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# THE TESTING OF PHYSICAL EFFICIENCY

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The sequellae of the great War have set many a task to the medical and anthropological sciences, and one of the most urgent of these is how to determine in the best way the physical efficiency of a given person. In a preliminary way the writer has dealt with this problem before the International Institute of Anthropology, Paris, 1920, and in the present paper will endeavor to describe his methods as far as developed.

The indications are, it may be said at once, that it will be necessary, besides employing a general procedure capable of giving us a good estimate of the physical efficiency of any subject presented for examination, to use also modified methods for testing men of different vocations, similarly as is done by psychologists in the testing of mental qualities.

The methods to be described here may be termed "somatotechnic," in harmony with the term "psychotechnic" usually adopted for similar procedures in psychology.

It is plain that the anthropological measurements usually employed are not sufficient for the purpose in view. Also it would not be advisable to put too great a weight on any single anthropological character. For instance, an above-the-average stature is not always an indication of physical superiority, but may be connected with delicate muscles, and a considerable weight of body might indicate an unhealthy obesity. Even a combination of several anthropological characteristics does not always help much as for instance in the case of the *Index ponderalis.*

In estimating a person's physical efficiency it is necessary to take into consideration, aside of his general physical characteristics, also the respective organs and tissues connected with muscular work. For this purpose it seems advisable to proceed in the following way: (1) To determine anthropometrically the extent of the different tissues, especially bones, muscles and skin with the subcutaneous fat; (2) to determine by physiological methods the qualities of the principal organs, such as muscles (reaction to impulses, fatigability etc.), lungs, the vascular system, etc.; and (3) to determine, by careful medical examination the state of health with possible serious hereditary defects and other pathologic factors of the body. And it is desirable to express the state or grade of physical efficiency by as far as possible a simple formula.

So far as the development of the body is concerned (skeleton, muscles and fat), the author makes use chiefly of the dimensions of the extremities, which are easy of access and represent essentially organs of physical work, similarly as the brain represents essentially mentality. The mutual relation of the tissues in the body, we may assume, is and changes substantially the same as in the extremities. The osseous parts of the extremities give us a good idea of the skeleton as a whole. The development of the skeleton therefore is estimated from the thickness of the bones of the extremities, measured where they are easy of access, and in relation to the stature. The writer measures the maximum transversal dimension of the lower end a.) of the humerus, b.) of the forearm, c.) of the thigh bone, and d.) of the leg; in other words the transverse diameter of the humeral and femoral condyles and of the wrists and ankles. The condylar measurements for greater accuracy are taken on the bent extremities; and the squared average of the four dimensions—$o$ (ossa)$^2$—multiplied by stature in centimeters—$L$ (Length), gives a value representing the weight of the skeleton ($O$ = skeleton). The coefficient $k_1$ which there are reasons to believe amounts from 1.0 to 1.2 (still to be tested on corpses) will equalize all arisen errors. The formula then reads thus: $O = o^2 \times L \times k_1$. The procedure is not an arbitrary one, but based on due considerations. A young man of 180 cm. height and 72.5 kg. weight, gave respectively 73, 55, 105 and 78 for the four dimensions on the limbs, which gave the average of 78 mm. or 7.8 cm. The square of this (60.84 cm.$^2$) multiplied by the stature and by the coefficient 1.2, gave as the representation of the weight of the whole skeleton 13,141 gr. i. e. 18.1% of the weight of the whole body.

For the estimate of the quantity of the skin and of the subcutaneous fat, the writer uses the thickness of the skin fold on the upper arm, above the biceps; on the forearm, on the plantar side where the maximum breadth of the forearm occurs; on the thigh halfway between the inguinal fold and the knee, above the quadriceps muscle; on the calf of the leg; on the thorax half way between the nipples and the umbilicus (on the costal margin); and on the abdomen half way between the navel and the anterior superior iliac spine. These dimensions are secured by a sliding compass with blunt points,[1] with the exertion of a mild pressure just to enable the skin fold to slip out of the branches when the fingers don't hold it any longer. . One half of the average of these several dimensions gives the thickness of the skin together with the subcutaneous fat ($d$) and by multiplying this with a value representing the surface[2] of the body ($S$) and a coefficient $k_2$, the total quantity of the skin and of the body fat ($D$) is obtained according to the formula: $D = d \times S \times k_2$. Presumably again the fat of the viscera undergoes the same changes in the various stages of health as the subcutaneous fat. In the above-named young man the surface areas was, 21,407 cm.$^2$; and the average thickness of the skin fold, 8.17 mm., the half of this 4,085 mm. Taking the coefficient $k_2$ as 0,13, the result for the weight of the skin inclusive of the fat will be: $21{,}407 \times 4{,}085 \times 0{,}13 = 11{,}338.19$ gr., or 15.6% of the weight of the body.

For the estimation of the quantity of muscles ($M$) one of the following formulae might be used: $M = k_3 \times r^2 \times L$, or $M = k_4 \times c^2 \times L$; $k_3$ and $k_4$ being assumed coefficients (to be more exactly determined on corpses),

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[1] The sliding compass adjusted in this way has been manufactured by Brothers Cížek, Prague, Czechoslovak Republic.

[2] For the calculation of the surface of the body there were several methods recommended; the most simple is the one of *Vierordt-Meehe*: $S = 12{,}312\sqrt[3]{P}$, who takes only the weight of the body (P) in consideration and therefore it is least reliable. A more thorough method is the one adopted by *Miva-Stölzner*: $S = \frac{4{,}5335\sqrt[6]{P^4 \times L^4 \times Ct^2}}{Ct\quad P\quad L}$ in which there are not only the length of the body (L) but also the circumference of the thorax (Ct) taken in calculation. A still more accurate method seems to be the one of *Du-Bois-Delafield*: $S = P^{0.425} \times L^{0.725} \times 71.84$, and of *Bouchard*, for lean bodies: $S = 0.45\,Ca\,L + 7.70\,\frac{P}{Ca} + 3.31\,L\sqrt{\frac{P}{3.14L}}$, for stout bodies: $S = 0.46\,Ca\,L + 7.84\,\frac{P}{Ca} + 3.33L\sqrt{\frac{P}{3.14L}}$, which prefer the circumference of the waist (Ca).

$r$ and $c$ respectively the average radius and the average circumference of the extremities without skin and without subcutaneous fat, and $L$ the stature. The circumferences are taken, on the arm above the venter of the biceps with the arm flexed without any exertion of strain; on the forearm the maximum; on the thigh half way between the trochanter and the lateral epicondyle; and on the leg the maximum circumference of the calf. These dimensions serve for the calculation of the mean circumference and of the mean radius (circumference = $2r$), from which is subtracted the thickness of the skin and of the subcutaneous tissue of the respective parts obtained by the method described above). The square of the radius of the "muscular column" thus obtained (including of course the osseous nucleus), multiplied by the respective stature and coefficient, gives a value which may be taken as representing the total quantity of the muscles. In the above mentioned young subject the figures were as follows: The mean circumference 35,825 cm., hence the radius 57 mm.; thickness of skin 3.88 mm.; the radius of the "muscular column" is then $57-3.88=53.12$ mm. The respective coefficient appears to be about 6.5 and thus we get the following formula: $M\ 5{,}312^2 \times 180 \times 6.5 = 33{,}072.77$ gr., or approximately 45.5% of the whole weight of the body. Calculating in this way it is of course assumed that the development of the muscles and the skeleton is mutual and corresponding; it would require a more complicated formula to take a special consideration of the development of the skeleton, such as for instance $M=(k_5 r^2 L)-k_6 O$.

Investigations on corpses for the purpose of obtaining the accurate coefficients are still lacking, but preliminary calculations give us confidence that the method employed here is fairly suitable for the purpose for which it has been designed. The writer used it on twelve boys of 16–17 years of age, apprentices of different trades (3 blacksmiths, 6 butchers and 3 barbers), all in good state of health, with the following results:

| | Stature cm. | Circumference of Thorax cm. | Weight of Body kg. | Estimated Weight of | | | Dynamometric Effect lbs. Eng. |
|---|---|---|---|---|---|---|---|
| | | | | Skeleton gr. | Muscles gr. | Skin & Fat gr. | |
| Minimum | 157 | 80.0 | 47.8 | 8,206 | 19,407 | 8,763 | 219 |
| Maximum | 181.5 | 91.5 | 74.7 | 14,169 | 33,073 | 16,793 | 404 |
| Average | 166.9 | 85.5 | 57.3 | 10,389 | 24,492 | 10,889 | 309 |

The last column in the above table adds to the data on bodily development a figure showing in a general way the physiological efficiency of the muscles. This figure is the sum of the dynamometric measurements of the pressure with the right and left hand together with pressure and tension with both hands together, and is expressed in English pounds. The next table gives the results by the trades, and shows that the apprentices of butchers and blacksmiths have certainly on an average a heavier skeleton and a greater quantity of muscles than those of barbers:

| Apprentices | Stature cm. | Circumference of Thorax cm. | Weight of Body kg. | Estimated Weight of Skeleton gr. | Estimated Weight of Muscles gr. | Estimated Weight of Skin & Fat gr. | Dynamometric Effect lbs. Eng. |
|---|---|---|---|---|---|---|---|
| 3 barbers | 165.5 | 81.8 | 51.2 | 9,823 | 21,374 | 9,987 | 241 |
| 3 blacksmiths | 169 | 84.7 | 58.7 | 10,167 | 25,382 | 10,476 | 311 |
| 6 butchers | 166.6 | 87.9 | 59.7 | 10,783 | 25,607 | 11,545 | 343 |

The figures are by no means perfect, but give a good idea of how the method works.

In the course of the tests there was visible a distinct relation between the quantity of the muscles and the dynamometric effect, so that it was possible to come to the deduction that a quantity of muscles amounting to 25 kg. corresponds to about 300 lbs. of dynamometric strength; a quantity of more than 27 kg. answers to about 350 lbs.; a mass under 23 kg. to about 250 lbs. The dynamometric record does not always correspond exactly or even very closely to the quantity of muscles, for outside of other possible reasons the muscular strength of the hands as tested by the dynamometer is not a perfect expression of the efficiency of the whole body—there may be a disproportionate development of different groups of muscles. This has been shown strikingly in the tests of three teachers of gymnastics. The records in these cases were:

|  | Stature cm. | Circumference of Thorax cm. | Weight of Body kg. | Estimated Weight of Skeleton gr. | Estimated Weight of Muscles gr. | Estimated Weight of Skin & Fat gr. | Dynamometric Effect lbs. Eng. |
|---|---|---|---|---|---|---|---|
| D. V. | 169.3 | 92.7 | 72.0 | 13,045 | 34,566 | 9,459 | 567 |
| A. J. | 171.1 | 92.1 | 72.5 | 11,396 | 38,462 | 7,305 | 463 |
| F. J. | 163.7 | 94.7 | 62.0 | 10,042 | 32,363 | 6,188 | 436 |

The first man, D. V., shows by far the highest dynamometric strength, whereas A. J. gives the highest figure for the quantity of muscles. This discrepancy is accounted for by the fact that A. J. had recently a bilateral affection of the scapular muscles and evidently cannot yet handle the dynamometer with the expected muscular strength. Besides this there is an excessive development of the thoracobrachial muscles in D. V., whereas A. J. has especially developed the antebrachial and tibial muscles. The circumference of the arm above the deltoid and close to the insertion of the pectoral muscle in maximum extension of the arms (as in measuring the span), was, in D. V., 38.2 cm., in A. J., 34.7 cm., and in F. J., 35.3 cm.

A sufficient number of investigations in this line shall furnish us with accurate data which when properly arranged will constitute a good basis for comparisons and enable us to determine almost at a glance whether a given person has or has not according to his age, sex etc. an average skeleton, medium, feeble or bulky muscles, insufficient, normal or excessive quantity of fat.

With regard to the aforesaid it is of interest to compare the respective figures of a very emaciated woman of 52 years of age with those of a woman of 30 with general obesity.

| Stature cm. | Circumference of Thorax cm. | Weight of Body kg. | Estimated Weight of | | | Dynamometric Effect lbs. Eng. |
|---|---|---|---|---|---|---|
| | | | Skeleton gr. | Muscles gr. | Skin & Fat gr. | |
| 160.2 | 79.5 | 39.5 | 8,404 | 12,726 | 2,738 | 113 |
| 158 | 119.0 | 90.0 | 8,072 | 18,798 | 47,685 | 211 |

The value for the skeleton in both women, it is seen, is about the same, but that for the quantity of muscles is in the first one considerably lessened, to which answers a diminished dynamometric effect. The greatest discrepancy is of course in the quantity of adipose tissue; in the emaciated woman the figure runs only to about 2.75 kg. of fat, whereas in the stout one it rises to more than 45 kg., i. e. just about half of the whole weight of her body. The whole weight of the body in the second woman of 30 years was 90 kg.; if we subtract from this the quantity of *excessive* fat, amounting to about 37 kg., we then get a normal weight of the body, with which the estimated quantity of bones and muscles as well as the dynamometric effect should really be compared.

The relative proportion of the figures for the weight of the skeleton, the muscles and the fat, gives us a basis for the control of our results. This control is possible if we assume that the weight of the intestines, brain and blood is varying but little; for the purpose the following formula has been used: $P-P\,k=O+M+D$. For illustration we may take the case of the young man mentioned first in this paper; the corresponding figures for him are: $72.5-(72.5\times 0{,}206)=13{,}141+33{,}073+11{,}338$. The coefficient $K_7=0.206$ is again but approximate and has to be verified on corpses. If the dimensions of the head and stature allow an estimate of the weight of the brain and intestines ($J$), then we get the following formula: $P-Pk_8=O+M+D+J$.

The comparison of the estimates of the different parts of the body here dealt with gives us a good idea of their mutual relation. The proportionate development of the skeleton, as passive part, and especially that of the muscles, as active part of the motor apparatus, is of much importance for the estimate of physical efficiency. But the estimate of the adipose tissue is also of value in view of the importance of this tissue in the economy of the body.

The proportional figures representing the numerical values of the different systems or parts may be calculated in per cent of the whole weight of body, the last one being taken as 100. The data obtained thus are seen in the following table:

| | Percentage of | | | |
|---|---|---|---|---|
| | Skeleton | Muscles | Skin and Fat | Remainder of Body |
| 12 Apprentices Average | 18.1 | 42.7 | 18.9 | 20.3 |
| Range of Variation | 14.4–21.1 | 39.9–50.0 | 15.1–23.0 | 15.2–23.7 |
| D. V., Gymnast | 18.1 | 48.0 | 13.1 | 20.8 |
| Woman, 52 yrs., emaciated | 21.3 | 32.2 | 6.9 | 39.5 |
| Woman, 30 yrs., fat | 9.0 | 20.9 | 52.9 | 17.2 |

These data nevertheless have to be considered with some discreetness. A better base for comparison is offered by the weight of the skeleton which, except in old age, is but little liable to changes. Using the weight of the skeleton as 100 the data appear as follows:

| | Weight of Skeleton = 100 | |
|---|---|---|
| | Percentage of Muscles | Skin and Fat |
| 12 Apprentices, Average | 235.8 | 104.8 |
| Range of Variation | 192.7–283.3 | 85.3–146.9 |
| D. V., Gymnast | 265.0 | 75.5 |
| Emaciated Woman | 151.4 | 32.6 |
| Fat Woman | 232.8 | 590.7 |

The writer is well aware of the fact that the methods set forth in this paper have their deficiencies and that the diverse coefficients will have to be calculated very carefully with regard to sex, age, stature etc. with due control on corpses.[1] He is well aware also that the qualities of the different tissues also demand consideration, as well as the results of other physiological tests. It will be desirable, for instance, to ascertain the quantity of the inspired air in relation to the weight of body and especially in relation to the quantity of muscles; but such details cannot be discussed at the present moment, they need considerable further study. For the present another important factor also has been omitted, namely the mental influence on muscular work; in other words we have not taken into consideration in connection with the tests of strength, the influence of exercise, training, experience and the mental tone of the subject at the time of the tests; this also must be reserved for future determination.

The method of ascertaining physical efficiency as here approached, has for its purpose the possibility of a completion of the psychotechnical examination, so that we may get a fuller insight into the physical and mental efficiency of any given individual, and will be useful or called upon in Life Insurance examinations, in Colleges and Sanataria, before a definitive choice of a profession, trade, line of sport, wherever a particular efficiency is required, and on other occasions.

The method will doubtless have to be perfected and differentiated to meet different wants, but the writer feels convinced that the measurements and determinations of physical anthropology—alone or in connection with psychology—will in future prove of considerable industrial and social utility.

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[1] In calculating the coefficients the writer profited by data found in the literature for the weight of different organs and systems of organs. According to *Vierordt* (Anat. Daten und Tabellen, 3rd ed. 1906, p. 44) the coefficients for adult persons would be: $k_1 = 1.15$, $k_2 = 1.22$, $k_3 = 6.6$; the first figure and the second one seems to be a little bit too low, the last one was just a little too high.