LENGTH AND WEIGHT

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SYNOPSIS OF SIMILAR STUDIES

Methods for predicting the normal weight for a given person from one or more of his physical measurements have been proposed from time to time, but have surprisingly seldom been tested simultaneously on the same series of healthy individuals. Even a brief test will reveal astoundingly diverse predicted weights for the one and the same subject, according to the formula applied. The conclusion seemed fair therefore that more study was necessary to determine which of these competing "standards" was most worthy of the name.

The procedure chosen to test existing weight standards was simple though tedious. It has been described elsewhere in detail. In brief, we applied a given standard to a given case, then took the difference between this theoretical weight and the subject's actual weight (which last was assumed to be the correct basis), and translated this difference in pounds from the observed weight into a percentage deviation or error. The formula was
$$\frac{(PW - W) \times 100}{W}$$
 For instance, if the predicted weight was 120 lbs. and the weight 100 lbs., the difference of 20 lbs. was recorded as a 20% prediction error. By summing the errors thus calculated, and dividing through by the number of subjects measured we secured the average error of the prediction standard A. Standards B, C, etc. were similarly tested in turn.

In 1917 twenty healthy and active male medical students, aged 22-34 years, were weighed and measured and their weights predicted by the following formulae:

<i>U. S. Army:</i>	H. 64 inches	average W. 128 lbs.	H. 69	W. 148
	65	130	70	155
	66	132	71	162
	67	134	72	169
	68	141	73	176

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<i>Bornhardt's:</i>	$W \text{ (in k.)} = H \text{ (in cm.)} \times \text{Chest-girth (in cm.)} \div 240.$
<i>Broca's:</i>	$W \text{ (in k.)} = H \text{ (in cm.)} \text{ minus } 100.$
<i>Guthrie's:</i>	$W \text{ (in lbs.)} = 110 + (5.5 \times \text{number of inches of } H \text{ above } 60).$
<i>Medico-Actuarial:</i>	This American insurance table is too long to quote here.
<i>Von Noorden's:</i>	$W \text{ (in k.)} = H \text{ (in cm.)} \times 0.455.$

The relative accuracy of these six methods for estimating normal weight was found to be as follows:

1. Bornhardt's:	5.5% error	4. Guthrie's:	9.5
2. U. S. Army:	7.33	5. Broca's:	13.1
3. Medico-Actuarial:	7.35	6. Von Noorden's:	19.7

In 1920 the theory and practice of our trial-technic were discussed in greater detail, and the evidence enlarged by the addition of data on 229 U. S. soldiers, aged 18-34, who had been active in service and under our observation for a number of months. These results confirmed the preliminary series, and the consolidated 249 subjects showed the following mean errors in prediction by the several standards:

1. Bornhardt's:	6.0%	4. Guthrie's:	11.5
2. Army:	8.3	5. Broca's:	14.6
3. Insurance:	8.6	6. Von Noorden's:	23.4

Further analysis of the data obtained by Bornhardt's method showed no material variation in accuracy at varying ages, weights, heights and chest-girths.

Finally the conclusion was offered that just as Bornhardt's rule (based on height and chest-girth) as a rough measure of surface seems both theoretically and empirically the best guide so far offered for guessing weight, so we expected that experiment would discover an even better rule (based on height, chest and a third factor) expressing a rough measure of volume. For fundamentally weight must be proportional, not to length nor surface, but to cubic mass.

In March 1921 were published the results of experimental efforts to improve Bornhardt's rule by altering it in ten different ways. For example, it was made an expression of cubic contents instead of surface by multiplying the height by the *square* of the chest circumference, and by multiplying the chest by the square of the height. These efforts were fruitless.

Next, in April 1921, were published extensive historical and theoretical considerations of the "essential stature" (stem-length or trunk-length) as a substitute for the full stature, and actual new observations

along this line¹ were presented in June 1921. In the latter article were examined two of the most promising of these tables of weight in reference to the essential height, namely those given in the recently available books by Von Pirquet and by Dreyer and Hanson. It was found that the weights of thirty-two healthy males, aged 13 to 52 years, were predicted with the following errors, according to: 1. Dreyer and Hanson: 4.47%; 2. Bornhardt: 8.0%; 3. Von Pirquet: 17.0%.

OEDER'S UPPER LENGTH AND WEIGHT FORMULA

Oeder in 1908 stated that he had been searching for a weight formula during the past twenty-four years of study of 23,400 patients.

In 1909 and 1915 he reported observations on the relation of weight to what he called the Proportional-Length (PL), which was twice the "Oberlänge," i. e. the distance from the vertex to the theoretical center of the symphysis.

The landmark for this measurement he took as the upper edge of the symphysis as found by palpation, and to this measurement he added two centimeters, which he had estimated to be half the usual vertical thickness of the bone. The result which may be translated as Upper Length, and which we shall abbreviate as UL, he believed to be not more than one centimeter in possible error, and this error he regarded as of no account.

He then modified Broca's simple and much used formula, W (in k.) = H (in cm.) minus 100, by substituting for the Height the Proportional Length ($2 \times UL$), thus: W (in k.) = PL (in cm.) minus 100.

As male *subjects* for study he used patients who came to him, whether under or overweight, generally the latter; and used only those whose growth he considered complete, namely those at least 24 years old and 135 cm. tall. After measuring them he predicted by his formula what their weights should be when they should have been treated till in a "normal state of nutrition."

The *signs of the normal state of nutrition* he laid down as follows:

1. Invisibility of the intercostal spaces near the sternum;
2. Invisibility of the intertendon spaces on the backs of the hands;
3. Equal level of abdomen and chest when supine;
4. Abdominal fat layer of 2 to 3 cm. as measured (to nearest half centimeter) with calipers, at the base of a fold picked up just to the right of the navel (Indexstelle, Vergleichsstelle). For this "Fettpolstermessung" he found nearly the

¹ In print.

same figures (2-3 cm., average for men 2.5 cm., for women 2.7 cm.) in normals of both sexes and all adult ages (men 24 and over, women 21 and over). While granting that the distribution of the fatty layer varies slightly in the sexes and at different ages, he found the variation so small that "the normal state of nutrition can generally be defined fairly accurately for any subject by the same measurement, the Index-fettpolsterdicke alone."

The nutrition he would often consider normal, even in the absence of one or the other of these signs, most frequently number 2.

When these "central-normal-inspection-signs" seemed to him to indicate that normal nutrition had been reached, he recorded the patient's weight as the "central-normal-weight" and compared this actual weight (Istgewicht) both with the predicted weight according to Broca's formula and with the predicted weight according to his own (Formelgewicht). He concluded that Broca's gave a greater error than his own, which he maintained to "hold true in 97% of men."

CRITICISM BASED ON THEORY

In principle, Oeder's measurement from vertex to midsymphysis ("Oberlänge") may be presumed to be most nearly comparable to the dorsal measurement from vertex to tip of coccyx, i. e. the "Stamm-länge II" advocated by Dreike 1895 and others whose work has been reviewed in our earlier paper. This measurement however we have not recorded, and can therefore make no exact comparison.

The only dorsal measurement which we have noted is the stem-length, and to this too Oeder's measurement bears a close relation, and like it might be expected to afford a basis for a weight-for-"length" formula more accurate than the time-honored weight-for-stature formulae.

The only writers who have discussed the utility of Oeder's formula so far as we know are Zickgraf 1912 and Brugsch 1920. The former is mentioned by Oeder as having given support, but we have not found that writer in the place to which Oeder refers. Brugsch recognized that some value in rendering medical judgment more objective may lie in Oeder's criteria of the normal state of nutrition, but he disputed the contention that patients who exhibit these criteria are to be considered as necessarily having normal weights. He asserted rather that "normal weight is average weight," that Oeder's subjects were not normals but mostly overfed adults of middle age, and that therefore his formula made young adults seem too lean.

For our part, while granting, as said above, certain interesting principles in Oeder's work, we also feel certain doubts as to the methods he used in developing these concepts:

1. We question, like Brugsch, the propriety of accepting as normals subjects admittedly abnormal at the start, and only presumptively rendered approximately normal.

2. This limited class of persons was further limited, as Oeder admitted, by considering only the *central* normals, i. e. those approaching neither upper nor lower borders, but "in approximately complete normality." This restriction is open to argument in view of the repeated evidence in the literature that the normal average is *not* a central figure (or curve), but that at the most the average is a dominant lying within a normal zone.

3. Oeder juggled the Oberlänge by adding or subtracting anywhere from 2 to 3.5 cm. to the measurement noted on subjects who seemed to him to have short or long necks. This procedure resembles that of artists such as Alberti ca. 1400, Leonardo da Vinci and Dürer ca. 1500, and even Schadow ca. 1800, who measured such individuals or classical statues as appealed to their ideals of beautiful proportions, and then constructed arbitrary "canons."

4. Oeder's method of assembling his numerical data seems erroneous from the viewpoint of statistics. For he added the actual weights of all his subjects, and again all the predicted weights, took the difference of these two sums and divided that difference by the number of subjects. The resulting average was incredibly small, but is devoid, we believe, of all value biometrically. For by adding the predicted weights directly, those which were too high balanced those which were too low, and so yielded a fictitious semblance of accuracy. This method may mask, for example, such a reduction ad absurdum as the following:

If in his case 1 his Formula-weight was 10 k. *above* the actual weight (and this may have been the fact for all we can tell from his article), while if for his case 2 the Formula-weight was 10 k. *below* the observed weight; and if in case 3 the predicted weight was 20 k. too high while in case 4 it was 20 k. too low; and so forth down the list; yet at the bottom of the columns the sum of these wild predictions would still equal the sum of the "Istgewichte" and the formula would apparently be perfect!

5. The categorical insistence that his figures "zwingen absolut," while complaining that nobody seems to believe him.

6. Definite location of the landmark is difficult in even moderately fat persons, painful in the fat, and incidentally sufficiently objectionable on grounds of delicacy to restrict its application in women.

CRITICISM BASED ON FACT

To test Oeder's work an unusual measurement is required. This we had not noted at the time of our preceding paper, but have since been able to record on twelve of the persons there studied. Despite this small number of observations, their indications seem so uniform that they seem worth reporting in Table I, as a guide for any further work with this measurement, either in reference to weight-prediction, or in reference to the abnormal endocrine ratio between the upper length and the stature.

UPPER-LENGTH AND PREDICTED WEIGHT

Case	UL Upper-Length Vertex-Midsymphysis			PL (2×UL)	PW (Oeder)	E %	PW (Broca)	E %
	Direct Meas.	Indirect Meas.	Mean		k		k	
H. G.	91	92	91.5	183	83	+ 8	81	+ 5
A. M. W.	94	93	93.5	187	87	0	86	- 1
D. T. V.	89.5	88	88.8	178	78	+11	77	+10
W. R.	95	94.5	94.8	190	90	+ 6	89	+ 5
E. B. B.	87	87	87	174	74	+17	79	+24
F. G. B.	86.5	87.5	87	174	74	+ 8	78	+13
F. G. T.	87	86	86.5	173	73	+15	71	+11
H. F. R.	88	90	89	178	78	+13	75	+ 9
H. B. W.	88.5	87.5	88	176	76	+23	75	+21
J. C. W.	89.5	88.5	89	178	78	+10	84	+18
E. H. C.	86	86	86	172	72	+ 3	73	+ 4
A. A. H.	89	88	88.5	177	77	+13	71	+ 4
Sum						127		125
Mean						10.6%		10.4%

Explanation of the column headings in the Table: The term Upper Length is a literal translation of Oeder's Oberlänge, and has been here abbreviated as UL. He does not state the position of his subjects during mensuration nor whether his measurement was direct or indirect. Direct measurement of the UL was made by us with the subject recumbent on a table, with the vertex against a wall, and the head so placed that the eyes looked straight up at the ceiling, or in more specific anatomical words so that an imaginary line from the lower edge of the orbit to the external auditory meatus was vertical to the table. The legs lay flat. The cephalad edge of the symphysis was palpated and a mark made on the skin. A tape was stretched from this mark to the wall, and to the distance read off were added 2

cm., following Oeder's rule, to get the UL or distance vertex-midsymphysis. Indirect measurement of the UL was obtained by subtracting from the stature the Unterlänge, or distance midsymphysis to soles. To take this lower length, the subject, without shoes, stood heels together against a wall instead of lying down, the tape was dropped from the mark at the top of the symphysis, the distance to the floor between the feet was read off and two centimeters were deducted.

Interpretation of the data in Table I is offered as follows:

The reliability of Oeder's measurement, merely as to technique (quite apart from the value of the derived formula), is seen by comparing the direct with the indirect columns. There the value is seen to vary by as much as 2 cm. or on the average by one centimeter. This confirms Oeder's view of the size of the technical error. Besides varying in size, the error varies in direction, that is, the indirect measurement was equal to the direct in 2 cases, larger in 3 cases, and smaller in 7 cases. Judging by this majority of seven, the tendency seems to be for the subject when standing to stretch out the lumbar spine more than when recumbent with legs flat, and thus to tilt the symphysis upward and yield a shorter upper length.

The importance of this error is very likely as Oeder maintained, "of no account," as regards his formula. At the same time a more constant measurement would be desirable if feasible, and one such feasible method would be to make a practice of (1) taking upper length directly, and (2) putting the subject in a constant position, preferably flat on his back with knees bent up and dorso-lumbar spine relaxed sufficiently to obliterate the lumbar curve so that the observer's hand cannot be slipped between the subject's back and the table. This change in position tips the pubis toward the head and so shortens the direct measurement, in fact by about four per cent in a few observations not here listed. This divergence we believe to be worth avoiding. Whether it be preferable to record the distance vertex-mid-symphysis with the spine flexed or flattened is open to argument. The latter position we find to yield more constant duplicates (at least on the few persons observed), and therefore believe it to be preferable.

The direction of the error in Oeder's formula seems to be constantly high; or, as Brugsch has put it, makes young adults seem too lean.

The accuracy of weight-prediction by Oeder's formula, as tested on our normal young adults is seen (from the Table here, from Table 3 of our earlier paper, and from untabulated calculations from applying the insurance figures to these test cases) to be unsatisfactory.

A summary of the percentage prediction error by the different methods discussed in the preceding paper and here, is given below listing first the weight-prediction standard which guessed nearest to fact:

PREDICTION ERROR, STATED AS MEAN PER CENT DEVIATION FROM ACTUAL WEIGHT

1. Dreyer and Hanson.....	3.9	4. Broca.....	10.4
2. Bornhardt.....	6.4	5. Oeder.....	10.6
3. Medico-Actuarial.....	7.9	6. Von Pirquet.....	14.5

REFERENCES

- Brugsch, T.: *Zeitschr. f. exper. Path.*, 30 June 1917, xix, 1.
 Brugsch, T.: *Zeitschr. f. exper. Path.*, 26 Aug. 1920, xxi, 271.
 Dreyer, G., and Hanson, G. F.: "The Assessment of Physical Fitness," Cassell, London, 1920; reprinted by Hoeber, New York, 1921.
 Gray, H., and Gray, K. M.: *Normal Weight*, Boston Med. and Surg. J., Dec. 27, 1917, clxxvii, 894.
 Gray, H., and Mayall, J. F.: *Body Weight in 229 Adults, Which Standard is the Best?*, *Archives Internal Medicine*, Aug. 1920, xxvi, 133.
 Gray, H., and Allen, F. B.: *Bornhardt's Formula*, Boston Med. and Surg. J., March 31, 1921, clxxxiv, 334.
 Gray, H., and Root, H. F.: *Stem-Length and Trunk-Length*, Boston Med. and Surg. J., Apr. 28, 1921, clxxxiv, 439.
 Gray, H., and Root, H. F.: *Weight Prediction by the Formulae of Bornhardt, of von Pirquet and of Dreyer*, Boston Med. and Surg. J., July 7, 1921.
 Oeder, G.: *Deutsch. med. Woch.*, 11 June 1908, xxxiv, 1079.
 Oeder, G.: *Zeitschr. f. Versicherungsmedizin*, 1909 (Not seen).
 Oeder, G.: *Med. Klinik*, 1909, iv, 461.
 Oeder, G.: *Med. Klinik*, 1909, v, 1225.
 Oeder, G.: *Berl. klin. Woch.*, 26 April and 3 May 1915, lii, 433 and 466.
 Oeder, G.: *Zeitschr. f. exper. Path.*, 26 Aug. 1920, xxi, 263.
 Von Pirquet, C.: *Zeitschrift f. Kinderheilk*, 1913, Orig. vi, 256.
 Von Pirquet, C.: *Zeitschrift f. Kinderheilk*, 1916, Orig. xiv, 211; also reprinted in his book "System der Ernährung," Berlin, 1919, ii, 284.
 Von Pirquet, C.: *Zeitschrift f. Kinderheilk*, 1918, xviii, 220.
 Von Pirquet, C.: *Oesterreichischen Rundschau*, 1920, lxiii, page 10 of reprint.