THE RELATION OF BIRTH WEIGHT TO PHYSICAL GROWTH

A STATISTICAL STUDY

BY

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It has been shown elsewhere (Illingworth, 1939; 1950; Illingworth, Harvey, and Gin, 1949) that the weight of a child at birth bears an important relationship to his subsequent weight and height. The aim of this study is to determine whether children with different birth weights differ in all the standard body dimensions, namely weight, pelvic and calf girth, chest circumference, standing and sitting height, and if these differences are established, to see whether they are sufficient to account for the differences in weight.

Methods

The investigation covers all children aged 5 to 8 years in the schools of the City of Sheffield, provided that (1) their birth weights could be satisfactorily determined, (birth weights of children born on district being obtained from the midwives' antenatal charts, and of those born in hospital from the infant welfare charts in the form of a note brought by the mother from the hospital to the child welfare clinic); (2) their addresses could be traced; (3) they came up on request (outside school hours) to the Children's Hospital for measurement; (4) they fell into one of the following three birth weight groups: Group A, 2,495 g. (5 lb. 8 oz.) or less, Group B, 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.), Group C, 3,856 g. (8 lb. 8 oz.) or more. There was no possibility of selecting children otherwise, because all children who satisfied these criteria were utilized for the investigation. A total of 238 children were measured: 99 in Group A, 66 in Group B, and 73 in Group C.

All measurements were taken or personally supervised by one of us (C.C.H.). The height was taken with the child standing barefooted against a backboard, taking care to avoid postural slackness. The weight was taken with the child wearing pants only or fully stripped. The sitting height was taken with the child in the sitting position on a solid base

with the sacrum against a backboard. The box was of such a height (11 in.) that in an average child the knee was flexed to a right angle when the heel was on the ground. Postural slackness was avoided. The arm of the measuring apparatus rested on the head. The pelvic girth was taken as the widest point of the bony crest and measured by obstetrical calipers. The chest circumference was measured at the level of the xiphisternum in the mid-position between moderate expiration and moderate inspiration, using a cloth tape measure. The calf girth recorded was the average of the maximum right and left calf girth when the child was standing at ease with the weight equally distributed upon both feet. The ages recorded are accurate to the nearest month. (For example, the age of a child who was stated to be 8 years and 20 days old was recorded as 8 years and one month.)

The statistical methods used are described in the Appendix.

Results

Tables 1, 2, and 3 show the essential results. It should be borne in mind when referring to these tables that the individual figures quoted, being based on small samples, are subject to fairly large errors, due to accidents of sampling, and their main use was to establish statistically significant differences between birth weight groups. The dimensions of the children were corrected to a constant age (for males 7 years, for females 6 years 10 months) in Tables 1 and 2, by corrections which are given in Table 3, and which were obtained from the data themselves by methods described in the addendum. Differences in Table 1 which are statistically significant are indicated by means of an asterisk. In Table 4 are given the mean dimensions of the groups uncorrected for age, together with the mean age of groups and the number of children in each group. It will be seen that there are differences of

TABLE 1
MEAN BODY DIMENSIONS AND WEIGHT OF CHILDREN CORRECTED TO CONSTANT AGE

Variable	Male			Female		
	Group A Birth Weight 2,495 g. (5 lb. 8 oz.) or less	Group B Birth Weight 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.)	Group C Birth Weight 3,856 g. (8 lb. 8 oz.) or more	Group A Birth Weight 2,495 g. (5 lb. 8 oz.) or less	Group B Birth Weight 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.)	Group C Birth Weight 3,856 g. (8 lb. 8 oz.) or more
Number ..	54	31	35	45	35	38
Weight (kg.) ..	21.54	22.52	24.68*	20.69	21.66	22.33*
Height (Stand.) (cm.) ..	116.56	117.85	121.63*	116.19	116.74	118.04
Height (Sit.) (cm.) ..	63.73	63.42	65.54*	63.28	63.17	63.55
Chest (cm.) ..	57.04	57.54	58.81*	54.80	55.36	56.06
Pelvis (cm.) ..	19.38	19.69	20.56*	19.12	19.15	19.34
Calf (cm.) ..	23.28	23.54	24.44*	23.09	23.74	24.54*

The statistical significance refers to differences on the whole between the three appropriate means, and not specifically to any pair.

TABLE 2
OBSERVED AND ESTIMATED DIFFERENCES IN MEAN
WEIGHT OF BIRTH WEIGHT GROUPS*
A. Males

Groups Compared Excess of:	Observed (kg.)	Estimated (kg.)	Observed Minus Estimated.	Standard Error of Observed Minus Estimated
B over A ..	0.98	0.57	0.41	0.28
C over B ..	2.24	1.75	0.49	0.30
C over A ..	3.22	2.31	0.91†	0.27

B. Females

Groups Compared Excess of:	Observed	Estimated	Observed Minus Estimated	Standard Error of Observed Minus Estimated
B over A ..	0.97	0.72	0.25	0.26
C over B ..	0.67	1.06	-0.39	0.27
C over A ..	1.64	1.78	-0.14	0.25

* Weights corrected to 7 years in males and to 6 years 10 months in females. Estimated weights for males were calculated from equation (1) and for females from (2). † of Statistical Significance

the order of a month in some cases, between mean ages of different groups, but that in spite of this the broad general picture presented by Tables 1 and 4 are the same.

It will be seen that in all measurements children with a low birth weight (5 lb. 8 oz. or less) were smaller than those of large birth weight (8 lb. 8 oz. or more), the measurements of those of average birth weight (7 lb. 2 oz. to 7 lb. 6 oz.) falling in all cases (except in sitting height) between the two.

Statistical Note. The standard error 'observed-estimated' was calculated from the pooled within-group residual standard deviation from the appropriate weight-predicting regression formula (either (1) or (2)). This assumed the value 1.22 kg. for males and 1.15 kg. for females, based on respectively 111 and 107 degrees of freedom. For example, the S.E. quoted for Group B and A males was given by $1.22\sqrt{1/54-1/31}$, Group A containing 54, Group B, 31 boys. These standard error estimates are a little on the small side, since no account has been taken of the errors in the coefficients of formulae (1) and (2). Most of the differences quoted do not exceed twice their standard errors, and are therefore not statistically significant; the third difference in Table 2 A, however, appears to attain significance.

There was a difference of 3.14 kg. (6 lb. 14 oz.) between male children who at birth weighed 5 lb. 8 oz. or less, and those who at birth weighed

TABLE 3
INCREASES IN BODY DIMENSIONS AND WEIGHT PER MONTH
OF AGES

Variable	Males		Females	
	All Groups	Group A Birth Weight 2,495 g. (5 lb. 8 oz.) or less	Group B Birth Weight 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.)	Group C Birth Weight 3,856 g. (8 lb. 8 oz.) or more
Weight (kg.) ..	0.18	0.24	0.09	0.17
Height (Stand.) (cm.) ..	0.49	0.59	0.38	0.45
Height (Sit.) (cm.)	0.19	0.26	0.13	0.14
Chest (cm.) ..	0.16	0.19	0.10	0.13
Pelvis (cm.) ..	0.06	0.07	0.03	0.02
Calf (cm.) ..	0.06	0.09	0.01	0.08

8 lb. 8 oz. or more. The difference in standing height was approximately 5.1 cm., in sitting height 1.8 cm., chest circumference 1.8 cm., pelvic girth and calf girth 1.2 cm.

Table 2 shows that for female children the

differences in dimensions are sufficient to account for the differences in weight, and that in males they account for about 70% of those differences.

Table 3 gives the correcting factors for age which were used in obtaining the figures of Table 1 from those of Table 4. There was no evidence of different changes of size with age from one male birth weight group to another, but there was an indication (see note on Table 5) that the lowest female birth weight group tended to increase in size more rapidly with age than the other; accordingly different correcting factors were used for the female groups, the same correcting factors for the male groups. The medical significance of this phenomenon is not clear.

Discussion

It is interesting to note the relationship between the weight at birth and all the measurements—weight, standing and sitting height, chest, pelvic and calf girth—in later childhood.

As stated elsewhere (Illingworth *et al.*, 1949), there is very little reference in the literature to any such relationship. Capper (1928), however, examined 437 prematurely born children at various ages in later childhood, and compared them with measurements of 'normal' children. He found that the prematurely born children usually remained below normal in both weight and height, at least

TABLE 4
NUMBERS, MEAN AGE, WEIGHT, AND BODY DIMENSIONS OF CHILDREN IN DIFFERENT SEX AND BIRTH WEIGHT GROUPS

Variable	Male			Female		
	Group A Birth Weight 2,495 g. (5 lb. 8 oz.) or less	Group B Birth Weight 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.)	Group C Birth Weight 3,856 g. (8 lb. 8 oz.) or more	Group A Birth Weight 2,495 g. (5 lb. 8 oz.) or less	Group B Birth Weight 3,238 g. (7 lb. 2 oz.) to 3,351 g. (7 lb. 6 oz.)	Group C Birth Weight 3,856 g. (8 lb. 8 oz.) or more
Number ..	54	31	35	45	35	38
Age (yrs.) ..	6.95	7.19	7.01	6.99	6.71	6.75
Weight (kg.) ..	21.42	22.94	24.70	21.14	21.54	22.17
Height (Stand.) (cm.) ..	116.25	118.98	121.69	117.30	116.21	117.61
Height (Sit.) (cm.) ..	63.61	63.89	65.56	63.78	62.99	63.41
Chest (cm.) ..	56.94	56.94	57.92	58.83	55.16	55.93
Pelvis (cm.) ..	19.34	19.84	20.57	19.26	19.11	19.32
Calf (cm.) ..	23.24	23.68	24.44	23.26	23.73	24.46

up to the fifteenth year. They were also smaller in skull and chest circumference. Boys tended to lag behind in weight more than girls, while girls tended to lag behind more in height than boys. He found that in the majority of prematurely born children the sitting height was greater than normal, and suggested that the delay in growth in the first ten years was due to slowness in the growth of extremities rather than to backwardness in the growth of the trunk. It is worthy of note that in our series the only mean measurement in the prematurely born group which was greater than the corresponding measurement in the children of average birth weight (7 lb. 2 oz. to 7 lb. 6 oz.) was that of the sitting height. The difference was a very slight one, and not of statistical significance, but it did occur in both male and female.

Capper also noted that the prematurely born children who had the smallest birth weight lagged further behind in subsequent weight and height. He did not, however, note that this was merely part of the general relationship of birth weight to body build, and that the same relationship applied to full term babies: the larger the birth weight, the larger in general being the body build.

The demonstration of the relationship of birth weight to body build in later childhood indicates the importance and possible long term effects of controllable factors which affect the weight at birth. Such factors are the induction of premature labour, the conservative treatment of placenta praevia, the prevention of prematurity by improvement of the nutrition and social circumstances of the mother, the proper treatment of the pregnant diabetic, and possibly the effect of stilboestrol (Smith and Smith,

1949) in reducing the incidence of prematurity and increasing the size of the baby.

Summary

The weight, standing and sitting height, pelvic girth, chest and calf circumference, were measured in 238 children, aged 5 to 8 years, of three birth weight groups (5 lb. 8 oz. or less, 7 lb. 2 oz. to 7 lb. 6 oz., and 8 lb. 8 oz. or more), and analysed by statistical methods. It was found that in all measurements the children of the lowest birth weight groups were smaller than those of the largest birth weight group, the measurements of the children of average birth weight falling in all cases (except in sitting height) between the two. Most of these differences were of statistical significance.

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STATISTICAL APPENDIX

Determination of Age Corrections

As a preliminary step, scatter diagrams were drawn showing each variable plotted against age for each birth weight group. Some of these are illustrated in Figs. 1 to 6; there were 36 altogether, but it is not practicable to show them all. From Figs. 5 and 6 it can be seen that one girl in each of Groups B and C was exceptional, and after pursuing the analysis for some way both with and without

these girls it was ultimately thought desirable to exclude them from analysis. This action was conservative in its effect: the differences between groups in mean dimension were on the whole more marked with than without them, though their statistical significance might perhaps be reduced. The main reason for their exclusion was that it was felt that they were vitiating the age corrections.

It was verified from the tables of Vickers and

Stuart (1943) that weight and the other dimensions increased in roughly a straight line with age in normal children and over the range of ages (5½ years to 9 years) covered by the data. It was therefore inferred that since the scatter diagrams gave no marked evidence to the contrary, a straight line relationship could be assumed for each group and each dimension. Regression lines were then fitted for each group, some of these being illustrated in Figs. 1-6. The excluded girls were not used in calculating the lines shown in Figs. 5 and 6.

To ascertain if, in making correction to constant age, the same correction could be used for all three birth weight groups, a common slope analysis, as described by Tippett (1931) was carried out for each sex. The results of this analysis are set out in Table 5, together with a footnote in which their statistical significance is discussed. From these analyses it was concluded that the same age correction could be used for all three male groups, variations in the slopes of the regression lines from group to group being attributable to chance, but that it would be safer to use separate group corrections for females in view of the marked tendency

FIG. 1. Relation between age and height (sitting) in male children with birth weights not greater than 5lb. 8oz.

FIG. 2. Relation between age and pelvis in male children with birth weights between 7lb. 2oz. and 7lb. 6oz.

of the regression slopes to differ. This difference manifested itself mainly in a tendency for the dimensions of the premature Group A (birth weight 5 lb. 8 oz. or less) to increase more rapidly than the other two groups. The age corrections used are given in Table 3; those for males are slopes of parallel regression lines fitted to all three groups.

Differences of Mean Measurements between Groups

The application of these age corrections to the group means produced the results quoted in Table 1.

For males, the ages were corrected to 7 years, for females to the mean age, 6 years 10 months. For testing the significance of the differences between male groups, a common-line analysis (*loc. cit.*) was carried out; for all dimensions the results of this, which are given in Table 6, established significant differences in level; that is to say, the differences between mean male measurements of groups from one group to another were too great to be ascribable to chance. For testing the significance between female groups a slightly different test was necessary because of the different age corrections; the differences between groups could be expected to vary according to the age to which correction was made. The estimated mean dimensions at 6 years 10 months were therefore compared by an analysis of variance test, given in Table 7. The differences were not so marked, but established themselves for weight and calf, and approached significance for chest measurement.

It should be pointed out that corresponding tests of significance carried out on different variables are not independent of one another; the various body measurements are related, and if one shows a marked difference

from group to group, others are likely to do so. Further, if differences are established for some variables, it is likely that they exist for related variables, although individual comparisons involving a related variable may fall short of establishing statistical significance. Similar remarks apply to the changes of the variables with age; if these differ from group to group for females, it seems likely *a priori* that they would do so for males too, yet their variation may be so much less marked from one male birth weight group to

FIG. 3. Relation between age and height (standing) in male children with birth weights not less than 8 lb. 8 oz.

FIG. 4. Relation between age and chest in female children with birth weights not greater than 5 lb. 8 oz.

another that a common correction will suffice. This seems to be the case here. Henceforward all work was carried out on variables corrected to a constant age (for males, 7 years, though it is immaterial, for females 6 years 10 months), and such correction will be implicitly assumed in what follows.

By carrying out the multiple regression (within groups) of weight on the five measurements a formula was obtained for each sex by which average weight could be estimated, given the five measurements. The formulae are given in equations (1) and (2):

Males: Mean weight = constant + $0.18 \times$ standing height + $0.03 \times$ sitting height + $0.27 \times$ chest + $0.29 \times$ pelvis + $0.49 \times$ calf. (1)

Females: Mean weight = constant + $0.19 \times$ standing height + $0.04 \times$ sitting height + $0.31 \times$ chest + $0.19 \times$ pelvis + $0.68 \times$ calf. (2)

It is possible to obtain a formula of this kind for each group; in such a case it is based entirely on comparisons between children in the same group, and apart from the constant is uninfluenced by the mean weight or dimensions of the group. By

pooling these within-group comparisons, a single formula may be obtained for the whole sex, amounting to a kind of average of the three separate formulae, which is not influenced by variations in mean measurements from group to group; this is how equations (1) and (2) were obtained.

These formulae were used to estimate the differences in mean weight of groups which would be expected from the differences in mean dimensions of the groups; the mean dimensions of each group are substituted giving three expected mean weights; these we subtracted in pairs, incidentally eliminating the constant term, and compared with the observed differences in mean weight. This was done in Table 2. For males (Table 2 A), some of the difference in weight between groups remains to be accounted for, though the proportion is only of the order of one-third. For females (Table 2 B), there is no evidence of a non-zero residue, and it must therefore be concluded that the difference in weight between groups is explained. One may surmise that a few extra measurements in the males might have removed the unexplained residue.

FIG. 5. Relation between age and weight in female children with birth weights between 7lb. 2oz. and 7lb. 6oz.

FIG. 6. Relation between age and weight in female children with birth weights not less than 8lb. 8oz.

TABLE 5

ANALYSIS OF VARIANCE: COMPARISON OF SLOPES OF REGRESSION LINES ON AGE BETWEEN BIRTH WEIGHT GROUPS

A. Males

Variable	Due to Common Slope		Variations in Slope between Groups		Residual Variation	
	Mean Square	Degrees of Freedom	Mean Square	Degrees of Freedom	Mean Square	Degrees of Freedom
Weight (kg.) ..	445.84*	1	3.91	2	6.30	114
Height (Stand.) (cm.) ..	3,169.00*	1	19.51	2	24.89	114
Height (Sit.) (cm.) ..	490.93*	1	1.20	2	6.72	114
Chest (cm.) ..	357.60*	1	8.68	2	7.84	114
Pelvis (cm.) ..	51.19*	1	0.24	2	1.11	114
Calf (cm.) ..	45.79*	1	2.38	2	1.95	114

B. Females

Variable	Due to Common Slope		Variations in Slope between Groups		Residual Variation	
	Mean Square	Degrees of Freedom	Mean Square	Degrees of Freedom	Mean Square	Degrees of Freedom
Weight (kg.) ..	253.66*	1	18.05	2	7.01	112
Height (Stand.) (cm.) ..	2,414.30*	1	38.08	2	22.10	112
Height (Sit.) (cm.) ..	363.78*	1	18.66	2	6.56	112
Chest (cm.) ..	181.49*	1	7.18	2	5.77	112
Pelvis (cm.) ..	16.25*	1	2.61	2	1.24	112
Calf (cm.) ..	34.48*	1	5.37	2	2.01	112

Statistical Footnote: to determine the statistical significance of the mean square 'Variations in Slope between Groups' in Table 5, its ratio to the mean square 'Residual Variation' was compared with the 5% value of the variance ratio for the appropriate combination of degrees of freedom, and was adjudged significant if it exceeded it. The mean square 'Due to Common Slope' was tested in a similar manner. None of the 'Variations in Slope' mean square attain significance, but those for female weight, sitting height, and calf do not fall far short of it, which makes it desirable to use different age corrections for females. The inclusion of the two exceptional females has the effect of increasing the statistical significance of these differences, and with them several of the 'Variations in Slope' mean square attain the 5% level of significance.

TABLE 6

ANALYSIS OF VARIANCE: COMPARISON OF LEVELS OF
PARALLEL REGRESSION LINES ON AGE BETWEEN MALE
BIRTH WEIGHT GROUPS

Variable	Variations in Level		Residual Variation	
	Mean Square*	Degrees of Freedom	Mean Square	Degrees of Freedom
Weight (kg.) ..	105.32	2	6.37	114
Height (cm.) (Stand.) ..	278.25	2	25.23	114
Height (cm.) (Sit.) ..	46.09	2	6.74	114
Chest (cm.) ..	33.80	2	7.99	114
Pelvis (cm.) ..	15.11	2	1.12	114
Calf. (cm.) ..	14.67	2	1.99	114

* The significance of the variations in level mean square was determined by calculating its ratio to the residual mean square and comparing it with the appropriate 5% value of the variance ratio.

TABLE 7

ANALYSIS OF VARIANCE: COMPARISON OF MEAN
MEASUREMENTS OF FEMALE BIRTH WEIGHT GROUPS

Variable	Variations in Mean		Residual Variation	
	Mean Square*	Degrees of Freedom	Mean Square	Degrees of Freedom
Weight (kg.) ..	28.19†	2	7.01	112
Height (cm.) (Stand.) ..	36.13	2	22.10	112
Height (cm.) (Sit.) ..	1.38	2	6.56	112
Chest (cm.) ..	16.46	2	5.77	112
Pelvis (cm.) ..	0.53	2	1.24	112
Calf (cm.) ..	21.68	2	2.01	112

* The significance of the variations in mean mean square was obtained by comparing it with the residual mean square as in Table 6.

† Measurements corrected to 6 years 10 months.