data. Here particularly relevant are the measurements of skinfold thickness. The caliper used in this study was activated by a coil spring exerting a pressure of about 5,7 gm/mm$^2$ at a 1 cm opening of the caliper jaws and of about 6,3 gm/mm$^2$ at a 3 cm opening*.

The skinfolds, varying in thickness principally on account of the width of the layer of subcutaneous fat, were measured at 7 sites:

(1) below the chin, (2) half–way up the upper arm, (3) on the chest, above the right nipple, (4) on the back, below the right scapula, (5) at the waist, in the midaxillary line, (6) on the abdomen, to the right of the navel, and (7) at the thigh, close to the patella.

Measurements of several external dimensions were taken using steel tape applied with a minimal pressure (for the circumferences), and spreading calipers (for the bony diameters). The circumference of the chest (level of the nipples) and the abdomen (level of the navel) were measured at the end of a normal expiration. The bi–cristal diameter, measured with a considerable pressure on the calipers, represents the most »pure« bony measure while the bideltoid diameter includes all 3 types of tissues (bone, muscle, and subcutaneous fat). The purpose of these measurements was the characterization of body form and, especially, of the size of the skeleton frame.

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* In the new model (KEYS, 34) the pressure is higher (10 gm/mm$^2$) and constant throughout the total range of measurements.

## RESULTS

As indicated in Table 1, the active men are heavier ($\Delta = 3,2$ kg) and would be characterized as somewhat overweight (6,2 per cent above the tabular age weight standard). Are they, then, relatively more »obese« than the inactive men? The densitometric as well as the anthropometric analyses indicates that just the opposite is true.

Table 2 shows that the specific gravity is higher in the active group. This is reflected in lower fat content of the body, as estimated by the Rathbun–Pace formula. The »fat–free« weight is *higher* ($\Delta = 4,8$ kg). Statistically, the difference between the mean value of specific gravity of the active and inactive men closely approaches the 5 per cent level of significance (with a value of the F–test equal to 3,9, as compared with $F\ 0{,}05 = 4{,}0$). The difference in the »fat–free« weight exceeds the 1 per cent level of significance (with $F = 7{,}8$; $F\ 0{,}01 = 7{,}1$).

Table 2

*Body composition, based on specific gravity of the body (at 35,5° C) and the Rathbun-Pace equation (1945) for the estimation of body fat*

| Group | Active (N = 29) M | SD | Inactive (N = 27) M | SD |
|---|---|---|---|---|
| Specific gravity* . . . . . . . | 1,0493 | 0,010 | 1,0435 | 0,012 |
| % fat . . . . . . . . . . . . | 24,3 | 5,2 | 27,3 | 6,3 |
| Fat, kg. . . . . . . . . . . . | 19,8 | 5,8 | 21,4 | 7,8 |
| »Fat-free« weight, kg. . . . | 61,7 | 7,0 | 56,9 | 5,7 |

The specific gravity values were obtained at water temperature of $35^0$ to $36^0$ C. At $35{,}5^0$ C the absolute density of water is 0,993 858. Thus the mean body densities, corresponding to specific gravity values given in Table 2, can bi obtained as $D_B = \text{spec. gr.} \times D_W$, where $D_B$ = density of the body, $D_W$ = density of the water.

From these data we have calculated the »excess« weight (6), the »excess« fat ($\Delta F$), total fat, and the fat–free weight (Table 3). Using the equations derived from the study of experimentally induced obesity, the absolute levels of fatness are lower than were derived by the Rathbun–Pace formula (Table 2). This is due, in a large measure, to the fact that in the system developed by Behnke and his collaborators the lowering of

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* These values were obtained by using the approximative formula:

$$\text{spec. gr.} = M_A \,/\, (M_A - M'_W - V_R)$$

where $M_A$ = weight in air, $M'_W$ = apparent weight in water, $V_R$ = residual volume. The use of the correct formula

$$\text{spec. gr.} = M_A \,/\, (M_A - M'_W - D_W \cdot V_R),$$

where $D_W$ = density of the water in the tank, yields mean values of 1,0492 and 1,0434.

specific gravity is ascribed solely to the addition of fat to the initial body mass. Interestingly enough, the difference (Δ = 4,3 kg) between the fat–free weight of the 2 activity groups, computed according to the new system (KEYS and BROŽEK, 28), is only slightly more conservative than that indicated in Table 2.

Table 3

*Body composition, based on average values of body density and the Keys-Brožek equations (1953) for the estimation of body fat*

| Group | Active (N = 29) | Inactive (N = 27) |
|---|---|---|
| Density | 1,0429 | 1,0371 |
| Overweight (G), % of gross wt. | 15,8 | 20,5 |
| Overweight (G), kg* | 12,88 | 16,05 |
| »Normal« weight** (total – G, kg) | 68,62 | 62,25 |
| Overweigt (G), as % of »normal« wt. | 18,8 | 25,8 |
| Δ fat, % of wt. | 9,8 | 12,7 |
| Δ fat, kg*** | 8,0 | 9,9 |
| Total fat, % of wt. | 21,5 | 23,8 |
| Total fat, kg | 17,5 | 18,6 |
| Fat-free weight, kg | 64,0 | 59,7 |

* Weight of tissues with a density of 0,948.
** Weight of tissuses with a density of 1,063.
*** Sixty-two percent of G.

Within the envelope of fat (Δ F), gained by both groups of middle–aged men in the process of aging, the active men appear to have retained much of the tissue mass of »normal« density (68,8 kg versus about 70 kg for the average young healthy adult). The inactive group, with a value of 62,2 kg, appears to have lost a good deal of such tissue and replaced it by »fat«. In terms of the »gain« (G), expressed as percentage of »normal« weight, both groups are »overweight« (in comparison with young men) but the degree of »excess« weight is considerably larger in the inactive group. A comparison with the gross body weight, expressed as percentage of the tabular age–weight standard in Table 1, brings out clearly the advantage of the densitometric analysis and the reversal of judgment as to which group is fatter.

Body density is affected by the amount of the subcutaneous as well as the inner fat. With age there appears to be a shift in the relative amounts of these two components (ŠKERLJ et al., 35) and there are other methodological considerations which make the use of skinfolds as criteria of fatness less straitforward than it might appear at first sight. However, in view of the limitations inherent in the densitometric analysis, the small but systematic differences in the thickness of the skinfolds should be noted.

They support the conclusions reached on the basis of calculations based on specific gravity and the density of the body. Throughout (see Table 4), the skinfold–thickness values were smaller in the active men.

Table 4

*Skinfold thickness, in mm., in physically »active« and inactive men*

| Group | Active (N = 29) M | Active (N = 29) SD | Inactive (N = 27) M | Inactive (N = 27) SD |
|---|---|---|---|---|
| Skinfold site | | | | |
| Chin | 11,0 | 2,4 | 12,5 | 5,4 |
| Arm | 16,4 | 3,3 | 16,5 | 5,6 |
| Chest | 28,3 | 5,6 | 29,3 | 8,8 |
| Back | 21,2 | 5,3 | 23,0 | 10,0 |
| Waist | 20,7 | 4,5 | 20,9 | 9.0 |
| Abdomen | 26,8 | 4,9 | 28,2 | 9,0 |
| Thigh (above knee) | 10,4 | 2,9 | 11,0 | 4,1 |

While the chest circumference is larger in the active men, reflecting a somewhat better developed musculature, the inactive men have a larger abdominal circumference. Numerically of interest is the *difference* between the two circumferences which is significantly smaller ($F = 7,6$; $F_{0{,}01} = 7,1$ for one and 55 degrees of freedom) in the inactive men. While in the active group in no case was the abdominal circumference larger than the chest circumference, in the inactive group there were 7 (25 per cent) individuals with negative differences between the 2 circumferences. This is another indicator of greater fatness of the less active subjects (cf. SARKISIAN, 36).

Table 5

*Trunk circumferences and diameters, in cm*

| Group | Active (N = 29) M | Active (N = 29) SD | Inactive (N = 27) M | Inactive (N = 27) SD |
|---|---|---|---|---|
| Circumferences | | | | |
| (1) Chest | 101,6 | 6,2 | 99,1 | 8,5 |
| (2) Abdomen | 92,6 | 7,2 | 93,7 | 12,1 |
| Difference (1) — (2) | 9,0 | 4,3 | 5,4 | 5,6 |
| Diameters | | | | |
| (1) Bideltoid | 45,1 | 2,4 | 44,6 | 2,0 |
| (2) Biacromial | 39,3 | 1,9 | 38,7 | 1,5 |
| (3) Bicristal | 28,6 | 1,3 | 29,2 | 1,7 |
| (4) Bitrochanteric | 34,2 | 1,6 | 34,2 | 2,1 |

The active men had, on the average, wider shoulders but the difference in bideltoid diameter only approached and did not reach the 5 per cent level of statistical significance ($F = 3{,}5$; $F_{0{,}05} = 4{,}0$). The absence of a difference in the lateral dimensions of the skeleton (biacromial, bicristal, and bitrochanteric diameters), together with a closely matched height of the body in the two samples, largely removes the possibility that the higher density of the physically active men could be due to a larger skeletal frame. Data on the mineralization of the bones are not available.

## DISCUSSION

Physical activity, in addition to genetic factors and nutrition, exercises an important influence on the composition of the human and animal body. The European practioners of the art of poultry feeding, finding delight and profit in amply fattened geese, have long been applying this principle in a negative way, by restricting the bird's activity to a minimum while simultaneously forcing calories down its throat.

At times the human infant is exposed to much the same treatment by his oversolicitous mother as the goose of Alsace or Bohemia, except that the order of events is usually reversed, with the excessive food intake coming first and the reduced activity following and, in turn, aggravating the situation. The marked rise in man's (and woman's) fat content during the period of »maturity« (roughly from 20 to 55 or 60 years) appears to be due, in a large measure, to the reduction in physical activity not corrected by a parallel reduction in the caloric intake (BROŽEK, 14). However, hormonal factors, responsible for the greater fat content of the female (BROŽEK et al., 31a), may also be involved.

Surprisingly enough, the effects of activity are not discussed in Brody's encyclopedic treatise (31), except for reference to the correlation between the exercise level and heart weight (p. 628). He points out that aquatic animals, not obliged to overcome the pull of gravity, invariable have relatively smaller hearts than terrestrial animals who must lift the body during walking or running.

The effects of long-continued muscular exercise on the chemical composition of some tissues of beef cattle were investigated by Mitchell and Hamilton (38). Unfortunately, for our purposes, the authors were interested only in the properties of the lean meat and all overlying fat was separated by knife before the organs and the carcasses were ground and sampled for chemical analysis. Even so the results of the experiments, carried out for about 4 months under well controlled conditions, are not without interest. In each of the experiments one lot of 4 animals was closely confined while the experimental animals were exercised on an inclined treadmill for one and for three and a half hours, respectively.

Fat was determined by extraction with ether. In the »heavy work« experiment the average amount of fat was lower in 9 of the tissues sampled, identical in 1, and higher in 1 sample in the exercised than in the confined animals. The grand mean values of all the 11 samples were 2,04 and 2,30 per cent of fat (on the fresh basis). In the liver the percentages were 1,60 and 2,41, in the heart 2,77 and 3,25, respectively. In the »light work« experiment the tendency for the tissues from the exercised steers to exhibit smaller fat content than the corresponding tissues from unexercised steers was very definite in the liver (1,72 vs. 2,63%) and suggestive in the heart (1,90 vs. 2,38%) while the samples of the muscle tissues showed no consistent effect of muscular training. These differences are in the same direction as the differences observed between our active and inactive men. They indicate that the »fatness« associated with relative inactivity is not limited to the large fat depots but extends also to the »lean« tissues.

The opinion is generally held that different sports tend to produce in man specific, recognizable body »types«, the chief factor being the overdevelopment of groups of muscles used intensively in the particular sport. Riedman (39) points to the enlargement of calf muscles of the dancer and the runner, the broadening shoulders of the football player, the development of the back muscles of the weight lifter, and the increase of the chest muscles of the swimmer, but does not refer to any quantitative (anthropometric) data.

The sparse early anthropological literature on exercise and physique was reviewed by Škerlj (11) who noted Westenhöfer's idea that physical exercise represents a kind of physiological experiment. Indeed it is one of the most frequent types of »experimentation« on man, resulting in functional as well as structural alterations. Yet, in view of the frequency of participation as well as the diversity of athletic activities and occupational work, the morphological alterations have received inadequate attention. The older as well as the more recent literature on the quantitative aspects of changes in body build, associated with physical exercise, was discussed critically by Tanner (12, p. 451).

One of the perennial problems has been the separation of the effects of selection and of the physical activity proper. Müller (40) has stressed that women with a leptosome body build have a greater tendency to take part in sports than those with an eurysome, »typically female« body build. That in Škerlj's own study (11) the selective factors have been present is indicated by the fact that the stature of the several groups of athletes he has examined was larger than in the general population, the muscular body build (in Sigaud's classificatory system) was predominant and, in women, the breasts were frequently underdeveloped. For our purposes, the application of measurement to bony dimensions alone represents the principal limitation of Škerlj's interesting study. Some of the later studies by American authors presented also data on body weight.

However, it should be noted that changes of the gross body weight represent very complex data. Similar complexity is inherent in body dimensions, such as the limb and trunk circumferences which have a bony, muscular and adipose component. In order to be biologically interpretable, body weight and body dimensions should be analyzed into the principal tissue constituents.

A detailed anthropometric study on changes in body build during training in weight lifting was carried out by Tanner (12) on 10 healthy college students, outspokenly »mesomorphic« (in Sheldon's terminology, SHELDON, 41), at the outset. The subjects had 23 to 44 hours of weight-training spread over about 4 months. Body weight showed small fluctuations, with an overall gain of about 2 lbs. in about 3 weeks, followed by a slight decrease in the subsequent 3 months. The most notable change was an increase in the circumference of the upper arm, both loose and contracted (4 to 11 per cent of the pre–training value). As there were no concurrent changes in the thickness of subcutaneous tissue over the front or back of the upper arm, the gain in the arm circumference must be interpreted as being due to the growth of muscular tissue, cessation of exercise for 4 months was associated with a partial or complete return of the circumference values to the pre–training level. In the forearm circumference the changes were smaller (a gain of 1 to 7 per cent) and the »disuse atrophy« during the absence of training was more complete. The leg measurements (especially the thigh circumference) showed less consistent changes, in the direction of a decrement. The author interprets these changes as alterations in the amount of subcutaneous fat; no actual measurements of skinfolds at these sites were made. The subcutaneous tissues, measured under the left scapula and above left iliac crest showed a slight overall gain (less than 2 mm at the end of the training period), due chiefly to large gains in one subject. Measurements of trunk thickness and trunk breadth, made from photographs, showed some decrease during training. The losses represented, presumably, a loss of body fat, perhaps intra-abdominal rather than subcutaneous. These changes were very small and the available data do not allow a refined tissue analysis.

As far as we are aware, the first physico–chemical study of the effects of different types of physical activity in living animals was carried out by Kohlrausch (8, 9). His densitometric technique was based on registering the rise in pressure in an air–tight compartment, containing the animal, when a known volume of air was added; the pressure changes had been calibrated by means of objects of known volumes. Density measurements were made during the course of physical training and the fat content was determined when the dogs were sacrificed. A low density was associated with high fat content, high density with a small amount of ether extract. In the course of light exercise the body weight increased, body density decreased and it was estimated that the body fat had increased. After several months of very heavy physical work, the weight showed a moderate decrease, while body density increased markedly, indicating a substantial decrement in body fat.

Having determined body volume by underwater weighing, Welham and Behnke (10) observed in »overweight« professional football players high specific gravity values, interpreted as an indication of a low fat content but a large »lean body mass«. A similar trend, though less pronounced, was noted in the present study.

The central question is: How valid is the analysis of body weight presented in this paper? The approach developed by Behnke and his co-workers was subjected to criticism in the section on Methods and was examined elsewhere in detail (Keys and Brožek, 28). Here we shall limit the discussion to skinfold measurements and the densitometric analysis based on the Minnesota studies on experimentally induced obesity.

Anthropometric findings have the advantage of the simplicity of measurement and, relatively, of interpretation. We have seen that the active men, inspite of being »overweight« for height, had somewhat thinner average skinfolds. We are on a safe ground when we interpret these differences as an indication that the active men are less »fat«. Whatever methodological errors may be involved, they are likely to reduce the actual differences in the amount of subcutaneous fat. Two of these potential errors come readily to mind: (1) If there are differences in the elastic characteristics of the »skin« (plus the subcutaneous layer), we would expect that these tissues would be firmer, i. e. less compressible (at a given pressure of the caliper) and would appear *larger* than the »flabby« tissues of the inactive individuals. (2) The differences, if any, in the skin thickness would probably affect the measurements in the same direction.

Measurements of skinfold thickness are useful for the description of the way in which the subcutaneous fat is distributed. It is difficult, if not impossible, to estimate the total amount of subcutaneous adipose tissue. The possibility of shifts in the distribution of body fat between the subcutaneous and the deeper depots complicates the matter still further (Škerlj et al., 35).

The densitometric analysis of body composition has the advantage of dealing with the whole body mass. However, it assumes a fairly rigid uniformity in the composition of the constituent parts of the system. At present, the range of variability of these components is not adequately known. To begin with the reference body, what is the range of variation in the density of individuals satisfying the definition (clinical normality, age 25 years, standard weight for height)? This matter is under investigation in the Laboratory of Physiological Hygiene. Part of the variability in the reference standard will be due to variations in the size of the skeleton present in individuals of a given height; this variability could be reduced by taking into account additional criteria of the skeletal size (e. g. the bicristal diameter). Perhaps more useful than a value of body density corresponding to a precisely defined average skeletal mass would be the determination of body density in subjects *differing* in the width of the skeleton. Evaluation of the effect of the mineralization of the bones would yield a further refinement but technical difficulties are large and the potential gain in the accuracy of the densitometric analysis of body composition is small.

In the »standard body« used as a reference point, the bone minerals are estimated to constitute 6 per cent of the gross body weight and 7 per cent of the fat-free body weight. These values are identical with the average amount of ash in 5 bodies submitted to a detailed direct analysis by Mitchell et al. (42), Widdowson et al. (43) and Forbes et al. (44); the ranges (cf. KEYS and BROŽEK, 28) were from 4,9 to 7,6 per cent and from 5,0 to 9,9 per cent, respectively. Retaining the same relative proportions between fat, extracellular fluid and »cells« as are postulated in the reference standard, the lowering of bone mineral to 4 per cent of the body weight is associated with the lowering of body density from 1,0629 to 1,0484 while the increase of bone mineral to 8 per cent of body weight would raise the value of body density to 1,0777. These are substantial differences which would simulate, in the Minnesota system, an increment of body fat to 19,4 per cent and a decrement to 8,6 per cent, while the percentages calculated directly from the mass and volume of the components are 14,3 and 13,7 per cent of body fat; the reference density of value of 1,0629 corresponds in the system to 14 per cent of body fat. This comparison indicates that the interindividual variability in the bony mass is a more important factor than has been generally recognized and that an independent estimate of the skeletal weight and its mineral content would increase the validity of densitometry.

In the present study the factor of body height was eliminated (controlled) by the process of matching. Several measurements of the width of the skeleton were made but indicated no statistically significant differences between the physically active and inactive group. Thus the presence of differences in the amount of bone mineral is not likely to complicate the densitometric analysis.

As far as the other components of the standard body are concerned of special interest are the »cells«, with an estimated density of 1,057, which include principally the muscle mass. It should be noted that this density is not widely different from the density of the standard body as a whole (1,0629). Consequently, the loss of muscles in the reference man would only slightly increase the body density. A reduction of body weight by 2 and 12 per cent, respectively, if totally accounted for by »cells«, would raise the density of the body to 1,0630 and 1,0638, respectively. It appears (Table 3, values of »normal« weight), by comparison with the weight of the reference body of the same height (about 70 kg), that these are the respective magnitudes of the changes in the active and the inactive group.

Use of these densities, instead of the »standard« density of 1,0629, would alter the equation (4) for estimating the amount of tissue »gain« (G), yielding 12,96 kg and 16,52 kg as the value of G in the active and inactive subjects. Fortunately, these values differ negligibly from the data in Table 3 which indicates slightly more conservative differences in the »fatness« of the active and inactive men (G of 12,88 and 16,05 kg).

Having discussed some aspects of the variability of the standard of reference we can consider the second component in the system of analysis, the »G« (»gain« – or loss) and its constituents. The density of human fat obtained as the ether extract of subcutaneous and abdominal tissues removed at surgery, exhibits a remarkable uniformity. There is apparently no significant difference according to sex or site. In 20 samples obtained from men and women the values ranged from 0,8996 to 0,9015, with a mean of 0,9007; the determinations refer to a temperature of 36$^0$ C (Fidanza *et al.*, 31).

In the experiment on induced obesity the density of the added tissue has varied in different individuals within very narrow limits around the mean value of 0,948 (cf. Keys *et al.*, 32). It should be noted that the range of weight gains was large (from 2,5 to 21,0 kg) and that the initial weight of the subjects showed also fairly large deviations from the age – height – weight standards (from 15 per cent underweight to 13 per cent overweight).

However, these were intraindividual changes, all in the direction of weight gain resulting from an excess intake of calories. In an athlete who gains weight in the course of an intensive training the composition of the gained mass (»G«) will be different. Ranke (p. 131, 45) suggested that *complex* alterations in body composition take place in the course of military training; the recruits' muscle mass may increase while the mass of adipose tissue decreases, and these changes may be so balanced that the gross body weight remains unaltered. The complexity of the situation has been indicated already in the early experiments of Kohlrausch (9). Certainly during weight loss the composition of the tissues lost will differ at different periods of prolonged caloric deficiency, even disregarding the changes in body hydration, with relatively large losses of depot fat at the outset and an increasing fraction of other soft tissues at later stages.

We have no information on the density of the tissues gained by man in the course of different types of exercise. But it should be noted that this is *not* the problem examined in the present study. In both groups there appears to be a *loss* of such »athletic tissue«, i. e. principally muscles – – a small loss in the active men and a considerable loss in the inactive subjects. The accumulation of fat is also present in both groups. Even in the active group there has been a considerable increase in subcutaneous fat and a decrement in body density (1,0429 vs. 1,0629), as compared with the values for young men.

In the sample on the basis of which the reference standard (clinically healthy man 25 years old, 176 cm tall) was defined, the body weight was about 70 kg; the height happens to be the same as the means of the two groups of middle-aged subjects. In the active group of the middle-aged men the »heavier« tissues, with a density of 1,0629, account for about 69 kg, while the total body weight is close to 82 kg. In the inactive group these values are 62 and 78 kg, respectively. An informative way for expressing the values of the tissues with a density of 1,0629 and of the »adipose tissue« (density of 0,984) is to refer them to the standard weight of the young men. The values in the active and the inactive men are about 98 and 88 per cent, and 25 and 27 per cent, respectively.

These data may be interpreted in such a way that the active individuals have largely retained the body of the young men and added to it »adipose tissue«, defined physiologically (i. e. G). The inactive men have lost a fair amount of the »heavier« tissues, principally through muscle atrophy, replaced it by fat and, in addition, gained fat in the process of aging.

The study of growth and aging, with physical activity as an »independent« variable, is a fruitful field for the application of the newer techniques for the analysis of body composition in the living man. It is desirable to extend these investigations to other populations, differing in the amount of physical work or exercise (as well as in other aspects of the mode of life), especially to groups engaged in occupational work involving fairly high levels of energy expenditure.

## CONCLUSIONS

The composition of the human body represents a problem area which is of interest to several theoretical and applied disciplines, including the science of human work and the physiology of exercise. Methodologically, important contributions have been made by biophysics (densitometry), biochemistry (total body water and fluid spaces), radiology (tissue composition of the body, especially of the limbs; estimation of bone mineralization), and physical anthropology (skinfold measurements, skeletal dimensions; evaluation of fatness from standard photographs).

The purpose of the present study was to examine the body composition in 2 groups of middle-aged men who exhibited longstandig differences in the amount of habitual physical exercise. The subjects were drawn from a larger sample of business and professional men living in a metropolitan Midwestern community of the U. S.

Anthropometrically, the two samples were matched for height, and the lateral dimensions of the skeleton showed no consistent and statistically significant differences. The »active« men were somewhat heavier but both the difference between the chest and abdominal circumference (larger in the active, smaller in the inactive group) and the skinfolds indicated that it was the body of the inactive men that contained a larger amount of adipose tissue. In other words, the active men were »overweight«, the inactive group was »overfat«.

Body density, used as a criterion of the total body fat was higher in the active than in the inactive men, indicating a lower fat content. Densitometric analysis of body composition was carried out by the technique developed by Behnke and his co-workers, and by a system developed at the University of Minnesota on the basis of studies on experimentally induced obesity. Both systems indicated a difference in »fatness« in the direction suggested by the anthropometric data, but the most striking feature was the large fat-free weight of the active group which showed minimal »disuse atrophy« of the muscular tissues, characteristic of the »normal« process of aging in relatively physically inactive individuals.

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*References*

1. *Brožek, J.*, Measuring nutriture, Am. J. Physical Anthropol. *11* (n. s.) (1953) 147–180.
2. *Keys, A., Brožek, J., Henschel, A., Mickelsen, O.* and *Taylor, H. L.*, The Biology of Human Starvation, Univ. Minn. Press, Minneapolis, 1950.
3. *Mack, P. B., Trapp, H. D.* and *Brown, W. N. Jr.*, The quantitative estimation of bone density, in Keys *et al.*, 1950, p. *1081*.
4. *Taylor, H. L., Brožek, J.* and *Keys, A.*, Basal cardiac function and body composition with special reference to obesity, J. Clin. Investigation, *31* (1952) 976.
5. *Chapman, C. B., Gibbons, T.* and *Henschel, A.*, The effect of the rice-fruit diet on the composition of the body, New England J. Med., *243* (1950) 899.
6. *Behnke, A. R.*, Physiologic studies pertaining to deep sea diving and aviation, especially in relation to the fat content and composition of the human body, Harvey Lect. *37* (1941/2) 198.
7. *Behnke, A. R.*, Absorption and elimination of gases of body in relation to its fat and water content, Medicine, *24* (1945) 359.
8. *Kohlrausch, W.*, Methodik zur quantitativen Bestimmung der Körperstoffe in vivo, Arbeitsphysiol., *2* (1930) 23.
9. *Kohlrausch, W.*, Zur Kenntnis des Trainingszustandes, Arbeitsphysiol., *2* (1930) 46.
10. *Welham, W. C.* and *Behnke, A. R.*, The specific gravity of healthy men. Body weight ÷ volume and other physical characteristics of exceptional athletes and of naval personnel, J. A. M. A. *118* (1942) 498.
11. *Škerlj, B.*, Menschlicher Körper und Leibesübungen, Warsaw: Tow. Naukowe Warszavskie, 1936.

12. *Tanner, J. M.*, The effect of weight-training on physique. Am. J. Physical Anthropol. *10* (n. s.) (1952) 427.
13. *Henschel, A.*, Federation Proc. *10* (1951) 62 (abstract).
14. *Brožek, J.*, Changes of body composition in man during maturity and their nutritional implications, Federation Proc. *11* (1952) 784.
15. *Stuart, H. C.*, *Hill, P.* and *Shaw, C.*, The growth of bone, muscle and overlying tissues as revealed by studies of roentgenograms of the leg area, Monographs Soc. Res. Child Devel. No. 26, 1940.
16. *Reynolds, E. L.*, The distribution of subcutaneous fat in childhood and adolescence, Monographs Soc. Res. Child Devel., No. 50, 1950. Child Development Publ., Evanston, Illinois, 1951.
17. *Mack, P. B.*, *Brown, W. N.* and *Trapp, H. D.*, The quantitative evaluation of bone density, Am. J. Roentgenol. Radium Ther., *61* (1949) 808.
18. *Brown, W. N.* and *Birtley, W. B.*, A densitometer which records directly in units of emulsion exposure, Rev. Scient. Instruments, *22* (1951) 67.
19. *Behnke, A. R.*, *Feen, B. G.* and *Welham, W. C.*, The specific gravity of healthy men, J. A. M. A., *118* (1942) 495.
20. *Rathbun, E. N.* and *Pace, N.*, Studies on body composition. I. The determination of body fat by means of the body specific gravity, J. Biol. Chem., *158* (1945) 667.
21. *Pace, N.* and *Rathbun, E. N.*, Studies on body composition. III. The body water and chemically combined nitrogen content in relation to fat content, J. Biol. Chem., *158* (1945) 685.
22. *Pace, N.*, *Kline, L.*, *Schachman, H. K.* and *Harfenist, M.*, Studies on body composition. IV. Use of radioactive hydrogen for measurement in vivo of total body water, J. Biol. Chem., *168* (1947) 459.
23. *McCance, R. A.* and *Widdowson, E. M.*, A method of breaking down the body weights of living persons into terms of extracellular fluid, cell mass and fat, and some applications of it to physiology and medicine, Proc. Roy. Soc. London, s. B. *138* (1951) 115.
24. *Brožek, J.* and *Keys, A.*, Evaluation of leanness-fatness in man: A survey of methods, Nutrition Abst. & Rev. *20* (1950/51) 247.
25. *McCance, R. A.* and *Widdowson, E. M.*, Composition of the body, Brit. Med. Bull., *7* (1951) 297.
26. *Edelman, I. S.*, *Olney, J. M.*, *James, A. H.*, *Brooks, L.* and *Moore, F. D.*, Body composition: Studies in the human being by the dilution principle, Science, *115* (1952) 447.
27. *Behnke, A. R.*, *Osserman, E. F.* and *Welham, W. W.*, The clinical significance of the lean body mass and its estimation from excess fat and total body water determinations, 1953. In press.
28. *Keys, A.* and *Brožek, J.*, Body fat in adult man, Physiol. Rev., *33* (1953) 245.
29. *Brožek, J.*, *Henschel, A.* and *Keys, A.*, Effect of submersion in water on the volume of residual air in man, J. Applied Physiol., *2* (1949) 240.
30. *Jaekle, H.*, Ueber die Zusammensetzung des menschlichen Fettes, Z. physiol. Chem., *36* (1902) 53.
31. *Fidanza, F.*, *Keys, A.* and *Anderson, J. T.*, The density of human body fat, 1953, in press.

31.a *Brožek, J.*, *Chen, K. P.*, *Carlson, W.* and *Bronczyk, F.*, Age and sex differences in man's fat content during maturity (abstract), Federation Proc. *12* (1953) 21.

32. *Keys, A.*, *Anderson, J. T.* and *Brožek, J.*, Weight gain from simple overeating. I. Character of the tissue gained, 1953 (to be published).
33. *Association of life insurance medical directors*, Medico-actuarial mortality investigations, New York: Assoc. Life Ins. Med. Dir. and Actuarial Soc. Amer., 1912, vol. 1.
34. *Keys, A.*, A caliper for estimating subcutaneous fat from skinfold measurements, 1953 (to be published).
35. *Škerlj, B.*, *Brožek, J.* and *Hunt, E. E., Jr.*, Subcutaneous fat and age changes in body build and body form of women, Am. J. Phys. Anthrop., n. s., *11* (1953), in press.

36. *Sarkisian, S. S.*, Specific gravity of healthy men; report of 835 cases, U. S. Nav. Med. Bull. *46* (1946) 1207.
37. *Brody, S.*, Bioenergetics and growth, Reinhold, New York, 1945.
38. *Mitchell, H. H.* and *Hamilton, T. S.*, Effect of long-continued muscular exercise upon the chemical composition of the muscles and other tissues of beef cattle, J. Agric. Res., *46* (1933) 917.
39. *Riedman, S.*, The physiology of work and play: A textbook in muscular activity, New York: The Dryden Press, 1950.
40. *Mueller, I.*, Ueber die Beziehungen der Konstitution der Frau zu ihren beruflichen und sportlichen Neigungen, Arch. Frauenkunde (Leipzig), *18* (1932) 180.
41. *Sheldon, W. H.*, The varieties of human physique, New York: Harper, 1940.
42. *Mitchell, H. H., Hamilton, T. S., Steggerda, F. R.* and *Bean, H. W.*, The chemical composition of the adult human body and its bearing on the biochemistry of growth, J. Biol. Chem., *158* (1945) 625.
43. *Widdowson, E. M., McCance, R. A.* and *Spray, C. M.*, The chemical composition of the human body, Clin. Sc., *10* (1951) 113.
44. *Forber, R. M., Cooper, A. R.* and *Mitchell, H. H.*, 1953, Ms. (to be published).
45. *Ranke, O. F.*, Arbeits- und Wehrphysiologie mit Hinweisen auf die Sportsphysiologie, Quelle und Meyer, Leipzig, 1941.

*Sadržaj*

## FIZIČKA AKTIVNOST I GRAĐA TIJELA

Svrha ove radnje bila je ispitivanje razlika u građi tijela dviju grupa ljudi srednje dobi, kojih je kvantitet fizičkog rada kroz dugi vremenski period bio različit. Ispitanici su pripadali većoj grupi ispitanika, koji su živjeli u Minneapolis-St. Paulu (SAD), a bili su činovnici i ljudi slobodna zvanja.

Obadvije grupe bile su uzete tako, da je njihova srednja visina bila jednaka. Lateralne dimenzije kostura nisu pokazivale statistički značajnih razlika. Grupa »aktivnih« bila je nešto teža, ali antropometrijski podaci (razlika opsega prsiju i trbuha i debljina potkožnog tkiva) pokazivali su, da tijelo ispitanika u neaktivnoj grupi sadržava veću količinu masnog tkiva.

Densitometrijska analiza građe tijela izvršena je tehnikom Behnkea i njegovih suradnika i po sistemu, koji je izrađen na univerzitetu u Minnesoti na temelju studija eksperimentalno dobivene debljine. Gustoća tijela, uzeta kao kriterij ukupne količine masti, bila je veća u aktivnoj grupi. Te metode pokazale su razliku u »masnoći« u istom pravcu, na koji su upućivali antropometrijski podaci. Najzanimljiviji je podatak o velikoj težini tijela bez masti kod aktivne grupe. Ta činjenica se tumači relativnim odsustvom atrofije mišića, koja je karakteristična za »normalni« proces starenja.

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