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HEIGHT, WEIGHT, AND THE ASSESSMENT OF OBESITY IN CHILDREN

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There has been recent concern about the observed alteration over the past few decades of the distribution of weight for height in both adults and children and, in particular, about the increasing proportion of 'heavy' children (Scott, 1961; Khosla and Lowe, 1968). Increasing amounts of overweight are known to be associated with increasing morbidity and mortality rates for adults of a given age and sex (Kannel, LeBauer, Dawber, and McNamara, 1967) and several studies have shown that excessive weight in childhood is likely to persist (Mullins, 1958; Lloyd, Wolff, and Whelan 1961; Asher, 1966; Eid, 1970). Moreover, it has recently been found that overweight children may experience more illness than other children at a very early age (Hutchinson-Smith, 1970; Tracey, De, and Harper, 1971).

Extreme overweight will usually indicate some degree of obesity, but it is evident that measures of height and weight alone cannot provide an accurate measure of adiposity as they will also reflect the size of the other body compartments. Several indices derived from height and weight have been shown to correlate highly with measures of adiposity, such as skinfold thickness, body density, and fat content calculated by subtraction of lean body mass from total body weight, lean body mass being derived from potassium-40 measurements (Billewicz, Kemsley, and Thomson, 1962; Forbes, 1964; Khosla and Lowe, 1968; Evans and Prior, 1969). The correlation coefficients are of the order 0·8 but may be lower for some values of height, which led Florey (1970) to suggest that height and weight alone do not give an adequate estimate of adiposity. Despite their limitations, however, the ease and relative accuracy with which measurements of height and weight can be taken make them useful measures for epidemiological studies and screening programmes.

From an examination of weight distributions and measures of adiposity it is usually assumed that in adults the distribution of obesity is independent of height (Clements and Pickett, 1954; Billewicz *et al.*, 1962; Evans and Prior, 1969; Benn, 1971). Attention has, therefore, focused on a weight for height index which also has this property. However, this assumption of height independence may not be true for adiposity in children. Wolff (1955), in a review of the literature, cites several studies which show that the height of obese children is above average for their age, and his own study supports this view. Garn and Haskell (1960) also suggest that there is a positive association between height and obesity, demonstrating a positive correlation between thoracic fat thickness and stature at each age between about 3 and 13 years. More generally, it seems desirable to retain as much information as possible in any analysis by treating height and weight as separate variables in order to study their joint effect on other measurements.

Functions of height and weight may be used in a number of ways and different functions will be appropriate in different situations, depending on which factors these measurements are being used to assess. Without the corresponding analyses, there can be no objective grounds for choosing one particular function of height and weight as, for example, a morbidity indicator.

The present paper does not attempt to answer this kind of question but simply to study the interrelationships of the three most commonly used weight for height functions, in a population of children. Although some previous work has been done along these lines (see, for example, Benn, 1971), it has used measurements made in adult populations.

METHOD

Measurements of height and weight were available for 13,498 children in the National Child Development Study (Davie, Butler, and Goldstein, 1972). This was set up in 1965, as a follow-up to the 1958 Perinatal Mortality Survey, to trace all children then living in England, Wales, and Scotland who had been born during the week of 3–9 March 1958. Analysis of the height and weight data was limited to those

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children who had been measured between April and December 1965 (95% of all children in the study) so that the age range of the sample would not be too large. The children's heights were measured, without shoes, to the nearest inch, and weight, in underclothes, to the nearest pound.

The three types of classification investigated are:

1. weight centiles at each height;
2. relative weights .. $\frac{\text{Observed weight}}{\text{Mean weight for height}}$
3. power indices of the type $\frac{\text{Weight}}{(\text{Height})^n}$

Results

Weight Distribution for Different Height Groups

Boys and girls were considered separately throughout the analyses, and the population was divided into eight height groups. Table I shows weight centiles for each height group.

When mean or median weights and heights are calculated within different age groups it has been found (Ehrenberg, 1968) that the weight-height relationship exhibits some curvature, and it has also been shown that there is increasing variance of weight with increasing height. However, both the curvilinearity and heteroscedasticity can be largely eliminated by a log transformation of weight. Similarly, if the mean (or median) weights are calculated for children at each height regardless of age, it is found that there is a linear relationship between log (mean or median weight) and height. Figure 1 shows this and also demonstrates that this no longer holds when age is taken into consideration.

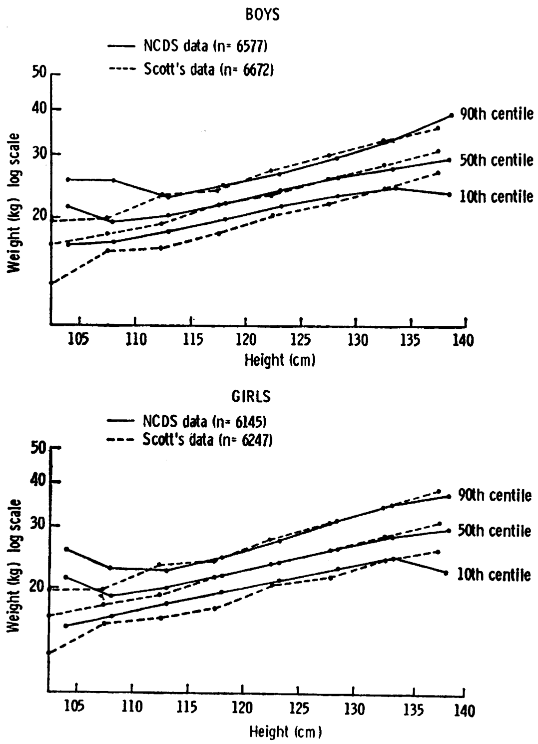

FIG. 1. Body weight distribution according to height.

This figure compares the weight/height relationship of the 7-year-old children in the National Child Development Study with Scott's data for London schoolchildren of the same range of heights but with ages ranging from 4 to 13 years (Scott, 1961). The median weights for both groups of children agree closely over the middle range of heights, but at the extremes of the height range the median weights for the 7-year-olds depart from those of the 4–13-year-olds. In particular, the median weight of the short 7-year-olds is considerably greater than the median weight of children of the same height but wider age range. Differences also occur between the two samples in the range of weights at each height. For Scott's data there is a gradual divergence of the 10th and 90th centiles, measured on a log scale, with increasing height. For the National Child Development Study there is a divergence for low and high values of height. The only British data comparable to those of the National Child Development Study are from the National Survey of Health and Development (Douglas and Blomfield, 1958), which followed a cohort of children born in 1946. Dr. Douglas has kindly provided data on the height and weight of these children, measured at the age of 7, and these show similar patterns to the National Child Development Study data.

Weight for Height Classification

Weight Centiles From the above results it can be seen that age as well as height should be taken into consideration in the preparation of standard weight tables against which overweight can be measured. However, as has already been pointed out, it is questionable whether a given centile represents the same degree of relative adiposity for children of the same age but different heights, although centile standards, by definition, provide a classification of weight for height which is independent of height.

Relative Weight In this approach, observed weight is divided by some standard weight for height where the standard represents the same location point on the weight distribution at each height. If each weight for height distribution, for example, is log-normal, then it is possible to standardize the weight distribution for given height.

TABLE I

BODY-WEIGHT DISTRIBUTIONS FOR DIFFERENT HEIGHT GROUPS
BOYS, AGED 7 YEARS TO 7 YEARS 9 MONTHS

	Midpoint of Height Group (cm)							
Weight (kg) (No. of children)	< 105·0 (104)	108·0 (132)	113·0 (557)	118·0 (1,585)	123·1 (2,426)	128·1 (1,320)	133·2 (378)	≥136·0 (75)
10th centile	16·6	17·1	18·3	19·8	21·7	23·2	24·7	23·5
50th centile	21·1	19·4	20·3	22·0	24·0	26·0	28·2	29·5
90th centile	25·5	25·5	22·8	24·5	26·9	29·8	33·6	39·6
10th centile/50th centile	0·787	0·881	0·901	0·900	0·904	0·892	0·876	0·797
90th centile/50th centile	1·209	1·314	1·123	1·114	1·121	1,146	1·191	1·342

BODY-WEIGHT DISTRIBUTIONS FOR DIFFERENT HEIGHT GROUPS
GIRLS, AGED 7 YEARS TO 7 YEARS 9 MONTHS

	Midpoint of Height Group (cm)							
Weight (kg) (No. of children)	< 105·0 (120)	108·0 (170)	113·0 (663)	118·0 (1,687)	123·1 (2,158)	128·1 (1,024)	133·2 (257)	≥136·0 (66)
10th centile	15·3	16·4	17·9	19·4	21·0	22·7	24·7	22·7
50th centile	20·8	18·8	20·0	21·7	23·7	26·0	28·3	29·9
90th centile	25·6	22·6	22·4	24·6	27·4	31·3	35·2	37·7
10th centile/50th centile	0·736	0·872	0·895	0·894	0·886	0·873	0·873	0·759
90th centile/50th centile	1·231	1·202	1·120	1·134	1·156	1·204	1·244	1·261

Centiles were assessed by linear interpolation between sample values. The original height measurements were to the nearest inch; these have been converted to the nearest 0·1 cm.

In particular, if the variances of the corresponding normal distributions are the same at each height, the 'relative weight' has a fixed distribution independent of height (Billewicz *et al.*, 1962). For the present sample of children the relative weight distributions do not have the same form at each height, as can be seen from the ratios of the centiles in Table I.

POWER INDICES Indices of the form $\frac{\text{Weight}}{(\text{Height})^n}$ have been used as measures of obesity by investigators studying both child and adult populations, and several comparisons have been made of the most commonly used indices (Billewicz *et al.*, 1962; Khosla and Lowe, 1968; Evans and Prior, 1969; Benn, 1971). These indices have been studied for adult populations and an attempt has been made to identify an index which is uncorrelated with height, for the reasons given above. Benn (1971) showed that under certain assumptions, in particular that the correlation of adiposity and height is zero, an index of the form W/H^n, constructed to be uncorrelated with height, is also the index which correlates most highly with adiposity. The correlation coefficient, however, measures only the strength of a *linear* relationship and if, for example, adiposity is higher at both extremes of height, then the above argument does not necessarily lead to that function which is most closely related to adiposity. In children, therefore, a power index merely designed to be uncorrelated with height may not be appropriate. Nevertheless, two recent surveys of obesity in childhood (Crisp, Douglas, Ross, and Stonehill, 1970; Topp, Cook, Holland, and Elliot, 1970) have used different power indices to classify children and we shall therefore investigate the behaviour of some of these indices and compare it with that of other measures.

Benn (1971) showed that where a linear relationship exists between log mean weight and log height, mean weight may be approximately represented by a power function of height H^n,

where $n = b\frac{H}{W}$ (b = constant, H = mid-range value of heights, W = mid-range value of weights)

and n is approximated by the slope of the plot of log (mean weight) on log (height). Moreover if, as suggested by Billewicz *et al.* (1962), the distribution of the relative weight index is independent of height, the derived power index would also be independent of height.

Four power indices were calculated: $\frac{W}{H^3}$ (related to Ponderal Index), $\frac{W}{H^2}, \frac{W}{H^{1\cdot75}}, \frac{W}{H^{1\cdot50}}$. In Fig. 2 the linear correlation coefficients of these indices and height are plotted against n and it can be seen that zero correlation would be expected at about $n = 1\cdot75$ for girls and $n = 1\cdot70$ for boys. Regression on

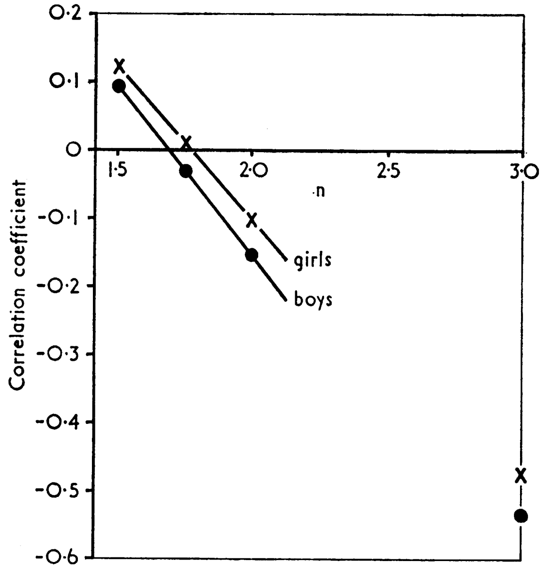

FIG. 2. Correlation coefficients between W/H^n and H for different values of n.

height of these indices gave the following linear regression equations and correlation coefficients (r):

$$\textit{Boys}\ \frac{W}{H^{1\cdot70}}=6\cdot88-0\cdot001\ \mathrm{H};\ r=-0\cdot01$$

$$\chi^2\ (1\ d.f.)=0\cdot3;\ P>0\cdot05$$

$$\textit{Girls}\ \frac{W}{H^{1\cdot75}}=5\cdot15+0\cdot001\ H;\ r=0\cdot011$$

$$\chi^2\ (1\ d.f.)=0\cdot9;\ P>0\cdot05.$$

Thus a value of n can be found such that the linear correlation between the index and height is effectively zero but when a second order polynomial of the type $\frac{W}{H^n}=a+b\,H+c\,H^2$ is fitted and a test of significance for $c=0$ is carried out, Table II shows that c is significantly different from zero for the above two values of n. This confirms that the procedure used for deriving the index does not guarantee that an index which is uncorrelated with height is also independent of height. It emphasizes that even if the assumptions underlying the use of the indices are good *average* approximations they may still result in serious errors of classification of extreme groups, since this is the area where the approximation is worst. This will now be shown in more detail.

COMPARISON OF THE CLASSIFICATION OF CHILDREN AS OVERWEIGHT BY THREE METHODS

As the findings are similar for boys and girls, results will be given for boys only. The values of the 3rd, 10th, 25th, 50th, 75th, 90th, and 97th weight centiles were calculated for children in each height group. Values were then derived for the relative weight index, $\frac{\text{observed weight}}{\text{mean weight}}$, and the power index $W/H^{1\cdot70}$ such that in the height interval centred on 123·1 cm, the classification of children by both indices would correspond to the classification into eight groups according to the weight centiles. Because weight is recorded only to the nearest pound each index can take only certain discrete values, and the distribution of the children in the eight groups chosen for each index will therefore only approximate to the percentage distribution indicated by the centile values.

Table III shows the distribution of the relative weight and power indices at each height. If those children in the bottom row of Table III are considered to represent the overweight group, it can be seen that the proportion thus classified as overweight varies considerably with height and with the three methods. If the proportion of children in the bottom row is analysed by height groups (Bhapkar, 1968) it is found that there is a significant 'quadratic trend' for both indices, indicating more 'overweight' children at the extreme values of height. From Table IV it can be seen that, of the 354 boys classified as overweight by at least one method, 149 were so classified by all three, 101 by two, and 104 by one.

TABLE II

TESTS OF SIGNIFICANCE FOR QUADRATIC TERM IN THE REGRESSION OF DIFFERENT POWER INDICES $\frac{W}{H^n}$ ON HEIGHT AND HEIGHT SQUARED

	Index	Coefficient of Quadratic Term ($\times 10^6$)	Standard Error ($\times 10^6$)	χ^2 (1 d.f.)
Boys	W/H^3	6·3	0·2	855·8 ***
	W/H^2	488·4	25·5	364·2 ***
	$W/H^{1\cdot70}$	1,834·0	107·9	288·5 ***
	$W/H^{1\cdot50}$	4,465·0	282·6	250·6 ***
Girls	W/H^3	6·9	0·2	857·9 ***
	W/H^2	539·2	28·1	368·7 ***
	$W/H^{1\cdot75}$	1,627·0	93·0	306·1 ***
	$W/H^{1\cdot50}$	4,969·0	308·6	259·5 ***

Significance level *** $P<0\cdot001$

Since the degrees of freedom in the denominator of the F statistic are large, the χ^2 statistic is quoted for simplicity.

DISCUSSION

Definitions of obesity based on weight for height are essentially indirect. In children, as in adults, a function of weight and height useful for classification might be based on the observed association with morbidity and mortality rates. The relationship between morbidity and mortality rates and variations in body composition is also of importance here and has not been adequately studied.

Table III

(a) DISTRIBUTION OF RELATIVE WEIGHT INDEX AT EACH HEIGHT GROUP FOR BOYS

Relative Weight Weight/Mean Weight	Midpoint of Height Group (cm)								
	< 105·0	108·0	113·0	118·0	123·1	128·1	133·2	⩾136·0	Total
⩽0·845	20 (19·2)†	11 (8·3)	21 (3·8)	43 (2·7)	56 (2·3)	71 (5·4)	31 (8·2)	14 (18·6)	267 (4·1)
–0·902	12 (11·6)	29 (22·0)	38 (6·8)	100 (6·3)	273 (11·3)	144 (10·9)	57 (15·1)	11 (14·7)	664 (10·1)
–0·939	8 (7·7)	13 (9·8)	87 (15·6)	201 (12·7)	172 (7·1)	147 (11·1)	39 (10·3)	5 (6·7)	672 (10·2)
–0·996	11 (10·6)	28 (21·2)	113 (20·3)	467 (29·5)	860 (35·4)	340 (25·8)	71 (18·8)	15 (20·0)	1,905 (29·0)
–1·052	18 (17·3)	17 (12·9)	166 (29·8)	447 (28·2)	377 (15·5)	333 (25·2)	79 (20·9)	6 (8·0)	1,443 (21·9)
–1·109	10 (9·6)	6 (4·5)	63 (11·3)	148 (9·3)	470 (19·4)	126 (9·6)	45 (11·9)	8 (10·6)	876 (13·3)
–1·203	15 (14·4)	8 (6·1)	56 (10·1)	145 (9·1)	151 (6·2)	89 (6·7)	31 (8·2)	5 (6·7)	500 (7·6)
> 1·203	10 (9·6)	20 (15·2)	13 (2·3)	34 (2·2)	67 (2·8)	70 (5·3)	25 (6·6)	11 (14·7)	250 (3·8)
Total	104 (100·0)	132 (100·0)	557 (100·0)	1,585 (100·0)	2,426 (100·0)	1,320 (100·0)	378 (100·0)	75 (100·0)	6,577 (100·0)

†Percentages in parentheses
χ^2 (49 d.f.) = 707·7 ***
Linear trend of proportion in last row on columns χ^2 (1 d.f.) = 11·2 ***
Quadratic trend of proportion in last row on columns χ^2 (1 d.f.) = 32·8 ***

(*b*) DISTRIBUTION OF POWER INDEX $\frac{W}{(H^{1\cdot70})}$ AT EACH HEIGHT GROUP FOR BOYS

Power Index $\frac{W}{H^{1\cdot70}}$	Midpoint of Height Group (cm)								
	< 105·0	108·0	113·0	118·0	123·1	128·1	133·2	⩾136·0	Total
⩽5·705	2 (1·9)†	4 (3·1)	23 (4·1)	55 (3·5)	67 (2·8)	45 (3·4)	17 (4·5)	17 (22·7)	230 (3·5)
–6·085	4 (3·9)	18 (13·6)	89 (16·0)	187 (11·8)	193 (7·9)	97 (7·3)	25 (6·6)	6 (8·0)	619 (9·4)
–6·339	2 (1·9)	16 (12·1)	111 (19·9)	250 (15·8)	324 (13·3)	108 (8·2)	39 (10·3)	7 (9·3)	857 (13·0)
–6·719	10 (9·6)	29 (22·0)	136 (24·4)	535 (33·7)	663 (27·3)	289 (21·9)	57 (15·1)	6 (8·0)	1,725 (26·3)
–7·099	8 (7·7)	22 (16·7)	116 (20·8)	337 (21·3)	616 (25·4)	332 (25·2)	97 (25·6)	11 (14·7)	1,539 (23·4)
–7·481	5 (4·8)	11 (8·3)	45 (8·1)	112 (7·1)	337 (13·9)	250 (18·9)	51 (13·5)	5 (6·7)	816 (12·4)
–8·115	14 (13·5)	9 (6·8)	25 (4·5)	86 (5·4)	164 (6·8)	112 (8·5)	49 (13·0)	10 (13·3)	469 (7·1)
> 8·115	59 (56·7)	23 (17·4)	12 (2·2)	23 (1·4)	62 (2·6)	87 (6·6)	43 (11·4)	13 (17·3)	322 (4·9)
Total	104 (100·0)	132 (100·0)	557 (100·0)	1,585 (100·0)	2,426 (100·0)	1,320 (100·0)	378 (100·0)	75 (100·0)	6,577 (100·0)

†Percentages in parentheses
χ^2 (49 d.f.) = 1,217·6 ***
Linear trend of proportion in last row on columns χ^2 (1 d.f.) = 20·6 ***
Quadratic trend of proportion in last row on columns χ^2 (1 d.f.) = 133·5 ***

Table IV

CLASSIFICATION OF CHILDREN AS OVERWEIGHT BY RELATIVE WEIGHT INDEX, POWER INDEX, AND WEIGHT CENTILE: BOYS

Power Index $W/H^{1\cdot70}$	Relative Weight Weight/Mean Weight	Weight at or above 97th Centile	Totals
+	+	+	149
	+	+	23
+	+		78
+		+	0
+			95
	+		0
		+	9
322	250	181	354

Kemsley, Billewicz, and Thomson (1962) distinguish two basic uses of a weight for height standard—as a basis for group comparisons and as a clinical instrument for detecting very heavy or very light individuals. In the case of clinical standards a distinction should be drawn between the method of constructing the standards and the method of using them. For example, if it can be shown that a power index of the form W/H^n contains all or nearly all the information appropriate to deriving weight for height standards (Benn, 1971), then less work, in terms of smaller samples, is needed to derive adequate standards than if separate weight distributions have to be analysed for each height. On the other hand, it may not be very convenient for, say, a clinician to have to calculate this ratio even when $n=2$, let alone if $n=1\cdot83$. It would seem preferable in this case to spend more resources on providing standards which are easy to use.

For comparisons between groups or treatments, as pointed out above, different functions of height and weight are appropriate in different situations. The results of the present study demonstrate that in children the three functions commonly used to classify individuals are not equivalent.

Two important properties emerge from a study of the weight distributions. For the population under study it is found that there is greater variability of relative weight at both extremes of the height range than in the middle range of heights. Whether this indicates an increased proportion of 'obese' children at the extremes of the height range or whether, for example, lean body mass is more likely to be increased in these children cannot be decided from the present data. However, in a study of body composition from potassium-40 measurements, Forbes (1964) divided his overweight children into two groups, those in whom there was an increase in lean body mass of more than 10% above the calculated ideal, and those in whom lean body mass was not increased to this level. In the former group bone age was found to be advanced; the overweight had often been present since infancy and the children were often tall for their age. On average 29% of the excess weight was accounted for by increase in lean body mass and 71% by fat. In the second group more than 90% of the excess weight was attributable to fat, the obesity had usually developed after infancy, bone age was not advanced, and the children were of normal height for their age. Thus, it may be that there are differences in the composition of the excess weight of children of different heights and the same age.

The second important fact to be observed from the weight distributions is the divergence of the median weights of the present sample from Scott's sample at both extremes of the height range. The increase in average height with age means that, for example, the short children in Scott's sample will be predominantly young children of average height for age, whereas in the present sample they are children who are short for their age. Thus, when compared with a typical (younger) child of the same height, the short child will be relatively heavier and the tall child, when compared with a typical (older) child of the same height, will be, to a lesser extent, lighter.

The present results indicate that caution is necessary when using any weight for height index for child populations. It has been shown that the assumptions made for adult populations are not applicable to children. In order to make a meaningful choice between different classifications a greater knowledge is needed of the association between health status and the different measures of weight for height as well as a better understanding of the relationship between the different measures and body composition.

SUMMARY

The weight distribution for a large sample of 7-year-old children was examined and the uses of three methods of deriving weight for height standards were studied.

The three types of standards are not equivalent as measures of overweight, and, in particular, neither a power type index nor a relative weight index may be used in place of centile standards of weight for height. In calculating standards of weight for height in children, age should be taken into account.

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