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The Growth of the Brain and Skull in Children

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Published data for brain weight and head circumference in children were examined to determine whether there was evidence for development of brain size in 'spurts' rather than continuously. Graphical methods and various statistical analyses were used to detect significant deviations from a smooth progression in growth of the brain or skull. No convincing evidence for other than normal statistical sampling variations was found for either brain size or head circumference. It is premature to begin reorganization of school curriculae on the grounds that the brains of children grow in spurts.

INTRODUCTION

It is undoubtedly true that intelligence is largely determined by the number of neurons and the complexity of their interconnections within the brain, but no one has yet found a measure of brain structure that will predict intelligence reliably. Jerison[13] has shown that within mammalian and bird species there is a significant relationship between body size and brain size, such that given the average body size of a particular species, one can predict the average brain size. In this relationship, the brain weight is a function of the body weight raised to the two-thirds power. Jerison argues that allometric brain size is related to total information-processing capacity and, therefore, is a measure of intelligence, at least, at the between-species level.

However, within a species there does not seem to be the same relationship between brain weight and body weight. For example, Sholl[22] has shown that for some species 'the size of the adult brain may be independent of the body weight' (p. 257). It is not clear what a relationship between brain size and body size would mean at the species level. Are larger members of a species necessarily more intelligent than smaller ones? We do not even know that larger brained members of a species are necessarily more intelligent than smaller brained ones. Attempts to establish a relationship between human brain size and intelligence or achievement have never been successful.

Epstein[6] approached the question of the relationship between brain size and intelligence from a developmental point of view. Using Boyd's[2] data on brain size in children, Epstein came to the conclusion that the brains of children do not develop at a constant rate, but grow at greater or lesser rates depending upon the age of the child. He described 'growth spurts' at 6–8 years, at 10–12 years, and at 14–17 years of age separated by 'growth troughs' in which the rate of growth was slowed. Epstein also detected spurts and troughs in changes in head circumference for children over the same age range. These changes in growth rate of the brain, Epstein related to stages in development of mental capacities of children as outlined by Piaget[18].

It is not clear which parts of the brain are related to intelligence or learning ability in humans. Perhaps, if the cellular assemblages responsible for these func-

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tions are large and distributed widely in the brain, one might expect to be able to detect changes in their weight by measuring the weight of the entire brain. However, if the cellular assemblages are not large and distributed widely in the brain, then rather large percentage changes in their weights may go undetected by this method of measurement. For example, the hippocampus, a structure with a role in memory, has a volume of 10,350 mm^3 compared to the volume of the whole brain of 1,251,847 mm^3 and, thus, makes up only 0.8% by volume of the human brain[24]. If the hippocampus and only the hippocampus were to double in volume over the period of a year or two, it would still make up only 1.6% of the brain. In terms of mass of an initially 1200 g brain, this would be an increase, over this growth period, of less than 20 g. This amount could easily be obscured by even a modest variability in brain size or a modest increment in mass of the whole brain or brain and body.

In addition, Epstein correctly pointed out that most of the growth over the first 4 years probably represents the process of myelination. We do not know how much of later growth in brain size is attributable to myelination and we have no idea how myelination relates to either intelligence or learning ability. In any case, Epstein and others[7,8,9,25] have argued for sweeping changes in educational curriculae based upon these observations and a questionable assumption that children are only capable of mastering new concepts when their brains are growing at an accelerated rate, i.e. when they are in a 'growth spurt'. Because this issue has such importance in the education of children, it was worth re-examining the data in detail. A second examination failed to support the notion of growth spurts in either brain weight or head circumference.

METHODS

This study made use exclusively of published data on brain weight and head circumference. Epstein[6] used, as his primary source of brain weights, values published by Boyd[2]. Boyd, in turn, obtained the values from Scammon[21], who, unfortunately, did not report the details of the measurement of brain weights. Presumably, the postmortem brain was separated from the spinal cord at some standard site before weighing, but that site was not specified.

I have located 7 other studies of brain size in children, which cover the period from birth to 18 years[1,3,10,15,17,20,27]. All measurements were made on postmortem brains, but the condition of the brain at the time of the measurement was never specified. Presumably, all brains were fixed, but no information was given regarding whether the brains were soaked in Ringer's solution or saline for a period before weighing or whether or not ventricular fluids were carefully drained. Pfister[17] and Michaelis[15] divided the brain from the spinal cord below the level of the decussation of the pyramidal tract. None of the other investigators specified the point of division. All investigators eliminated from their samples obviously diseased brains. Most of the investigators did not consider brains from children who died with meningitis, hydrocephalus, gliosis, sarcomatosis, hyperemia, anemia, marasmus or other wasting.

For girls, average brain weights increased monotonically over the first 6–8 years in all studies. After age 8, there were some actual decreases in average brain weight with increasing age. The rate of growth of girls' brains appeared to have slowed after age 8–10 when the values approached those at age 18. For boys, the average brain weights decreased from one measurement to the next about as often as they increased across all studies, i.e., there is a study showing an increase in average brain weight over a given age range for each that shows a decrease. Part of this inconsistency may be explained by variations within a study and between studies in the way brains were prepared for measurement. There may also have been systematic changes in the cause of death of children at different ages, with some causes having a greater influence on the mass of the brain. Another source of variation is differences in sample sizes. Table I shows the number of brains measured in each study from each sex at each age. Only Boyd[2] and Vierordt[27] reported many measurements for older children. Many of the other studies contained sample sizes of one brain at many ages and, therefore, only the Boyd[2], Coppoletta and Wolbach[3], and Vierordt[27] data are presented here. The differences between brain weights at consecutive ages would be expected to be highly variable when sample sizes are small, and it is where sample sizes are smaller that this type of variation increases.

This study used mainly graphical methods for anal-

TABLE I

Number of cases in studies of brain size

M, males, F, females, B, both males and females considered together.

Age	*Study*														
	Bischoff		*Boyd*		*Coppoletta*	*Handmann*		*Michaelis*		*Pfister*		*Rudolph*		*Vierordt*	
	M	*F*	*M*	*F*	*B*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
—	12	12	137	122	9	65	41	—	—	—	—	3	—	36	38
1	3	2	—	—	15	9	7	2	6	1	—	—	—	17	11
1.5	2	2	167	143	18	—	—	—	—	—	—	1	—	3	4
2	2	5	—	—	10	6	6	10	15	—	—	1	—	27	28
2.5	1	—	90	86	10	—	—	—	—	2	—	—	—	2	7
3	2	4	—	—	11	4	8	2	10	1	—	1	—	19	23
3.5	1	4	64	58	6	—	—	—	—	—	—	—	—	1	2
4	—	3	—	—	4	2	3	4	7	1	—	1	—	19	13
4.5	—	—	56	44	3	—	—	—	—	2	1	—	—	—	—
5	1	2	—	—	7	2	2	5	1	—	1	1	1	11	19
5.5	—	—	49	33	4	—	—	—	—	—	—	—	—	—	—
6	3	6	—	—	5	4	—	3	2	—	—	1	—	10	11
6.5	—	—	26	31	—	—	—	—	—	2	—	—	—	—	—
7	3	—	—	—	7	—	—	1	1	—	—	—	—	14	8
7.5	—	—	28	24	—	—	—	—	—	—	—	—	—	—	—
8	—	3	—	—	3	4	4	1	1	—	—	—	—	4	9
8.5	—	—	26	23	—	—	—	—	—	—	—	—	—	—	—
9	—	—	—	—	6	—	—	2	1	—	—	—	—	3	1
9.5	—	—	15	8	—	—	—	—	—	—	—	—	—	—	—
10	2	2	—	—	3	—	—	—	—	—	—	—	—	8	4
10.5	—	—	23	10	—	—	—	—	—	—	—	—	—	—	—
11	—	3	—	—	6	—	—	—	—	—	—	—	—	7	1
11.5	—	—	22	8	—	—	—	—	—	—	—	—	—	—	—
12	2	3	—	—	8	5	16	—	2	—	—	—	—	5	2
12.5	—	—	18	13	—	—	—	—	—	—	—	—	—	—	—
13	2	1	—	—	—	—	—	—	—	—	—	—	—	8	3
13.5	—	—	16	16	—	—	—	—	—	—	—	—	—	—	—
14	6	—	—	—	—	—	—	—	2	—	—	—	—	12	5
14.5	—	—	28	16	—	—	—	—	—	—	—	—	—	—	—
15	1	2	—	—	—	—	—	—	—	—	—	—	—	3	8
15.5	—	—	18	15	—	—	—	—	—	—	—	—	—	—	—
16	—	4	—	—	—	14	17	—	—	—	—	—	—	7	15
16.5	—	—	10	19	—	—	—	—	—	—	—	—	—	—	—
17	3	5	—	—	—	—	—	—	—	—	—	—	—	15	18
17.5	—	—	18	23	—	—	—	—	—	—	—	—	—	—	—
18	6	4	—	—	—	—	—	—	—	—	—	—	—	18	21
18.5	—	—	22	16	—	—	—	—	—	—	—	—	—	—	—
Adult			2107	1330											

ysis. Both annual (the weight one year was subtracted from the weight the next year) and biennial (the weight one year was subtracted from the weight two years later) changes were computed and the change was always plotted at the midpoint of the annual or biennial interval. Biennial changes were computed for comparison with the values presented by Epstein[6]. Epstein claimed that the biennial differences must be used to pick up the brain growth spurts when they do not occur at the same age in each child, but examination of many of the figures presented here illustrates that the annual changes do not differ greatly from biennial changes.

Allometric comparisons were made by simply computing the ratio of mean brain weight to mean body weight. Epstein[6] used brain weight/body weight 'expressed as the percentage increase over that expected from slope at that age', but he did not specify how he obtained the expected value. I tried various ways of calculating the expected value and could not obtain those in his Fig. 1. However, as examination of Figs. 1 and 2 will show, peak differences in brain weight and brain weight/body weight ratio occur at the same ages as in his figure. Reed and Stuart[19] measured body weights of children at integer ages (i.e. 1, 2, 3 years), whereas Boyd[2] presented brain weights at half-integer ages (i.e. 1.5, 2.5, 3.5 years). To compute brain/body weight ratios, the body weight values and standard deviations of Reed and Stuart were interpolated to half-integer ages. The resulting values did not differ from the corresponding values from Heimendinger[11,12] and therefore are considered reliable. The curves of Figs. 2 and 5 are plotted using the interpolated Reed and Stuart data, but nearly identical curves can be plotted using the Heimendinger data.

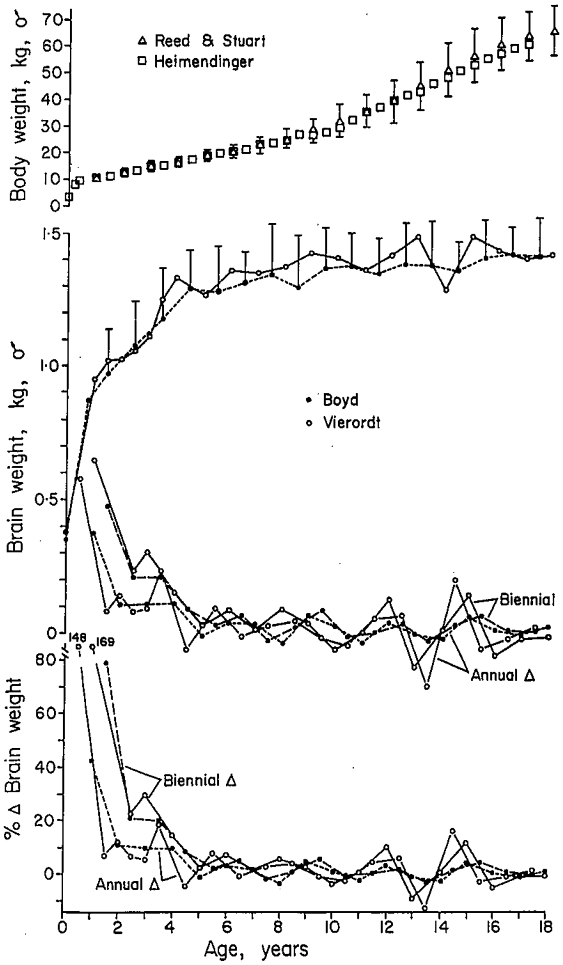

Fig. 1. Body and brain weights of boys at different ages. Body weights for boys are plotted against age in the upper panel. Standard deviations are shown for the Reed and Stuart[19] data only, but those for the Heimendinger[11,12] data are comparable. Brain weights from Boyd[2] (dashed curve) and from Vierordt[27] (solid curve) are plotted against age in the second panel. Annual and biennial changes in brain weight are plotted for the same data in the third panel with the points plotted at the midpoint of the age interval. Annual and biennial percent changes in brain weight are plotted in the lower panel.

Body weights were taken from two sources[11,12,19]. The values in these studies are not greatly different except that American children tend to be slightly heavier than Swiss children between 8 and 14 (girls) and between 12 and 18 (boys).

Head circumference has been measured in children in a large number of studies[4,5,11,12,16,26,28,29]. These studies come from a number of cultures including American[5,16,26,29] and European[4,11,12,28]. Only data from Eichorn and Bayley, Heimendinger, and Vickers and Stuart are presented here, but data from the other studies are comparable and substituting them does not change the conclusions to be drawn.

RESULTS

Brain weight

Fig. 1 shows body weights, brain weights, annual and biennial changes in brain weight, and percent changes in brain weight for boys between birth and 18 years of age. Body weight data were taken from Reed and Stuart[19] and Heimendinger[11,12]. The brain weight data plotted are from Boyd[2] (dashed line) and from Vierordt[27] (solid line). Standard deviations were calculated from Fig. 39 of Boyd[2] and plotted in Fig. 1 for boys and Fig. 4 for girls. Examination of Fig. 1 shows that there do appear to be decreases in the rate of growth of boys' brains beginning at about 4.5, 7.5, 9.5, 12 and 15 years of age in the Boyd data. These decreases are followed by increases ('spurts') which can be seen in both absolute annual changes and percent changes in brain weight. The result of these decreases and increases is the appearance of peaks in the records occurring at about 4, 6–7, 9, 12, and 15 years. None of the spurts in growth amounts to a change of more than 6–8% of the previous year's (or the year before the previous one) weight. Because the standard deviations of the Boyd data are 10–14% of the average brain weight, the spurts are likely the result of variability within the population, not a systematic increase in growth rate. Vierordt's[27] data also show spurts and troughs, but the spurts start

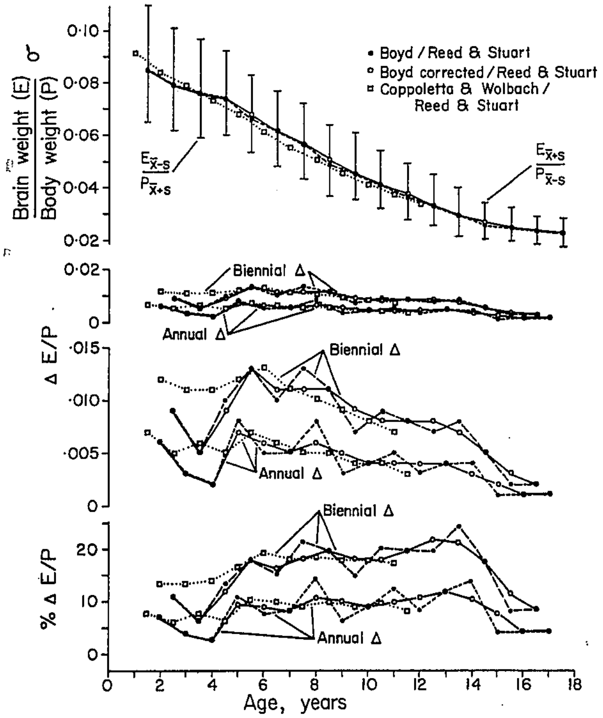

Fig. 2. Brain weight to body weight ratios of boys at different ages. Mean brain weight (E) to mean body weight (P) ratios are plotted against age using body weight data from Reed and Stuart[19] and brain weight data from Boyd[2] (original dashed; corrected solid) and Coppoletta and Wolbach[3]. Bars indicate ranges for Boyd data calculated as described in the text. Annual and biennial changes in the ratio are plotted for the same data in the second and third panels with the points plotted at the midpoint of the age interval on two different ordinate scales. Annual and biennial percent changes in the ratio are plotted in the lower panel.

at 1.5, 3, 4.5, 6.5, 10, 13.5, and perhaps 15.5 years of age in the annual change records. The peaks and valleys in the two sets of data are out of phase even in the biennial change records.

The same growth 'spurts' do not appear in the Coppoletta and Wolbach[3] data, rather there is a continuous decrease in growth rate throughout the period from birth to 12 years of age. This can be seen in the plot of Fig. 3 (open circles). Epstein[6] claims that the data of Coppoletta and Wolbach contain spurts at 6–7 years and 11–12 years of age. There is a small, statistically insignificant increase in brain weight at age 7, but the measurements end at age 12. It is impossible to determine whether there would have been a spurt at age 11–12. Coppoletta and Wolbach combined the measurements for boys and girls in their study. As will become apparent, data for girls and boys differ, and the absence of spurts could be the result of combining two curves slightly out of phase. This possibility was tested by combining the measurements for boys and girls in Boyd's data, with the result that the spurts were smaller, but present, except for the one at 12 years of age (Fig. 3, x).

It is possible that the growth spurts shown in the Boyd data reflect simple increases in rate of overall body growth rather than specific changes in brain growth. Fig. 2 shows the changes in brain weight/body weight for the same data as in Fig. 1, using body weights from Reed and Stuart[19]. The change in brain weight to body weight ratio has been plotted twice, once (second ordinate) on the same scale as the brain weight/body weight data (upper ordinate) and once (third ordinate) on a scale expanded 4 times compared with that for the ratio. When plotted on the

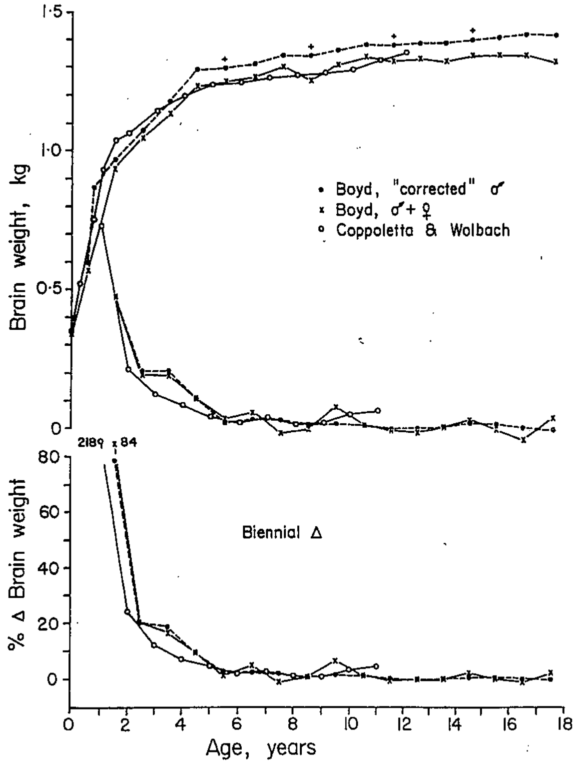

Fig. 3. 'Corrected' brain weights of boys. Boyd's[2] brain weight values were corrected by computing the mean of the value occurring before and the value occurring after a decreased weight. The mean is plotted (dashed curve) in place of the decreased value at position indicated by '+'. Annual and biennial changes and percent changes in the corrected weights are plotted in the center and lower panels. Also plotted in the same fashion are data from Coppoletta and Wolbach[3] (open circles) and from Boyd[2] (x) for both boys and girls considered together.

same scale, the changes in brain/body ratio approximate a straight line. The pattern of growth 'spurts' seen in Fig. 1 can also be seen on the expanded scale in Fig. 2 except that here the growth spurts start at about 4, 7, 9, and 12 years of age. Considering the brain weight to body weight ratio, the spurts reported by Epstein[6] in the Coppoletta and Wolbach data are still not evident. In Fig. 2, there is a very small increase in the ratio at 5.5–6 years, but none at 11–12 years of age.

Because the data for brain weight and body weight in Fig. 2 come from different studies, standard deviations of the ratio of brain weight to body weight are not available. In the figure is plotted an estimate of the variation in this ratio obtained by using the average brain weight plus one standard deviation divided by the average body weight minus one standard deviation as an estimate of a maximum value and the average brain weight minus one standard deviation divided by the average body weight plus one standard deviation as an estimate of a minimum value. This sort of measure should give a reasonable estimate of the range of the ratio, which should be equal to the mean ratio plus and minus 3 standard deviations. Using this estimate of the standard deviation at each age, none of the 'spurt' values for the brain weight to body weight ratio is significantly different from either the value for the age before or the age after it.

In Fig. 1, it is clear that each growth 'spurt' (third and fourth panels) is associated with a preceding *decrease* in average brain size (second panel). Note that the decreases occur regularly, about 3 years apart. These decreases are not seen in the Coppoletta and Wolbach data, nor are they seen as regularly in the Vierordt data. I have no idea what could be the cause of this apparent decrease in brain size, but it is doubtful that the brain actually decreases in size in a normal child whose age is within the range from birth to 18 years. If the data from Boyd[2] are 'corrected' so that the mean value of the points preceding and following decreases in brain size are substituted for the decreased value, then the dashed curve of Fig. 3 results. Here the 4 substituted points are indicated by the '+' above them. Making this substitution eliminates the 'spurts'. A Kolmogorov–Smirnov test was used to assess the goodness of fit of the observed values (uncorrected Boyd values, solid curve of Fig. 1, center panel) to the predicted values (corrected values, dashed curve of Fig. 3, upper panel) of brain size[23]. The computed value of $K_d = 2$ falls far short of the $P = 0.05$ level and, therefore, we have no reason to conclude that the peaks and troughs are other than sampling variation.

The absence of spurts in the brain weight to body weight ratio is not the result of equal changes in body weight at the spurt ages. Examination of Fig. 1 (upper panel) shows that there are no short spurts, but, rather, a single increase in growth rate beginning at about 9 years and ending at about 17 years.

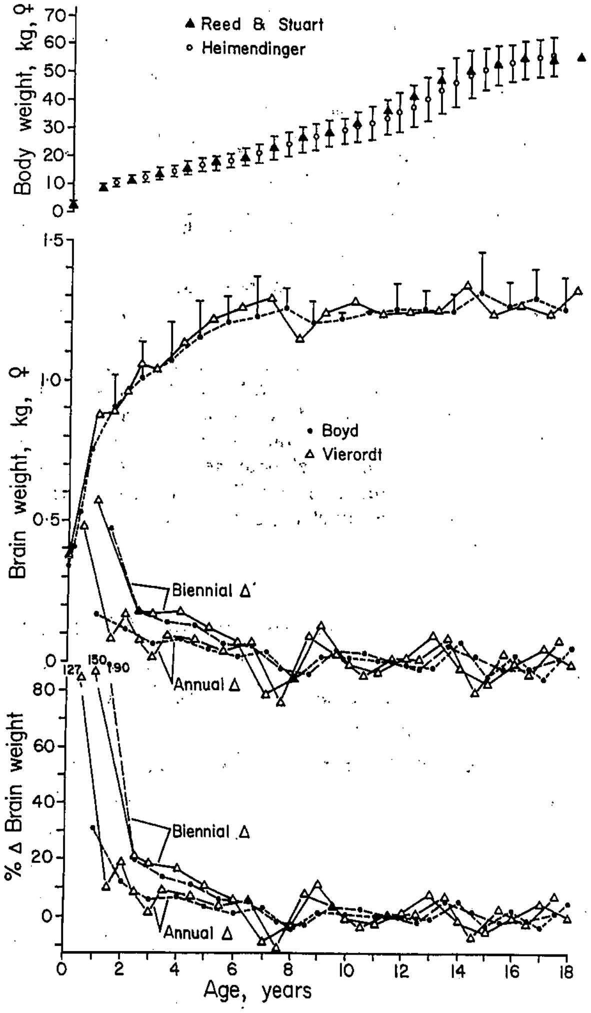

Fig. 4. Body and brain weights for girls at different ages. Body weights[11,12,19] are plotted in the upper panel along with the standard deviations for the Heimendinger[11,12] data only. Standard deviations for the Reed and Stuart[19] data are not different. Brain weights, taken from Boyd[2], along with changes in and percent changes in brain weights are plotted against age as in Fig. 1.

The growth of the brain in girls as measured by Scammon[2,21] is shown in Fig. 4. As in boys, there are apparent 'spurts' in brain growth, but in girls they start at about ages 8, 13, and 15 for annual changes in the Boyd data and about ages 1.5, 2.5, 7.5, 10.5, 14.5, and 16.5 in the Vierordt data. As in boys, the percent change during a spurt is less than or equal to the standard deviation of the brain weight measurements themselves. It would not be surprising to find that girls grow on a different timetable from boys, but the spurts are only apparent, again being associated with decreases in mean brain weight. Correcting the Boyd data for these decreases to obtain a monotonically increasing curve, removes all of the apparent spurts and troughs. A Kolmogorov–Smirnov test for goodness of fit of the observed to expected data for females yields the same result as that for males. Again, there is no reason to conclude that the peaks and troughs are other than sampling variation.

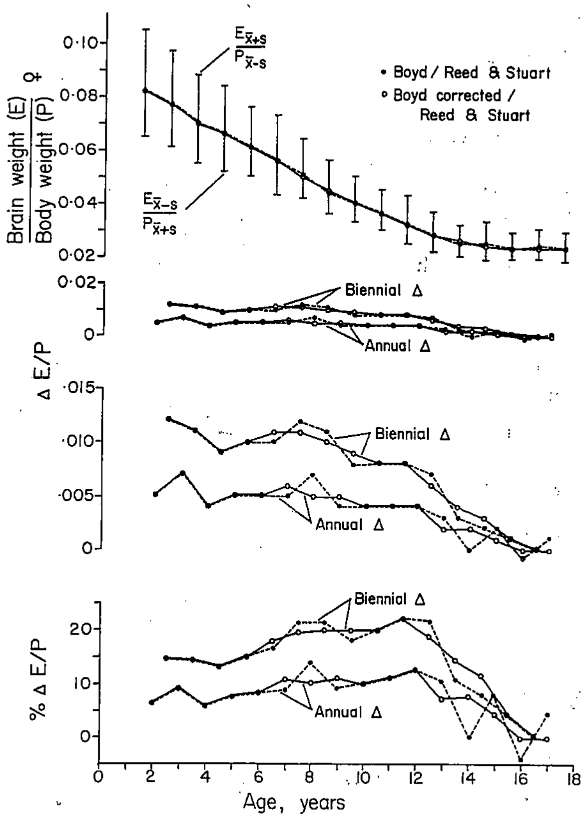

Fig. 5. Brain weight to body weight ratios for girls of different ages. Mean brain weights (E) were taken from Boyd[2] and plotted intact or corrected as described in the text. Mean body weights (P) were taken from Reed and Stuart[19]. Ratios are plotted in the upper panel, with annual and biennial changes and percent changes in the ratio plotted in the center panels and lower panel, respectively. Note that the changes in the ratio are plotted on the same ordinate scale as the upper panel (second panel) and also on an expanded ordinate scale (third panel).

Brain weight to body weight ratios are shown for girls in Fig. 5. Plotting the ratios shifts the peaks in the curves to ages 8, 12, and 15 (considering only annual changes). Again, note that the changes in brain weight to body weight ratio are plotted twice, once on the same scale as the ratio itself and once on a scale much expanded compared to that for the ratio itself, magnifying the small changes. Examination of the second panel (plotted on the same scale as the ratio) shows the corrected values yield a virtually straight line. Again, any real spurts are not being masked by equal changes in body weight. As can be seen in the upper panel of Fig. 4, there are increases in growth rate for the body beginning at 5–6 and ending at about age 16, with a small trough in the curve for Swiss children between 8 and 9. The reason for this trough is not apparent.

It is clear from examination of the various studies of brain weight in children that the measurement of brain weight is a highly variable activity. But, the mass of the human brain itself is highly variable. Scammon[21] measured the brains of 2107 adult males and 1330 adult females and obtained mean values of 1355 and 1220 g, respectively. Unfortunately, he did not report the standard deviations for these measurements, but presumably they are similar to those for older children, 10–14% of the mean value. The average brain weights of children equal or exceed the average for adults in the Scammon study by about age 10. Therefore, the adult brain size is achieved before the adult body size.

Woodward and Goldsmith[30] have described the use of cumulative sum techniques to detect changes in the average level of a sequence of measures arranged in chronological order. In this analysis, a constant value, usually the target level which the measurements are supposed to approach, is subtracted from each measurement and a cumulative sum chart, much like a cumulative frequency chart, is constructed. Such a chart is shown in Fig. 6 for the Boyd brain weight data for both boys (filled circles) and girls (open circles). In this chart, the constant value subtracted from each measurement is the mean of the last 4 brain weight values, i.e., for ages 14.5–17.5.

In cumulative sum analysis, a change in the aver-

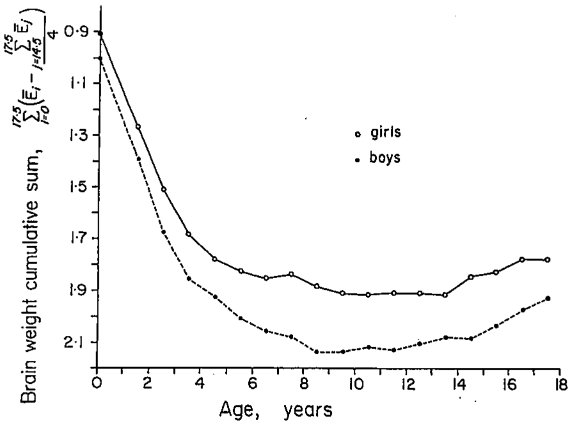

Fig. 6. Cumulative sum analysis. Cumulative sums of brain weights for girls (open circles) and boys (closed circles) were computed after subtracting the mean of the brain weight values for ages 14.5–17.5 years of age and plotted against age on the abscissa.

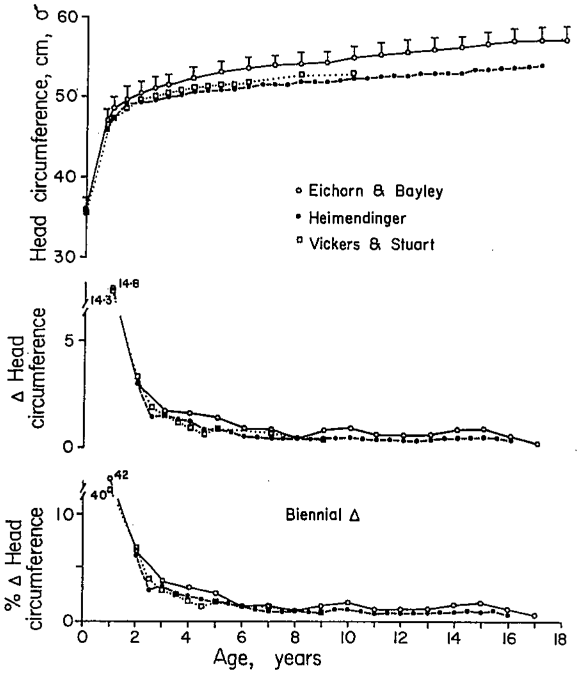

Fig. 7. Head circumferences for boys of different ages. Mean head circumferences were taken from Eichorn and Bayley[5] (solid), Heimendinger[11,12] (dashed) and Vickers and Stuart[26] (dotted) and plotted against age in the upper panel. Biennial changes and percent changes in head circumference are plotted in the center and lower panels. Note the expanded ordinate in the center panel.

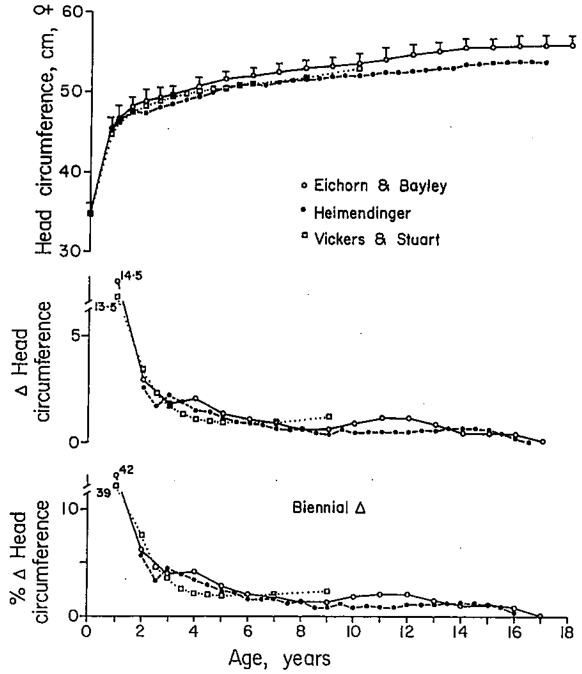

Fig. 8. Head circumferences for girls of different ages. Sources and method of plotting are as in Fig. 7.

age level of the measurements is indicated by a change in the slope of the curve. It is clear that the slope of the curves for both boys and girls in Fig. 6 changes smoothly from a negative value to less negative values as age increases to about 10–11 years, at which point the slope is nearly zero. After 11 years of age, the slope becomes positive. There are only small deviations from this behavior at 7.5 years, where the slope increases for both sexes, and at 13.5 years, where the slope increases for girls and decreases for boys. Even these deviations are very small. Using cumulative sum analysis, we can find little evidence for spurts.

Head circumference

Head circumference is related to brain weight by a power function, at least up to brain weights of 1000 g[29]. This allows one to estimate brain size from head circumference, and it suggests that as a variable head circumference should behave like brain weight, i.e. it should show spurts in growth if brain weight does. I have re-examined the changes in head circumference with age in 7 different studies[4,5,11,12,16,26,28,29]. Figs. 7 and 8 show plots of head circumference at ages 0–17 years for 3 different studies in boys and girls. There is not a hint of a spurt in the study of Heimendinger[11,12] and the small variations in values from Eichorn and Bayley[5] are 1–2% compared with standard deviations of 5%. The small variations in the boys' head circumference data (Fig. 7) of Eichorn and Bayley correspond only roughly in timing to the 'spurts' for brain size in Fig. 1, and there is no relationship between the small variations in the girls' head circumference data (Fig. 8) and the 'spurts' for brain size in Fig. 4. This is despite the large coefficients of correlation that exist between the Boyd brain weight data and both the Vickers and Stuart[26] and Heimendinger[11,12] head circumference data. For Vickers and Stuart, Pearson's r is 0.98 (boys) and 0.98 (girls), Spearmann's ϱ is 0.94 and 1.0, and Kendall's τ is 0.87 and 1.0. For Heimendinger, Pearson's r is 0.93 (boys) and 0.93 (girls), Spearmann's ϱ is 0.94 and 0.54, and Kendall's τ is 0.85 and 0.51. Data from Westropp and Barber[28], Dokladal[4], Winick and Rosso[29], and Nellhaus[16] have not been included in these graphs for the sake of clarity, but they are not different from those included.

DISCUSSION

In a re-examination of published data on brain weights of children, I have failed to find any convincing evidence for 'spurts' in growth of the brain during childhood. What variations there are from general trends are well within expected variations when sampling from a population, i.e., within one standard deviation. The same is true for changes in head circumference with age.

Using some of the same data, Epstein[6] came to the conclusion that there were spurts in growth of both head circumference and brain weight in children. He used a normalization procedure to plot the results of these studies, in which he set the largest change observed to a value of one regardless of how large that change was. This procedure can mislead the unwary by magnifying small changes which are within the limits of expected statistical variation.

It is not clear what significance 'spurts' would have if they existed. In animals, most of the proliferation of neurons occurs near the time of birth with only a small late postnatal increment[14]. Most of the later increase in mass comes about by proliferation of glial cells and the proliferation of axons and myelin, and, presumably, synaptic connections. It seems reasonable that changes in mental abilities are correlated with the increase in synaptic connections. We do not know what role glia may play in mental ability. In any case, we clearly do not have sufficient evidence to conclude that 'with virtually no increase of brain size and mass in the large majority of 12- to 14-year-olds, there is no growth in the capacity of the brain to handle more complex thinking processes . . .'[9]. Many adults learn new cognitive skills and handle more complex thinking processes without having an actively growing brain. A growing brain cannot be required, but it is possible that a certain minimal amount of brain or brain-interconnection is required to do these things. This would lead to a rough correlation of age with cognitive skills. It is certainly too early to start reorganizing school curriculae on grounds that the growth of the brain occurs in spurts.

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