HEIGHT-WEIGHT INDEX OF BUILD

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In a recent publication (No. 272, Carnegie Institution of Washington, pp. 483–554) Professor C. R. Bardeen discusses the height-weight index of build in relation to linear and volumetric proportions and surface area of the body during post-natal development. In treating the height-weight index of build, he states: "The volumes of objects of the same shape but of different sizes vary as the cube of a given diameter through these objects. The volumes of the bodies of individuals of the same external form but of varying heights vary as the cube of the stature multiplied by a factor which is conditioned by the form of the body, as is conditioned by the form of a sphere. This factor, in the case of the relation of volume to stature, expresses the part of a space equal to the cube of the height occupied by the volume of the body. Thus, if we assume that 27c-inches is the volume of a pound, the volume of a man weighing 150 pounds would be 4050 cubic inches. If he were 68 inches tall the volume of his body would occupy $\frac{4050}{314{,}432}$ of a space equal to the cube of his height or, expressed in terms of percentage, 1.288 per cent. The body of an individual 50 inches tall and of the same shape would occupy the same proportions of the cube of his height, or 1.288 per cent of 125,000, 1610 cubic inches. At 27 inches to the pound this would mean a weight of 59.6 pounds. . . . (p. 488–9).

"As a height-weight index in the study of stature, weight, and body form, we have adopted the weight of the body in pounds divided by the thousandth part of the cube of the height in inches (p. 489). . . . To reduce the inch-pound index to the centimeter-gram index, multiply the former by 0.02768. To change the centimeter-gram index to the inch-pound index either divide it by 0.02768 or multiply it by 36.13. Rohrer, in 1908, clearly pointed out the value of the quotient obtained by dividing the weight in grams × 100 by the cube of the height in centimeters as an index of 'Körperfülle.'

Its value has been recognized by Martin in his Anthropologie (1914). It has, however, been but comparatively little used." So far Bardeen.

Despite the statistical argument for using the cube of height as a unit of measure of "build," "robustness," "Körperfülle," and despite the emphatic assertions of Martin (1914, p. 156) that this formula best represents the difference in the development of robustness, there are grave doubts as to the usefulness of this index.

During the past winter the writer has been engaged in analyzing an extensive series of measurements made on nearly 2,000,000 men, which includes, among others, weight and height. An analysis of the extensive tables seems to indicate that the normal changes in weight were accompanied by corresponding changes in height that were best compared with the square of the height rather than the cube. That is to say, for varying classes of weight and height the quotient obtained by dividing the weight by the square of the height gave more nearly a uniform quotient, strictly gave a smaller deviation from the modal ratio, than did either the ratio of weight to the cube of the height or weight to the first power of the height. The average deviation from the modal quotient was least when the square of the height was used, next larger when the cube of the height was used and largest when the first power of the height was used as a divisor.

The details of the above-mentioned procedure were as follows: A correlation table was used giving the relation of height to weight for 868,445 American men measured at the time of the Selective Draft. This is a table drawn up by the Surgeon General's Office, War Department, and not yet published. There were taken seventeen entries of varying height and weight with over 1000 individuals in each combination; the weight in each case was divided by the first, second, and third powers respectively of the height. The combinations are indicated in the following fractions, in which the numerator is the weight in pounds and the denominator the height in inches: $\frac{117}{63}, \frac{127}{63}, \frac{117}{65}, \frac{127}{65}, \frac{137}{65}, \frac{117}{67}, \frac{127}{67}, \frac{137}{67}, \frac{147}{67}, \frac{157}{67}, \frac{127}{69}, \frac{137}{69}, \frac{147}{69}, \frac{157}{69}, \frac{147}{71}, \frac{157}{71}, \frac{167}{71}$. The quotient for the modal class of $\frac{137}{67}$ is, in the case of the 1st power of 67, 2.045; 100 $\times$ the quotient obtained by using the 2d power as a divisor is 3.052; and 10,000 $\times$ the quotient obtained by dividing 137 by the 3d power of 67, is 4.555. The deviation of each of the separate quotients was secured from 2.045, 3.052, and

4.555, respectively. This gives for the column of 1st power divisor the sum of the deviations, disregarding signs, as 2.587 which divided by 2.045, gives 1.265, the relative variability of the 16 group combinations, as obtained by using the first power of the height as a divisor. By using the 2d power of the height as a divisor the corresponding figure is 1.146, and by using the 3d power as a divisor it is 1.237. Hence, using the 2d power of the height for the outlying groups gives the smallest deviation from the condition found in the central or modal group.

Again, 5 extreme combinations were tested in relation of weight to height. These are as follows: $\frac{107}{61}$, $\frac{117}{61}$, $\frac{167}{73}$, $\frac{177}{73}$, $\frac{167}{75}$. Each of these combinations was found in several hundred individuals. Using the method employed for the 17 preceding combinations, we get an average relative deviation by using the first power of the height of .606; by using the 2d power, .230; by using the 3d power, .356. Thus, again, the 2d power gives the smallest average relative deviation from the modal combination of $\frac{137}{67}$. It appears that the use of the 2d power gives an average deviation that is under 50 per cent of that obtained by using the 1st power, and one which is much less than the relative deviation obtained by using the 3d power of the height.

TABLE 1

SHOWING (*a*) THE WEIGHT AND HEIGHT FOR WHICH THE HEIGHT-WEIGHT INDEX IS CALCULATED; (*b*) THE CORRESPONDING INDEX WHEN THE 1ST POWER OF HEIGHT IS USED (*c*) THE CORRESPONDING INDEX WHEN THE 2D POWER OF HEIGHT IS USED; (*d*) THE CORRESPONDING INDEX WHEN THE 3D POWER OF HEIGHT IS USED.

(*a*)	(*b*)	(*c*)	(*d*)
$\frac{117}{61}$, $\frac{117}{66}$, $\frac{117}{70}$	1.92 1.77 1.67	3.14 2.69 2.39	5.16 4.07 3.41
$\frac{127}{62}$, $\frac{127}{67}$, $\frac{127}{71}$	2.05 1.90 1.79	3.30 2.83 2.52	5.33 4.22 3.55
$\frac{137}{63}$, $\frac{137}{68}$, $\frac{137}{72}$	2.18 2.01 1.90	3.45 2.96 2.64	5.48 4.36 3.67
$\frac{147}{64}$, $\frac{147}{69}$, $\frac{147}{73}$	2.30 2.13 2.01	3.59 3.09 2.76	5.60 4.47 3.78
$\frac{157}{64}$, $\frac{157}{69}$, $\frac{157}{73}$	2.45 2.28 2.15	3.83 3.30 2.95	5.99 4.79 4.04
$\frac{167}{65}$, $\frac{167}{70}$, $\frac{167}{74}$	2.57 2.39 2.26	3.95 3.41 3.05	6.08 4.87 4.12

In additional respects the use of the 2d power as a divisor appears to give a better result than the use of the 2d or 3d power. As is well known, shorter men are more robust than tall men. By the use of the 1st power, the increase in robustness of abmodally short men over abmodally tall men is about 10 per cent; with the 2d power, it is about 30 per cent; with the 3d power it is about 50 per cent. It is quite clear that the shorter men are not 50 per cent more robust on the average than the tall men, though opinion may be divided as to whether a 30 per cent increase or a 10 per cent increase more nearly represent the general impression obtained by observing a number of men averaging 4 inches above the mean stature, as compared with a number of men averaging 5 inches below the mean stature. (Table 1.)

Were short people and tall people of the same shape, then it would be true that their weight would be expected to vary with the cube of any one dimension. But this assumption is not true. Were human bodies cylinders of the same diameter and of varying height, then it is clear that their variations in form would, be represented by variations in height alone. It is true that the human body, especially the trunk, approximates the condition of a cylinder whose vertical axis is more variable than the transverse axis.

Were human bodies cylinders of the same height but varying in transverse axis, then the differences in volume would be best indicated by the square of the transverse axis. The variations in robustness of persons of the same height are fairly accurately measured by the square of the transverse diameter or indeed of the chest circumference.

Were the human body a cube, sphere, or prism of constant proportions, then obviously the volume would vary as the cube of any one dimension. But this assumption is again only a rough approximation of the truth. As a matter of fact, the actual conditions are somewhere between that of a cylinder of constant diameter but of varying height and of a prism of constant proportions, and hence we may expect the proper denominator in the weight-height index to be between the first and the third power of the height. Empirically, the second power of the height proves most suitable.

Our empirical results are not new. On the occasion of the study by B. A. Gould, "Investigations in the Military and Anthropological Statistics on American Soldiers," 1869, especially on pp. 404–18, is found an illuminating discussion of the proportions of the body. In considering the relation between height and weight as derived from extensive tables of measurements taken of men at demobilization after the Civil war, he says, "We are irresistibly led to the singular and interesting discovery that the mean weights, at least within the limits of the present researches, appear to vary strictly as the square of the statures." And again, "No reasonable doubt seems admissible that this is the true law of normal variation in weight for statures within our limits, and we are thus led to the inference that the product of the ratios of increase in the breadth and thickness of the body is, on the average, equal to the simple ratio of the increase in length."

But Gould goes further and has discovered that: "The fact here elicited had been observed by Quetelet who says that the weights of individuals of different heights who have attained their full development are approximately as the squares of their statures." Gould further points out that even during the period of growth subsequent to the age of 16 years, the increase in weight appears nearer to the second than to the 2½ power of stature (proposed by Quetelet for the period of development), although when extended to the earliest years of life, it evidently requires modification. Gould indicates that this relation holds also for negroes and probably also for all races of men.

It is highly desirable to determine the law of relation of height to weight for the period of development from birth on. Quetelet (Sur l'homme, II, 53–61) says, "During the period of development the squares of the weights of different ages are as the 5th power of the stature." This conclusion he had obviously reached empirically. It is quite certain that Quetelet's empirical rule has a far better basis that the theoretical assumptions of Rohrer and Bardeen, and it is desirable to determine again on the basis of more extensive measurements, and by the method of Gould the proper relation between weight and stature in growing children. The final conclusion can, however, not be drawn until the quantitative series of index of build or robustness has been checked by the judgment as to relative "chubbiness" of a number of growing children.

As a contribution to this subject, there is given in the accompanying table a study of the relation of weight to stature based on the data obtained in Table A of Bardeen's paper. This table gives the weight and stature of male infants aged 1 to 30 months. In our table, we have taken the age in the odd months from 1 to 19, and then ages 20, 25, and 30 months. The corresponding weight in grams and the stature in centimeters are taken from Bardeen. In column 4 is given the ratio of weight to stature; in column 5, the ratio of weight to the square of stature; in column 6, Bardeen's index of build, which is the ratio of weight to the cube of stature expressed in English units of measure. In Column 7 is given the results of dividing the weight by the height raised to the 2½ power. A comparison of columns 4, 5,

TABLE A (FROM BARDEEN, TABLE A)

1	2	3	4	5	6	7
Age Months	Weight Grams	Height Centimeters	$\frac{\text{Weight}}{\text{Height}}$	$\frac{\text{Weight}}{\text{Height}^2}$	$\frac{\text{Weight}}{\text{Height}^3}$ (Rohrer's Index)	$\frac{\text{Weight}}{\text{Height}^{2\frac{1}{2}}}$
1	3,451	50.6	68.201	1.3479	0.962	.18948
3	4,840	55.6	87.051	1.5657	1.017	.20997
5	5,868	60.5	96.991	1.6031	0.957	.20611
7	7,017	64.4	108.959	1.6919	0.949	.21083
9	7,579	67.4	112.448	1.6684	0.894	.20321
11	8,412	69.6	120.862	1.7365	0.901	.20815
13	8,479	70.7	119.929	1.6963	0.867	.20174
15	8,825	73.0	120.890	1.6560	0.820	.19382
17	9,810	76.0	129.079	1.6984	0.808	.19482
19	9,818	76.1	129.014	1.6954	0.805	.19434
20	9,973	77.5	128.684	1.6604	0.774	.18861
25	10,542	80.0	131.770	1.6472	0.744	.18416
30	11,407	83.7	136.284	1.6282	0.703	.17797

6, 7, reveals some interesting differences. In column 4 the index of build of the infant doubles from 1 month to 30 months. That is to say, that on the average children become twice as chubby at 2½ years ss they were at 1 month of age. This is manifestly not in accordance with experience. Column 5 shows an increase in chubbiness to the 11th month which is the age at which infants ordinarily begin to walk. There is then a decrease in chubbiness, with some irregularities in the course, to the 30th month and this decrease amounts to about 5 per cent. Rohrer's index, which Bardeen adopts, shows a decrease in chubbiness beginning after the 3d month and decreasing fairly regularly, the total decrease being to the 30th month about 30 per cent. This again does not seem to agree with common observation. One cannot say that on the average babies at 2½ years have lost ⅓ of the chubbiness that they had at 3 months. Column 7 shows an increase in chubbiness to the 7th month with a fairly high index of robustness at the 11th month, followed by a gradual decline to the 30th month. The falling off from the 11th to the 30th month is something over 10 per cent.

On the ground of common observation it would seem that the indices calculated in columns 4 and 6 must be rejected as not representing properly the state of affairs, but between columns 5 and 7 there is not a great deal of choice. A decision as to which of these is preferable would have been made by the opinion based on experience of mothers, child-welfare organizations, and possibly pediatrists. The greater ease of calculating the indices of column 5 makes these indices preferable, other things being equal.

Table B is based upon Table E of Bardeen, which in turn is based on data from Quetelet, 1870, and gives the weight in kilos and stature

TABLE B (FROM BARDEEN, TABLE E)

1	2	3	4	5	6	7
Age Years	Weight Kilos	Height Centimeters	$\frac{\text{Weight}}{\text{Height}}$	$\frac{\text{Weight}}{\text{Height}^2}$	$\frac{\text{Weight}}{\text{Height}^3}$	$\frac{\text{Weight}}{\text{Height}^{2\frac{1}{2}}}$
Birth	3.1	50.0	62.00	1.2400	.2480	.17536
1	9.0	69.8	128.895	1.8473	.2646	.22111
2	11.0	79.1	139.064	1.7581	.2223	.19767
3	12.5	86.4	144.676	1.6744	.1938	.18015
4	14.0	92.7	151.024	1.6291	.1757	.16921
5	15.9	98.7	161.094	1.6322	.1654	.16429
6	17.8	104.6	170.172	1.6269	.1555	.15907
7	19.7	110.4	178.442	1.6163	.1464	.15383
8	21.6	116.2	185.886	1.5998	.1377	.14837
9	23.5	121.8	192.939	1.5841	.1301	.14353
10	25.2	127.3	197.957	1.5551	.1222	.13783
11	27.0	132.5	203.772	1.5379	.1161	.13360
12	29.0	137.5	210.909	1.5339	.1116	.13081
13	33.1	142.3	232.607	1.6346	.1149	.13703
14	37.1	146.9	242.552	1.7192	.1170	.14191
15	41.2	151.3	272.307	1.7998	.1190	.14632
16	45.4	155.4	292.149	1.8800	.1210	.15081
17	49.7	159.4	311.794	1.9561	.1227	.15493
18	53.9	163.0	330.675	2.0287	.1245	.15890
19	57.6	165.5	348.036	2.1030	.1271	.16347
20	59.5	167.0	356.287	2.1335	.1278	.16509
25	66.2	168.2	393.579	2.3400	.1391	.18042
30	66.1	168.2	392.052	2.3253	.1379	.17908

in grams from birth and at the end of each year subsequent up to 20 years, and also at 25 and 30 years. In this table column 4 gives the ratio of weight divided by stature. It will be seen that the index of build calculated in this way increases regularly from birth on and is over 6 times as great at 25 years as at birth. Obviously this ratio is not a good index of build. Column 5 gives the weight divided by the square of the stature. According to this index the baby at birth stands relatively low in chubbiness, has increased in this respect up to the end of the 1st year, and thereafter slowly declines in chubbiness to the 12th year. At the 25th year, the index of chubbiness or robustness is double that at birth and 50 per cent greater than at 12 years. This seems somewhat to exaggerate the extent of the filling out of the form from preadolescence to maturity and certainly to overweight the chubbiness or robustness of the average adult young man over that of the baby of one year. Column 6 gives Rohrer's index for each year. This index increases from birth to one year and then diminishes gradually to 12 years of age, after which it increases to 25 years of age. The increase from 12 years to 25 is something over 20 per cent. The index for the adult (.14) is about half that of the child of one year (.26). This, I think, would strike the average observer as somewhat exaggerating the robustness or chubbiness of the infant. Column 7 gives the weight divided by the stature raised to the power 2½, from Quetelet. Here we have a sharp increase in robustness from birth to one year, slightly declining to 12 years and then increasing to 25 years. The increase from 12 to 25 years is about 30 per cent. The robustness at 25 years is about 20 per cent less than at one year and corresponds rather closely with the child of 3 years. Owing to the circumstance that Quetelet's index does not show as great variations at the different ages as that of Rohrer or even that which involves the square of the stature, it seems probable that it accords more closely than either with the truth of the case in a developmental series, such as was considered in Table B. Also Quetelet's index brings out the proper relation between chubbiness of the

TABLE C. DEVIATIONS FROM 12-YEAR RATIO (BASED ON TABLE B).

	$\frac{\text{Weight}}{\text{Height}}$	$\frac{\text{Weight}}{\text{Height}^2}$	$\frac{\text{Weight}}{\text{Height}^3}$	$\frac{\text{Weight}}{\text{Height}^{2\frac{1}{2}}}$
12-yr. ratio	210.909	1.5339	.1116	.13081
Birth	148.909	.2939	.1364	.04455
1 yr.	82.014	.3134	.1530	.09030
2	71.845	.2242	.1107	.06686
3	66.233	.1405	.0822	.04934
4	59.885	.0952	.0641	.03840
5	49.815	.0983	.0538	.03348
6	40.737	.0930	.0439	.02826
7	32.567	.0724	.0348	.02362
8	25.023	.0659	.0261	.01756
9	17.970	.0502	.0185	.01272
10	12.952	.0212	.0106	.00702
11	6.137	.0040	.0045	.00279
12	0.000	.0000	.0000	.00000
13	21.698	.1007	.0033	.00622
14	31.643	.1853	.0054	.01110
15	61.398	.2659	.0074	.01551
16	81.240	.3461	.0094	.02000
17	100.885	.4222	.0111	.02412
18	119.766	.4948	.0129	.02809
19	137.127	.5691	.0155	.03266
20	145.378	.5996	.0162	.03428
25	182.670	.8061	.0175	.04961
30	181.143	.7914	.0263	.04827
Total dev.	1677.035	6.0534	.8636	.68476
Av. dev.	76.229	.2752	.03925	.03113
12-yr. ratio	.3614	.1794	.3517	.2379

infant of one year and the adult of 25 which is not properly brought out by using the square of the stature as a divisor.

Finally there is added in Table C, for comparison, the mean deviation of the indices in columns 4, 5, 6, and 7 for Table B. For the purpose of determining the average deviation the index at 12 years is taken as the basal line.

Table C shows that the average deviation from the 12-year ratio of the ratios obtained by dividing weight by 1st, 2d, 3d, and 2½th power of height respectively for each year prove to be smallest, on the average, when the 2d power is used as the divisor than when any other power is so used. The next smallest average deviation is found when the 2½th power is used as the divisor and next when the 3d power is used. The 1st power gives the largest average relative deviations. The conclusion from Table C then is that for the entire developmental series from birth to 30 years the ratio of weight to the 2d power of the height gives a better index of build than any other ratio.

To summarize, the best height-weight index of build is not the ratio of weight to the cube of height but some other ratio. For the first 30 months of development, it is doubtful whether the best index of build is that proposed by Quetelet (weight divided by height to the 2½th power) of the weight divided by the square of the height. The decision must rest on the agreement between the index and common observation as to "chubbiness." For the entire developmental series from birth to 30 years it is doubtful whether weight divided by the square or the 5/2d power of the height gives the most satisfactory index of build. But for young adult males the best index of build is apparently obtained by dividing weight by the square of stature.

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