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# THE GROWTH OF CHILDREN AT DIFFERENT ALTITUDES IN ETHIOPIA

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## CONTENTS

In this study were observed the effects of two widely differing environments on the growth and maturation of children from a presumed genetically homogeneous Ethiopian population. Major environmental differences included altitude above sea level, temperature, probably rainfall and humidity, together with the incidence of infectious disease. The results indicate that highland children, particularly boys, are taller, heavier and bigger in most physical dimensions than are lowland children. In both groups skeletal maturation is retarded (by American White standards) during later childhood; this retardation is more marked in lowlanders. In both groups, however, there is marked acceleration of skeletal maturation during early puberty. Haemoglobin values increase much more rapidly in highland children, but surprisingly, differences in chest dimensions are not particularly marked.

It is concluded that hypoxia of the degree found in the high-altitude group (approximately 3000 m) is not sufficient to affect adversely the growth of children. On the other hand, the increased incidence of infectious disease in the 'lowlands' (approximately 1500 m) and possibly the raised ambient temperature, may restrict growth and maturation of children living in this environment. Thus, in contrast to the situation in other high-altitude parts of the world, the highlands in Ethiopia appear to be more favourable to growth than the lowlands.

## 1. INTRODUCTION

Among mountainous areas of the world Ethiopia offers particularly suitable conditions for studying the effects of altitudinal variation on human populations. The centre of the country consists of a deeply dissected plateau, the heartland of the Amhara, the dominant tribe. Here the uplands have been heavily colonized up to altitudes of between 3600 and 3900 m, while below the steep escarpments which fall from the plateau are populous regions at between 1200 and 1800 m which will be referred to as 'lowlands'. The distances between highland and lowland settlements are often very short, but communications have been, and often still are, difficult. In some parts, however, the existence of roads crossing the escarpment has made communications between highland and lowland villages comparatively simple, and for the present investigation two villages were selected, one in the highlands and one in the lowlands, which are connected by a good road. The adult populations of these two villages were studied by a previous expedition, the results of which were described by Harrison *et al.* (1969).

The highland village, Debarech, lies in the Simien Mountains of north-western Ethiopia near the northern edge of the escarpment. Its altitude is approximately 3000 m and its population, mainly Coptic Christian with some Muslims, is about 5000. It is the seat of the Sub-Governor of the Simien region and is its principal market town. The inhabitants are engaged principally in farming, both crop- and stock-raising, or in services associated with the main highway which runs through the village.

Adi Arkai, the lowland village, lies below the Simien escarpment at an altitude of about 1500 m. By road it is 74 km from Debarech, but the direct distance is very much less than this – of the order of 30 km. The village has a population of about 2500 and the occupations of its inhabitants are broadly similar to those at Debarech.

Apart from the altitudinal variation between the two villages, differences in terrain and temperature are found. The terrain at Adi Arkai is hilly and irregular, whereas that at Debarech is much more level. Temperature differences are also marked in accordance with the normal altitudinal valuation. At both places day temperatures during the dry season may reach about

35 °C, and at Adi Arkai there is relatively little diurnal variation. At Debarech, on the other hand, night temperatures at this time may fall to freezing-point or below. Indeed, the two villages fall into quite distinct climatic zones well recognized by the Amhara themselves (Simoons 1960). Adi Arkai lies near the upper limit of the *K'olla* – the unhealthy lowland extending up to 1800 m – which is characterized by high summer temperatures (highest monthly means approach 30 °C). Debarech lies in the *Dega* (highland) zone above 2400 m where the highest mean monthly temperatures do not exceed 18 °C. There is little information about annual precipitation, but it seems permissible to suppose that it is higher in the highlands than in the lowlands.

The inhabitants of both villages are principally Amharic-speaking, although at Adi Arkai, near the edge of the Tigrean-speaking region, a fair proportion of the population speak this language. The existence of a road linking highlands and lowlands (constructed by the Italians during 1938–40) and the importance of the two villages as market centres for the surrounding countryside means that they contain numerous migrants, both from surrounding regions and also from considerable distance; the samples of adults examined by Harrison *et al.* (1969) showed clear evidence of migration, both from highlands to lowlands and vice versa, so that a good deal of mixing of populations seems to occur. Genetic marker studies on residents show practically no significant differences in gene frequencies between the two villages (Harrison *et al.* 1969).

The existence of two genetically similar populations living in environments which are in many respects very different, provides a suitable background for the study of environmentally determined phenotypic differences, since in terms of populations, such differences as exist can be ascribed to environmental causes. The investigation of Harrison *et al.* (1969) was directed principally to the anthropometry and respiratory physiology of adults and the results to be described are an attempt to extend the anthropometric study to growing children. The principal finding of Harrison *et al.* was that at high altitudes, adult males are significantly heavier and females significantly taller and heavier than lowlanders. The chest dimensions of high-altitude males were also greater than those of lowlanders and it is clearly important to establish at what stage in the growth process differences such as these become manifest. The comparison is all the more important because many workers at extremely high altitudes, particularly in the Andes, have found adult size to be smaller and growth rates of children to be slowed in comparison with equivalent lowland groups (Frisancho, 1966, 1969*a*, *b*, 1970; Frisancho & Baker 1970; Baker 1969).

While between-group comparisons in individual physical parameters are of considerable interest, it is difficult to extrapolate from them to overall physical differences between the groups. Various statistical techniques have been established to estimate such total differences (e.g. Mahalanobis 1936; Huizinga 1962; Hiernaux 1964) and recently the method of canonical analysis (Rao 1952) has been much employed. This technique, together with the closely related statistic of squared generalized distance (Mahalanobis 1936), has been used to estimate overall differences between the groups examined in this survey.

## 2. METHODOLOGY

### (*a*) *The sample*

The field work was undertaken by E. J. C. and I. G. P. during December 1967 and January 1968. Because of the excellent cooperation of both governmental and local officials and teachers it was possible to examine a total of 324 children in the village schools at Debarech and Adi Arkai. At the former place 93 boys and 76 girls were examined and at the latter 95 boys and 60 girls. The age ranges were from 5 to 19 for the boys and 5 to 16 for the girls. In addition, a few children of pre-school age were examined in each village. All the children were born in or near the place of examination and appeared to be in good health. With the aid of Ethiopian interpreters and the cooperation of the parents it was possible to obtain exact dates of birth of all children.

From the point of view of administrative ease, the examination of school populations in a growth study is in many ways ideal – the children are available in sufficient numbers when required and physical facilities are better than in a tented camp. However, there are some objections, the principal one being that in an underdeveloped country it is unlikely that children at school are representative of the child population as a whole. Although education is free in Ethiopia, there are obvious economic disadvantages in keeping at school a child who could be actively engaged in productive work for the household. Hence it seems probable that school-children will be preferentially drawn from families either of higher socio-economic status or who put a greater-than-average value upon education. Such differentiation will increase with the age of the child, since while there may be little economic loss in keeping a 6-year-old at school, there may be a considerable one where an 18-year-old is concerned. However, as far as the comparison between highland and lowland populations is concerned, the apparent cultural homogeneity of the region makes it unlikely that these deviations from random sampling are significantly different in the two villages. Hence we have made the assumption that comparisons between individuals of the same sex in the two villages are valid. In between-sex comparisons, it might be argued that the bias in favour of high socio-economic status is greater in girls than in boys. Again it seems unlikely that such bias, if it exists, will differ widely in the two villages, but its possibility necessitates greater caution in the interpretation of these comparisons.

### (*b*) *Methods of measurement and analysis*

The measurements made were those of the I. B. P. 'Full List' described by Tanner, Hiernaux & Jarman (1969). X-rays of the left wrist at a tube-film distance of 30 in (75 cm) were made on Ilfex film using a Picker portable X-ray apparatus. Haemoglobin estimations were made on finger-tip samples of blood using a photo-electric colorimeter. The following methods of analysis were used:

(*a*) Between-group comparisons of individual physical parameters were made by regression analysis, the independent variable being either chronological age or skeletal age, using the atlas of Greulich & Pyle (1959) as a basis for comparison. Regressions were usually rectilinear, and in the majority of instances where inspection proved this not to be the case, conversions of measurements to logarithmic units gave straight-line regressions. Differences in the elevations of regression lines (adjusted means), were tested by the techniques of covariance analysis (Snedecor 1956) in instances where it had emerged that within the limits of sampling errors, the regression lines could be assumed to be parallel. In the case of stature and body weight, observations were also plotted on percentile charts for European children (Tanner, Whitehouse & Takaishi 1966) and between-group comparisons were made on the basis of the frequencies with which individuals fell into the different European percentile ranges.

No attempt was made to compute polynomial regression equations for the logarithmic transforms of the three subcutaneous fat thicknesses measured, since the biological interpretation of such equations would have been extremely difficult. Instead, the values obtained for the triceps and subscapular skinfolds were plotted on the percentile charts for European children prepared by Tanner & Whitehouse (1962) and between-group comparisons were made in the manner described above.

(*b*) As a means of assessing overall differences between the four groups studied, computations were performed by the technique of canonical analysis. This part of the investigation was carried out on the IBM 1440 and English Electric KDF 9 computers in the University of Birmingham.

For each group the regressions of each variable, or its logarithm where appropriate, on chronological age were calculated and covariance adjustments of the mean values of each dependent variable were made to eliminate differences due to the varying age ranges of the four groups. The data so obtained were subjected to canonical analysis using the computational technique of Gower (1966) in the course of which a matrix of squared generalized distances (Mahalanobis 1936) was calculated. This form of analysis computes the overall degree of separation between each pair of the sex and altitude subgroups, making proper allowance for the statistical interrelationships (correlations) between all pairs of variables.

(*c*) In addition to the regression of actual measurements on age, the regressions of certain indexes and parameters derived from these measurements were calculated. These variables included:

$$\text{brachial index} \quad \frac{\text{forearm length}}{\text{upper arm length}} \times 100,$$

$$\text{cephalic index} \quad \frac{\text{head breadth}}{\text{head length}} \times 100,$$

$$\text{nasal index} \quad \frac{\text{nose breadth}}{\text{nose height}} \times 100,$$

$$\text{cormic index} \quad \frac{\text{sitting height}}{\text{stature}} \times 100.$$

A modification of Schreider's (1964*a*) limb length–body weight ratio was also calculated:

$$\frac{2 \times (\text{total leg length (cm)} + \text{total arm length (cm)})}{\text{body weight (kg)}}.$$

It will be referred to in the text as 'Schreider's index'.

$$\text{Body surface area (Dubois's formula: } A = W^{0.425} \times H^{0.725} \times 0.007184\text{)},$$

where $A$ is the surface area in m$^2$, $W$ is the body mass in kg and $H$ the stature in cm. The regressions of all these variables on chronological and skeletal age were calculated. A similar procedure was followed for haemoglobin levels.

## 3. RESULTS

Results will be presented in six sections: (1) developmental age (skeletal and dental development); (2) regressions of individual measurements on chronological and skeletal ages and the results of canonical analysis; (3) stature–body weight relationships; (4) skinfold thicknesses; (5) the regressions of the various indexes and of haemoglobin on chronological and skeletal ages; (6) puberty ratings.

### (a) *Developmental age*

#### (i) *Skeletal age*

The relationship between skeletal and chronological age was found to be nonlinear in all four groups of Ethiopian children as judged by accepted linear standards based upon European children (Greulich & Pyle 1959). There was pronounced retardation in skeletal development during childhood, followed by considerable acceleration with the onset of puberty (figure 1). The small number of points in the low-altitude parts of the figure is due to the loss of many of the X-ray films of these children. However, those remaining sample reasonably well the children of both sexes examined at the low-altitude village, and it appears that despite the numerical weighting in favour of the highland children, between-altitude comparisons are meaningful. Conversion of skeletal age to logarithmic units gave a better approximation to linearity and the results of the covariance analysis to eliminate differences due to the varying chronological age composition of the different groups are shown in table 1. In the comparisons between altitude, adjusted means are greater in the highland groups, significantly so in the males. In the between-sex comparisons, the adjusted means for females are the greater, especially at low altitudes. Regression coefficients show no significant differences between groups, although they tend to be greater in lowlanders irrespective of sex and in females irrespective of altitude.

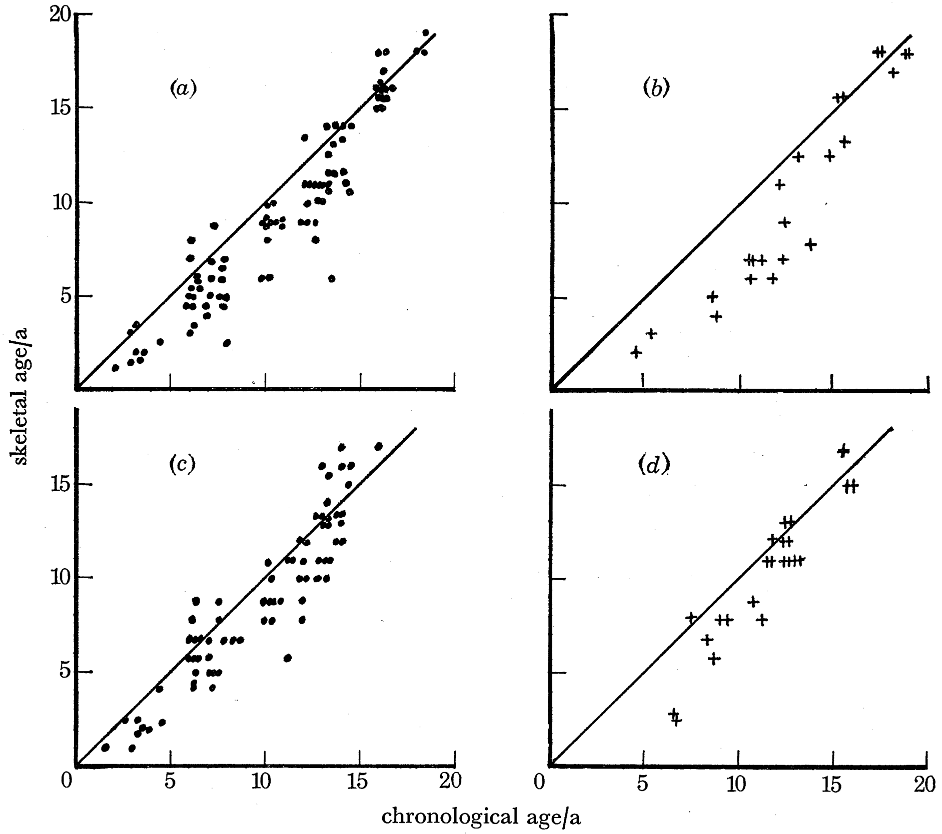

FIGURE 1. The relationship between skeletal and chronological age for the different groups of Ethiopian children. (*a*) High-altitude male (h.a.m.); (*b*) low-altitude male (l.a.m.); (*c*) high-altitude female (h.a.f.); (*d*) low-altitude female (l.a.f.). The straight lines indicate the relationship between skeletal and chronological ages in populations developmentally similar to the sample studied by Greulich & Pyle (1959).

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TABLE 1. MEAN VALUES (AFTER COVARIANCE ADJUSTMENT FOR DIFFERENCES IN AGE DISTRIBUTIONS) OF $\mathrm{LOG}_{10}$ SKELETAL AGES, AND THEIR REGRESSION COEFFICIENTS ON CHRONOLOGICAL AGE

h.a.m., high-altitude male; l.a.m., low-altitude male; h.a.f., high-altitude female; l.a.f., low-altitude female. **** $P < 0.001$.

| comparison | adjusted mean $\log_{10}$ skeletal age | | regression coefficient $b$ | |
|---|---|---|---|---|
| | h.a.m. | l.a.m. | h.a.m. | l.a.m. |
| h.a.m./l.a.m. | 0.9344 | 0.8509**** | 0.0548 | 0.0648 |
| | h.a.f. | l.a.f. | h.a.f. | l.a.f. |
| h.a.f./l.a.f. | 0.9101 | 0.8831 | 0.0679 | 0.0702 |
| | h.a.m. | h.a.f. | h.a.m. | h.a.f. |
| h.a.m./h.a.f. | 0.8845 | 0.9111 | 0.0548 | 0.0679 |
| | l.a.m. | l.a.f. | l.a.m. | l.a.f. |
| l.a.m./l.a.f. | 0.9000 | 1.0171**** | 0.0648 | 0.0702 |

(ii) *Dental development*

Since only a small number of children aged under 5 years were examined, it was not thought worth-while to report on the numbers of deciduous teeth erupted. In considering the permanent teeth, only the fact of eruption was noted; the degree of eruption, existence of dental abnormalities, the prevalance of caries, etc., were not taken into account.

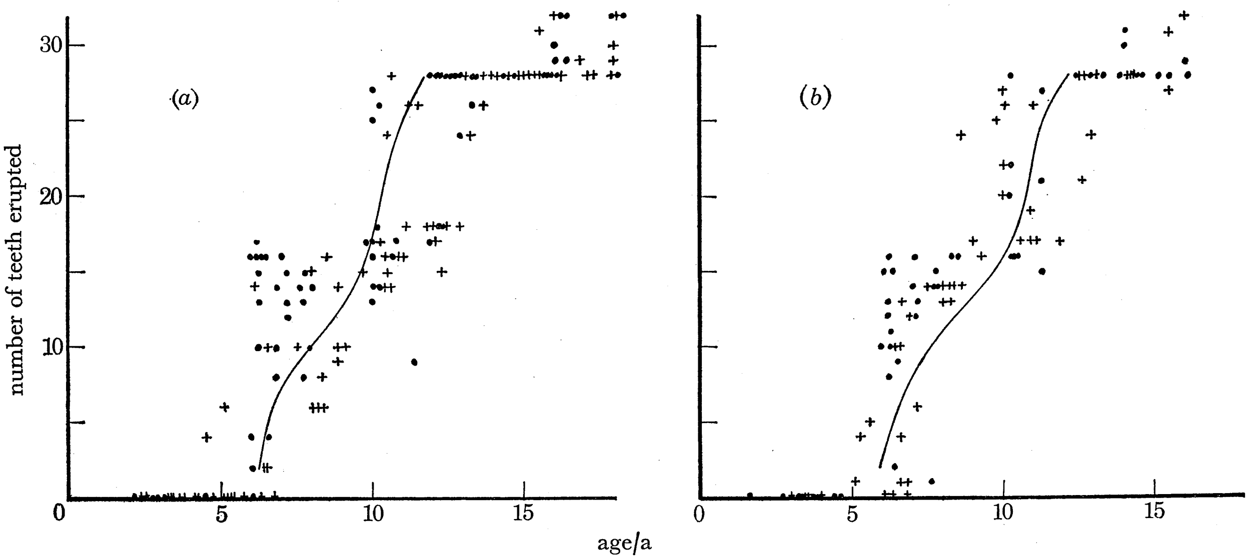

FIGURE 2. Numbers of teeth erupted in Ethiopian children. (*a*) Boys; (*b*) girls. The continuous line on each figure joins the means for U.S. White children. ●, High altitude; +, low altitude.

Figures 2*a* and 2*b* show the numbers of permanent teeth erupted in males and females of various ages at each altitude, compared with the norms for European children in the U.S.A. (Hurme 1949). For Ethiopian children of both sexes, particularly girls, the period between 6 and 9 years is one of relative dental advancement. From then until the age of 13 years there is little difference from European standards. Indeed, there is a tendency for boys to fall behind White standards.

Comparisons between highland and lowland groups of similar age (figures 3*a* and 3*b*) show that highlanders are advanced over lowlanders until the age of 10 in boys and 9 in girls. For the next year or two there is little difference between the groups, but at ages greater than 12 in boys and 10 in girls, highlanders again show advancement. Between-altitude differences in the mean numbers of teeth erupted in particular age-groups are statistically significant in boys in the ranges 6 to 7, 7 to 8 and 12 to 13. For girls, differences are significant only in the 6 to 7-year age-group.

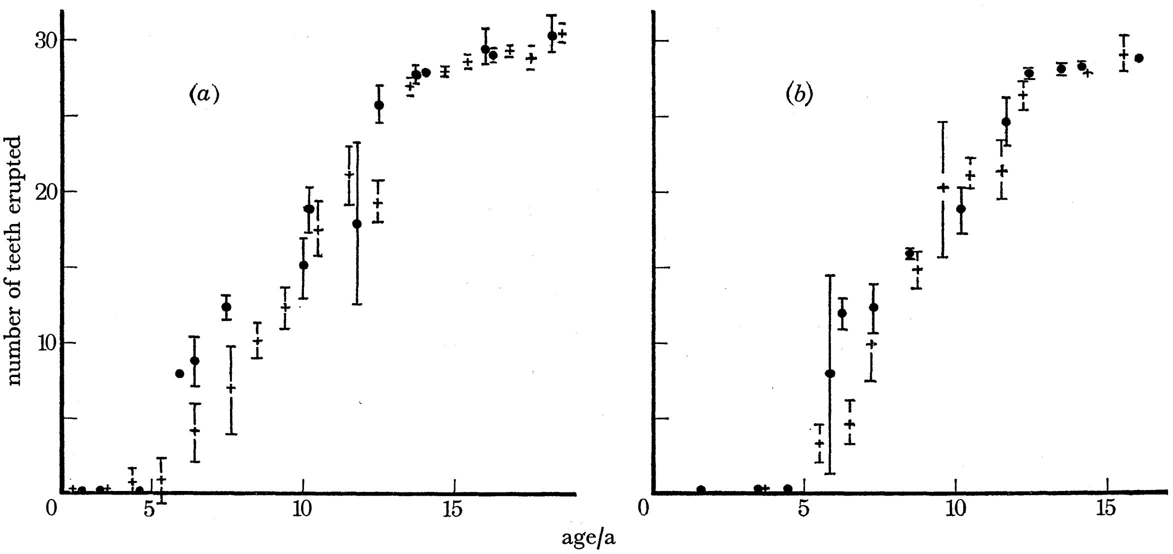

FIGURE 3. Between-altitude comparisons of numbers of teeth erupted (± S.E.M.) in children in different 1-year classes. (a) Boys; (b) girls. ●, High altitude; +, low altitude.

### (b) *Regressions of individual measurements on chronological and skeletal ages*

#### (i) *Chronological age*

The results of comparisons between adjusted means and regression coefficients for the various measurements on chronological age are summarized in table 2. A full presentation of the values of these means, of the regression coefficients and of the significance of differences resulting from the comparisons has been deposited in The National Lending Library, Boston Spa, Yorkshire, LS 237 BQ. The significance of differences between adjusted means has been estimated only in those comparisons in which regression coefficients do not differ significantly. From the between-altitude comparisons, it emerges that the males at high altitude are unequivocally larger than those at low altitude and the regressions of individual measurements on chronological age are steeper. For females, the overall differences are less clear-cut. While adjusted means are greater in the highlanders, regression coefficients are generally greater in the lowlanders.

In the comparisons between sexes differences are rather less marked. At high altitudes adjusted means are more often greater in males, although body weight is greater in females and regression coefficients, in the few instances in which differences are statistically significant, are also greater in females. At low altitude the general superiority of the females is clear; adjusted means of males are higher in fewer measurements than those in which means of females are greater and regression coefficients are consistently greater in females.

TABLE 2. SUMMARY OF THE RESULTS OF COMPARISONS BETWEEN ADJUSTED MEAN VALUES OF INDIVIDUAL MEASUREMENTS IN BOYS AND GIRLS FROM BOTH HIGH- AND LOW-ALTITUDE POPULATIONS, AND BETWEEN THE CORRESPONDING REGRESSION COEFFICIENTS OF EACH MEASUREMENT ON CHRONOLOGICAL AGE

The dimensions listed are those in which the values of $P$ derived from the comparisons were less than or equal to 0.05. Percentage differences between adjusted means are also given.

| males | | | females | | | high altitude | | | | low altitude | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| high altitude > low altitude | | low altitude > high altitude | high altitude > low altitude | | low altitude > high altitude | males > females | | females > males | | males > females | | females > males | |
| measurement | % difference | | measurement | % difference | measurement | measurement | % difference | measurement | % difference | measurement | % difference | measurement | % difference |
| *adjusted means* | | *adjusted means* | *adjusted means* | | *adjusted means* | | | *adjusted means* | | *adjusted means* | | *adjusted means* | |
| stature | 2.89 | nil | $\log_{10}$ body weight | 2.33 | nil | bicondylar humeral diameter | 15.05 | $\log_{10}$ body weight | 1.75 | bicondylar femoral diameter | 3.03 | stature | 3.70 |
| sitting height | 2.55 | | upper arm length | 5.51 | | wrist breadth | 2.84 | upper arm circumference (relaxed) | 6.39 | ankle breadth | 2.13 | suprasternal height | 3.61 |
| total arm length | 2.88 | | upper arm circumference (relaxed) | 4.73 | | hand breadth | 2.68 | upper arm circumference (contracted) | 3.38 | anteroposterior chest diameter | 6.40 | anterior superior iliac spine height | 4.56 |
| upper arm length | 6.03 | | upper arm circumference (contracted) | 5.85 | | bicondylar femoral diameter | 3.38 | | | head length | 1.47 | sitting height | 3.52 |
| bicondylar humeral diameter | 2.20 | | thigh circumference | 5.27 | | ankle breadth | 6.19 | | | | | total arm length | 2.56 |
| hand breadth | 2.15 | | total face height | 5.04 | | foot length | 2.21 | | | | | upper arm length | 3.21 |
| foot length | 3.53 | | nose height | 8.48 | | head length | 4.03 | | | | | forearm length | 2.91 |
| calf circumference | 4.06 | | | | | head height | 1.64 | | | | | | |
| biacromial diameter | 3.25 | | | | | | | | | | | | |
| bi-iliac diameter | 4.57 | | | | | | | | | | | | |
| transverse chest diameter | 4.67 | | | | | | | | | | | | |
| chest circumference | 3.55 | | | | | | | | | | | | |
| head length | 1.77 | | | | | | | | | | | | |
| head breadth | 2.63 | | | | | | | | | | | | |
| *regression coefficients* | | *regression coefficients* | *regression coefficients* | | *regression coefficients* | *regression coefficients* | | *regression coefficients* | | *regression coefficients* | | *regression coefficients* | |
| $\log_{10}$ body weight | | nil | stature | | wrist breadth | nil | | forearm length | | nil | | $\log_{10}$ body weight | |
| anterior superior iliac spine height | | | anterior superior iliac spine height | | biacromial diameter | | | thigh circumference | | | | upper arm circumference (relaxed) | |
| upper arm circumference (relaxed) | | | | | anteroposterior chest diameter | | | biacromial diameter | | | | upper arm circumference (contracted) | |
| upper arm circumference (contracted) | | | | | mouth width | | | | | | | thigh circumference | |
| thigh circumference | | | | | lip thickness | | | | | | | bi-iliac diameter | |
| total face height | | | | | head height | | | | | | | | |
| nose height | | | | | | | | | | | | | |
| mouth width | | | | | | | | | | | | | |

Table 3. Similar to table 2, except that the independent variable in the regression analysis was skeleta age, rather than chronological age

| males | | | | females | | | | high altitude | | | low altitude | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| high altitude > low altitude | | low altitude > high altitude | | high altitude > low altitude | | low altitude > high altitude | | males > females | | females > males | males > females | | females > males |
| measurement | % difference | measurement | % difference | measurement | % difference | measurement | % difference | measurement | % difference | measurement | measurement | % difference | measurement |
| *adjusted means* | | *adjusted means* | | *adjusted means* | | *adjusted means* | | *adjusted means* | | *adjusted means* | *adjusted means* | | *adjusted means* |
| mouth width | 4.50 | head height | 2.50 | transverse chest diameter | 4.41 | wrist breadth | 3.60 | stature | 3.09 | nil | bicondylar humeral diameter | 5.52 | nil |
| | | | | head breadth | 2.68 | ankle breadth | 4.00 | anterior superior spine height | 3.74 | | bicondylar femoral diameter | 5.46 | |
| | | | | | | head length | 1.88 | total arm length | 3.75 | | ankle breadth | 6.29 | |
| | | | | | | bigonial diameter | 7.81 | bicondylar femoral diameter | 5.79 | | transverse chest diameter | 8.49 | |
| | | | | | | head height | 2.30 | ankle breadth | 8.26 | | anteroposterior chest diameter | 6.50 | |
| | | | | | | | | foot length | 5.03 | | head length | 2.65 | |
| | | | | | | | | biacromial diameter | 3.35 | | head breadth | 3.93 | |
| | | | | | | | | transverse chest diameter | 3.40 | | total face height | 4.72 | |
| | | | | | | | | head length | 4.44 | | | | |
| | | | | | | | | bizygomatic diameter | 3.28 | | | | |
| | | | | | | | | bigonial diameter | 3.49 | | | | |
| | | | | | | | | mouth width | 3.39 | | | | |
| *regression coefficients* | | *regression coefficients* | | *regression coefficients* | | *regression coefficients* | | *regression coefficients* | | *regression coefficients* | *regression coefficients* | | *regression coefficients* |
| stature | | nil | | stature | | mouth width | | bicondylar humeral diameter | | thigh circumference | nil | | mouth width |
| $\log_{10}$ body weight | | | | $\log_{10}$ body weight | | | | wrist breadth | | | | | |
| suprasternal height | | | | suprasternal height | | | | hand breadth | | | | | |
| anterior superior iliac spine height | | | | anterior superior iliac spine height | | | | total face height | | | | | |
| sitting height | | | | sitting height | | | | nose height | | | | | |
| total arm length | | | | foot length | | | | | | | | | |
| forearm length | | | | total face height | | | | | | | | | |
| hand breadth | | | | nose height | | | | | | | | | |
| upper arm circumference (contracted) | | | | | | | | | | | | | |
| bicondylar femoral diameter | | | | | | | | | | | | | |
| ankle breadth | | | | | | | | | | | | | |
| foot length | | | | | | | | | | | | | |
| thigh circumference | | | | | | | | | | | | | |
| calf circumference | | | | | | | | | | | | | |
| bi-iliac diameter | | | | | | | | | | | | | |
| chest circumference | | | | | | | | | | | | | |
| bigonial diameter | | | | | | | | | | | | | |
| total face height | | | | | | | | | | | | | |
| nose height | | | | | | | | | | | | | |

### (ii) *Skeletal age*

The results, expressed in a similar way to those for chronological age, are shown in table 3. A full presentation of these results has been deposited in The National Lending Library, Boston Spa. They show some notable differences from the regressions of individual dimensions on chronological age. In particular, in the male between-altitude comparison, large numbers of measurements show significantly different regression coefficients, in all of which the highland children are superior to the lowland children. In the female between-altitude comparison the regression coefficients show similar, although less well-marked differences. In the between-sex comparisons the results are similar at either altitude, almost all significant differences, whether of adjusted mean or regression coefficient, being in favour of the males.

### (iii) *Canonical analysis*

The matrix of squared generalized distances (Mahalanobis 1936) is summarized in table 4. This indicates first, that overall between-sex differences are of similar degree at each altitude and secondly that between-altitude differences are similar in each sex. The overall difference between highland and lowland children is approximately equivalent to the male–female difference in each altitudinal group. The positions of each of the four groups on each of the three canonical axes produced in this analysis are listed in table 5. Much, although not all, the information relating to the overall separation between the groups can be represented graphically by plotting their positions on the first two canonical axes produced in the main analysis. This is shown in figure 4, where the circles drawn around the mid-point of each group include approximately 90 % of individuals. Although the separation is appreciable, there are considerable territories of overlap and the degree of differentiation does not permit an unknown individual to be assigned with any degree of certainty to one group or another.

TABLE 4. SQUARED GENERALIZED DISTANCES ($D^2$) BETWEEN THE DIFFERENT SEX AND ALTITUDE GROUPS (SCALING IS IN STANDARD DEVIATION UNITS)

| | squared generalized distances (all variates) in s.d. units | | | |
|---|---|---|---|---|
| group | h.a.m. | l.a.m. | h.a.f. | l.a.f. |
| high-altitude male | 0 | 6.21 | 6.78 | 11.44 |
| low-altitude male | — | 0 | 11.93 | 6.56 |
| high-altitude female | — | — | 0 | 7.96 |
| low-altitude female | — | — | — | 0 |

TABLE 5. COORDINATES OF EACH GROUP ON THE THREE CANONICAL AXES (SCALING IS IN STANDARD DEVIATION UNITS)

| | canonical axis | | |
|---|---|---|---|
| group | 1 | 2 | 3 |
| high-altitude male | +0.77 | +1.43 | +1.54 |
| low-altitude male | −1.40 | +0.86 | −0.55 |
| high-altitude female | +1.61 | −0.83 | −0.45 |
| low-altitude female | −0.99 | −1.46 | +0.46 |

Inspection of the loading factors produced in this analysis indicated that certain variables make, for one or more axes of the canonical space, an exceptional contribution to the separation between the different sex and altitude groups. These variables are listed in table 6. It will be seen that bicondylar femoral diameter, nose height and body weight contribute disproportionately to two axes, while ankle breadth, chest circumference and upper arm circumference (contracted) each contribute to one.

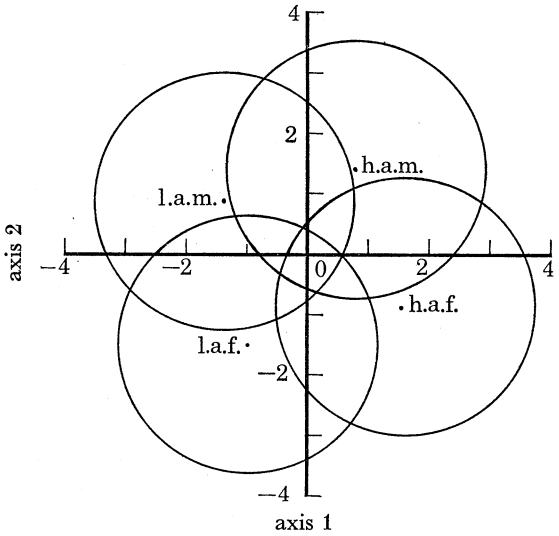

FIGURE 4. Illustration of the separation of the four groups along the two major canonical axes. A circle of radius 2.15 units around each point includes approximately 90 % of individuals in each group.

TABLE 6. VARIABLES CONTRIBUTING SIGNIFICANTLY TO THE SEPARATION BETWEEN GROUPS ON EACH CANONICAL AXIS

| canonical axis | | |
|---|---|---|
| 1 | 2 | 3 |
| bicondylar femur | bicondylar femur | — |
| — | ankle breadth | — |
| — | — | chest circumference |
| — | — | upper arm circumference (contracted) |
| nose height | — | nose height |
| body weight | — | body weight |

### (c) *Stature and body-weight relationships*

The existence of charts showing percentile ranges for stature and body weight in British children (Tanner *et al.* 1966) enables indirect comparisons of the different groups in the present study to be made. Figure 5 and table 7 show the distribution of children falling within the different percentile ranges for stature and figure 6 and table 8 give similar information for body weight. Comparison by $\chi^2$ analysis shows that for stature there are significant differences between highland and lowland males and lowland males and females, while for body weight highland–lowland differences are significant in each sex. All the altitudinal comparisons indicate that lowlanders are more often in the lower percentile ranges and in the between-sex comparison of stature at low altitude the males are the more frequently in the lower ranges.

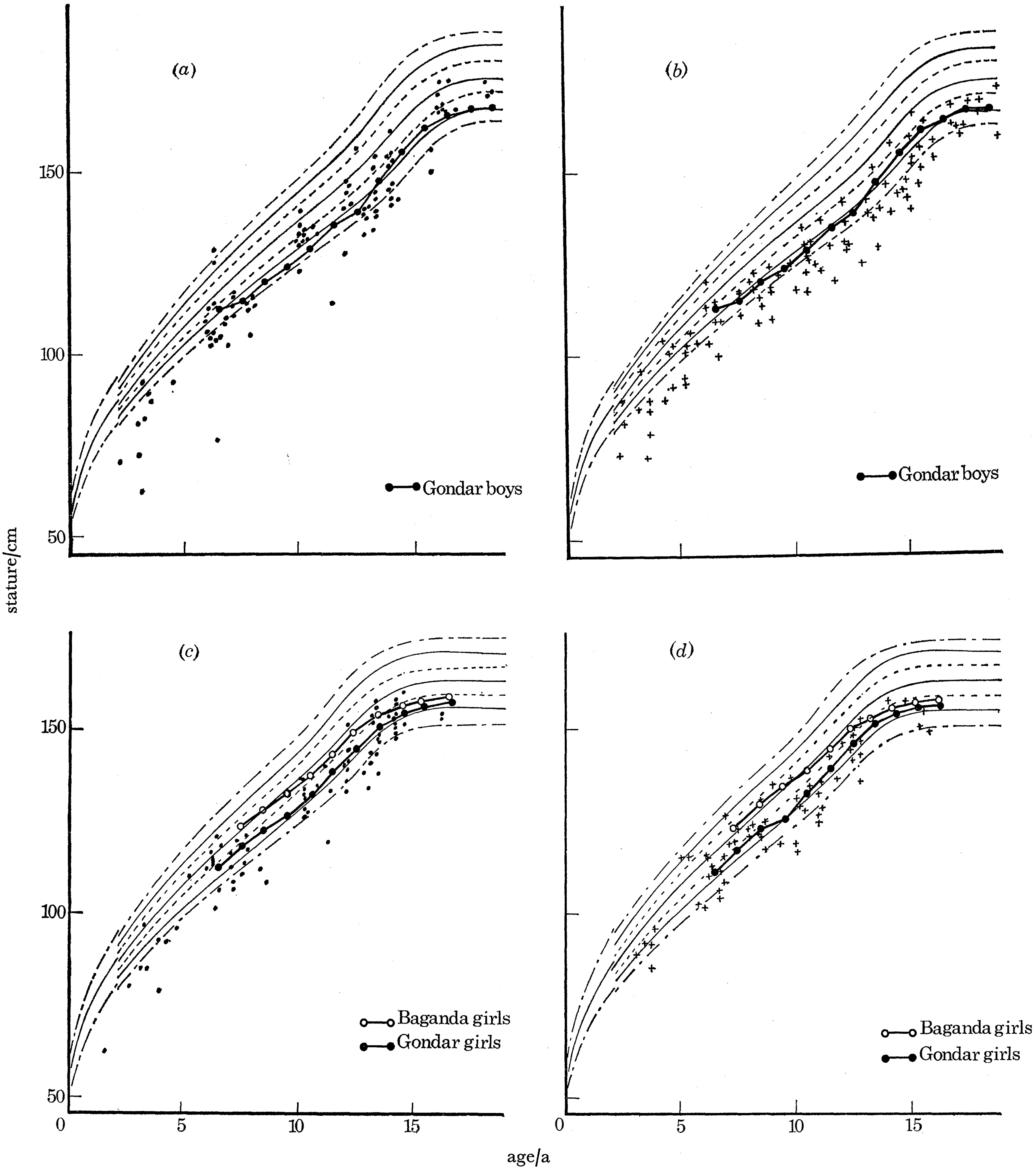

FIGURE 5. Distribution of stature of Ethiopian children of different groups among European percentile values (Tanner *et al.* 1966). (*a*) h.a.m., (*b*) l.a.m., (*c*) h.a.f., (*d*) l.a.f.

The results of regression analysis of the logarithm (to base 10) of body weight on stature are shown in table 9. While regression coefficients are not significantly different in between-altitude comparisons, adjusted mean logarithms of body weight differ significantly, highlanders being heavier than lowlanders. Between-sex comparisons show that at high altitudes females are significantly heavier than males, while at low altitudes females have a significantly greater regression coefficient.

TABLE 7. THE DISTRIBUTION OF ETHIOPIAN CHILDREN OF THE DIFFERENT GROUPS IN THE EUROPEAN PERCENTILE RANGES OF STATURE (TANNER *et al.* 1966) AND VALUES OF $\chi^2$ FOR DIFFERENT INTER-GROUP COMPARISONS

*** $0.01 > P > 0.001$; **** $P < 0.001$.

| | percentile range | | | | | | |
|---|---|---|---|---|---|---|---|
| group | < 3 | 3–10 | 10–25 | 25–50 | > 50 | comparison | $\chi^2$ |
| high-altitude male | 27 | 17 | 23 | 18 | 8 | h.a.m./l.a.m. | 13.817*** |
| low-altitude male | 47 | 21 | 17 | 10 | | h.a.f./l.a.f. | 3.312 |
| high-altitude female | 20 | 17 | 15 | 17 | 7 | h.a.m./h.a.f. | 1.146 |
| low-altitude female | 12 | 10 | 19 | 12 | 7 | l.a.m./l.a.f. | 20.720**** |

TABLE 8. THE DISTRIBUTION OF ETHIOPIAN CHILDREN OF THE DIFFERENT GROUPS IN THE EUROPEAN PERCENTILE RANGES OF BODY WEIGHT (TANNER *et al.* 1966) AND VALUES OF $\chi^2$ FOR DIFFERENT INTER-GROUP COMPARISONS

* $0.05 > P > 0.02$; **** $P < 0.001$.

| | percentile range | | | | | |
|---|---|---|---|---|---|---|
| group | < 3 | 3–10 | 10–25 | > 25 | comparison | $\chi^2$ |
| high-altitude male | 34 | 16 | 26 | 17 | h.a.m./l.a.m. | 16.995**** |
| low-altitude male | 59 | 18 | 11 | 7 | h.a.f./l.a.f. | 8.186* |
| high-altitude female | 26 | 15 | 14 | 21 | h.a.m./h.a.f. | 3.444 |
| low-altitude female | 32 | 12 | 10 | 6 | l.a.m./l.a.f. | 1.509 |

### (*d*) *Skinfold thicknesses*

These are shown graphically in figures 7 to 9, together with the European percentile values for triceps and subscapular folds (Tanner & Whitehouse 1962).

#### (i) *Triceps skinfold* (figure 7 *a*, *b*)

In both sexes the age-distribution of skinfold thickness is very different from that of European children. At earlier ages values are spread fairly uniformly over the 3rd to 97th percentile ranges, but by the age of 9 or 10 most children are below the 50th European percentile. In boys there is only a slight increase in later years but in girls there is a marked rise at ages above 12 years.

Differences between the distributions of the different Ethiopian groups are shown in tables 10*a–c*. In table 10*a* the overall comparisons are shown; only in the comparison between highland boys and girls is there a significant difference, which is in the direction of an increased proportion of girls with thicker skinfolds. However, if the populations are divided arbitrarily into those above and those below the age of 8 years, more differences become apparent. Table 10*b* shows the results in the younger age-groups. While there is no between-altitude difference for girls or between-sex difference at high altitude, the low-altitude boys show a significant preponderance of thicker skinfolds compared with the high-altitude boys, and low-altitude boys show the same preponderance in relation to low-altitude girls.

In older age-groups (table 10*c*) the findings are quite different. High-altitude girls have a greater frequency of thicker skinfolds than their lowland counterparts and high-altitude girls have thicker folds than boys at the same altitude.

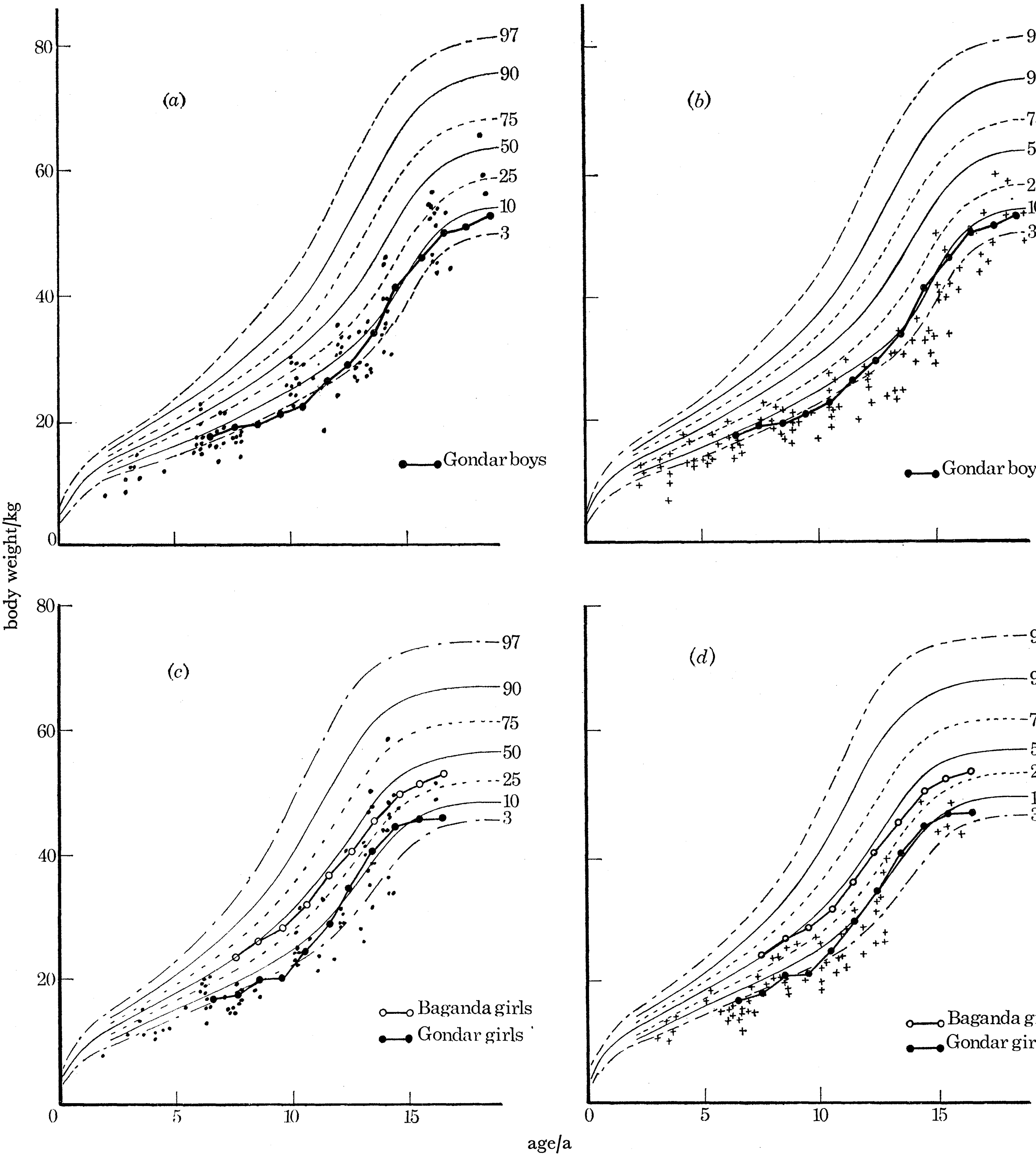

Figure 6. Distribution of body weight of Ethiopian children of the different groups among European percentile values (Tanner *et al.* 1966). (*a*) h.a.m., (*b*) l.a.m., (*c*) h.a.f., (*d*) l.a.f.

(ii) *Subscapular skinfold* (figure 8*a*, *b*)

As with the triceps skinfold, there are marked differences from European patterns. In both sexes, particularly boys, the distribution of thicknesses in young children are similar to that in Europeans, but while in boys the rise after the age of 8 years is very small, in girls the rise, particularly after the age of 12 years, is very pronounced.

TABLE 9. ADJUSTED MEANS OF $\log_{10}$ BODY WEIGHTS AND THEIR REGRESSION COEFFICIENTS ON STATURE

*** $0.01 > P > 0.001$.

| comparison | adjusted means ($\hat{y}$, $\log_{10}$ body weight/kg) | | regression coefficients $b$ | |
|---|---|---|---|---|
| | h.a.m. | l.a.m. | h.a.m. | l.a.m. |
| h.a.m./l.a.m. | 1.3990 | 1.3918*** | 0.0082 | 0.0079 |
| | h.a.f. | l.a.f. | h.a.f. | l.a.f. |
| h.a.f./l.a.f. | 1.3911 | 1.3470*** | 0.0089 | 0.0088 |
| | h.a.m. | h.a.f. | h.a.m. | h.a.f. |
| h.a.m./h.a.f. | 1.4026 | 1.4248*** | 0.0082 | 0.0089 |
| | l.a.m. | l.a.f. | l.a.m. | l.a.f. |
| l.a.m./l.a.f. | 1.3632 | 1.3440 | 0.0079 | 0.0088*** |

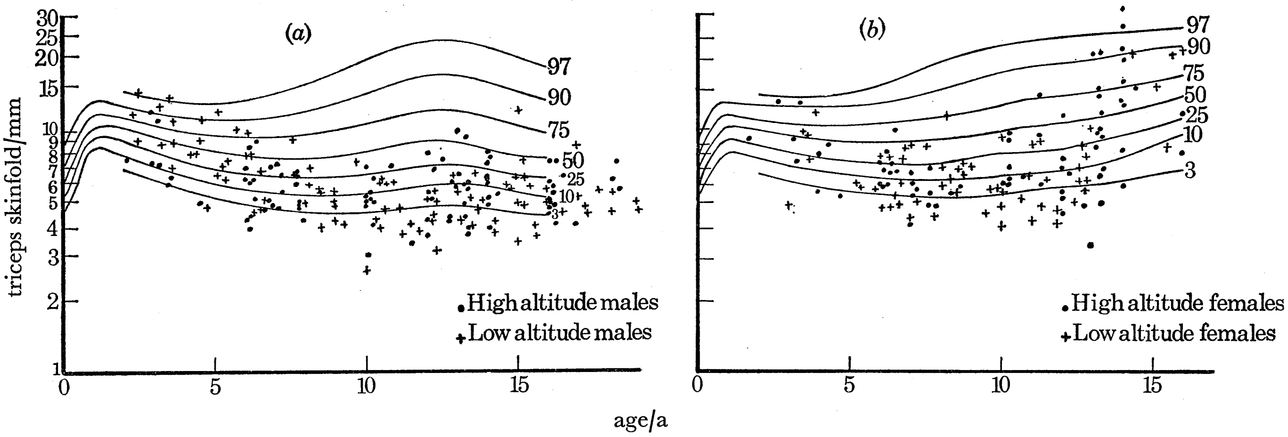

FIGURE 7. Distribution of triceps skinfold thickness of Ethiopian children among European percentile values (Tanner & Whitehouse 1962). (*a*) Boys; (*b*) girls.

Comparisons between the different Ethiopian populations indicate that while differences and similarities correspond broadly to those for the triceps skinfold, they are rather less marked and as shown in tables 11*a*–*c*, none of them reach the 5 % level of significance.

(iii) *Supra-iliac skinfold* (figure 9*a*, *b*)

No data are available on European percentile values, but the general picture is similar to that at the subscapular site, boys showing a prolonged fall to the ages of 8 to 10 and a gradual increase to relatively stable values after the age of 15. Girls have an earlier (10 to 13) spurt to much higher levels. Between-altitude differences are not obvious in either sex.

Table 10. The distribution of Ethiopian children of the different groups in the European percentile ranges of triceps skinfold thickness (Tanner & Whitehouse 1962) and values of $\chi^2$ for different inter-group comparisons

* 0.05 > $P$ > 0.02; ** 0.02 > $P$ > 0.01; *** 0.01 > $P$ > 0.001; **** $P$ < 0.001.

| group | percentile range | | | | | comparison | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| | < 3 | 3–10 | 10–25 | 25–50 | > 50 | | |
| | | | (*a*) Over the whole age range | | | | |
| high-altitude male | 17 | 28 | 18 | 14 | 6 | h.a.m./l.a.m. | 7.747 |
| low-altitude male | 22 | 16 | 18 | 14 | 15 | h.a.f./l.a.f. | 4.222 |
| high-altitude female | 13 | 19 | 11 | 14 | 19 | h.a.m./h.a.f. | 10.407* |
| low-altitude female | 17 | 15 | 9 | 11 | 8 | l.a.m./l.a.f. | 1.910 |
| | | | (*b*) Children less than eight years old | | | | |
| high-altitude male | 6 | 10 | 7 | 6 | 4 | h.a.m./l.a.m. | 12.827**** |
| low-altitude male | 3 | 1 | 3 | 8 | 14 | h.a.f./l.a.f. | 0.221 |
| high-altitude female | 6 | 7 | 6 | 7 | 3 | h.a.m./h.a.f. | 0.123 |
| low-altitude female | 7 | 5 | 1 | 6 | 3 | l.a.m./l.a.f. | 6.411** |
| | | | (*c*) Children eight or more years old | | | | |
| high-altitude male | 11 | 18 | 11 | 8 | 2 | h.a.m./l.a.m. | 2.860 |
| low-altitude male | 19 | 16 | 15 | 6 | 1 | h.a.f./l.a.f. | 5.636** |
| high-altitude female | 7 | 12 | 5 | 7 | 16 | h.a.m./h.a.f. | 9.375*** |
| low-altitude female | 10 | 10 | 8 | 5 | 5 | l.a.m./l.a.f. | 3.121 |

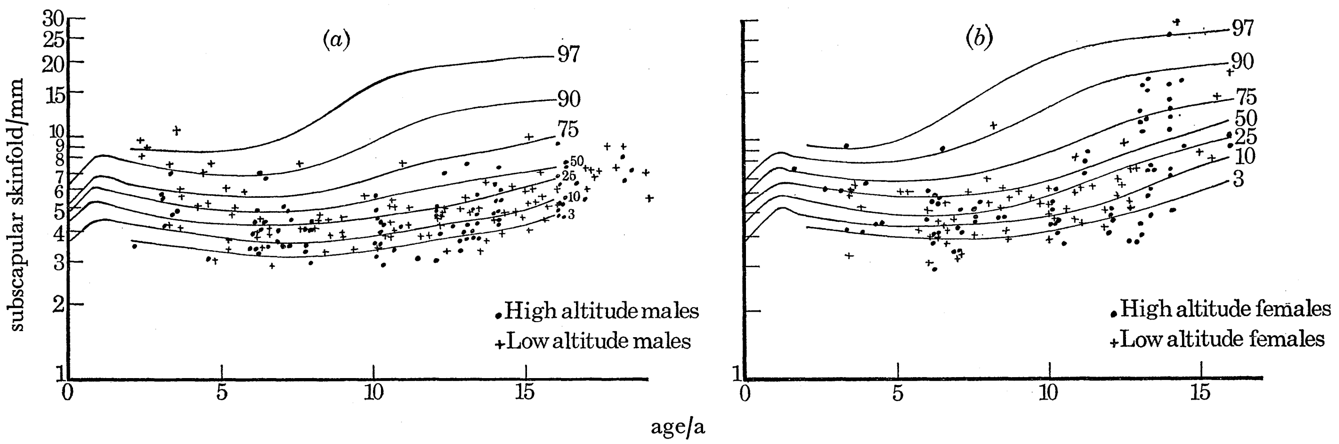

Figure 8. Distribution of subscapular skinfold thickness of Ethiopian children among European percentile values (Tanner & Whitehouse 1962). (*a*) Boys; (*b*) girls.

### (*e*) *Regressions of the various indexes on chronological and skeletal ages*

#### (i) *Regressions on chronological age* (tables 12*a*, 13*a*)

*Brachial index.* Differences in regression coefficients are significant only in females at different altitudes. Between-altitude differences in adjusted means are significant in males. Between-sex differences at similar attitudes are not significant.

*Cephalic index.* There are no differences in regression coefficients. Between-altitude differences in adjusted means are significant for females and between-sex differences are significant at high altitudes. Both these differences appear to be due to the greater cephalic index in high-altitude girls.

*Nasal index.* No significant differences in regression coefficients are seen, although the fall in the index is greater in highlanders of both sexes. Adjusted means show highly significant reductions in the index in highlanders of both sexes; there was no significant between-sex difference.

Table 11. The distribution of Ethiopian children of the different groups in the European percentile ranges of subscapular skinfold thickness (Tanner & Whitehouse 1962) and values of $\chi^2$ for different inter-group comparisons

| group | percentile range | | | | | comparison | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| | < 3 | 3–10 | 10–25 | 25–50 | > 50 | | |
| | | | (*a*) Over the whole range | | | | |
| high-altitude male | 13 | 21 | 24 | 12 | 13 | h.a.m./l.a.m. | 3.274 |
| low-altitude male | 8 | 16 | 29 | 14 | 18 | h.a.f./l.a.f. | 3.105 |
| high-altitude female | 14 | 13 | 15 | 10 | 24 | h.a.m./h.a.f. | 7.155 |
| low-altitude female | 8 | 14 | 15 | 10 | 13 | l.a.m./l.a.f. | 1.804 |
| | | | (*b*) Children less than eight years old | | | | |
| high-altitude male | 3 | 8 | 8 | 6 | 8 | h.a.m./l.a.m. | 1.620 |
| low-altitude male | 2 | 3 | 7 | 2 | 15 | h.a.f./l.a.f. | 0.274 |
| high-altitude female | 4 | 6 | 5 | 6 | 8 | h.a.m./h.a.f. | 0.213 |
| low-altitude female | 5 | 6 | 2 | 4 | 5 | l.a.m./l.a.f. | 1.570 |
| | | | (*c*) Children eight or more years old | | | | |
| high-altitude male | 10 | 13 | 16 | 6 | 5 | h.a.m./l.a.m. | 1.609 |
| low-altitude male | 6 | 13 | 22 | 12 | 3 | h.a.f./l.a.f. | 1.803 |
| high-altitude female | 10 | 7 | 10 | 4 | 16 | h.a.m./h.a.f. | 4.809 |
| low-altitude female | 3 | 8 | 13 | 6 | 8 | l.a.m./l.a.f. | 1.075 |

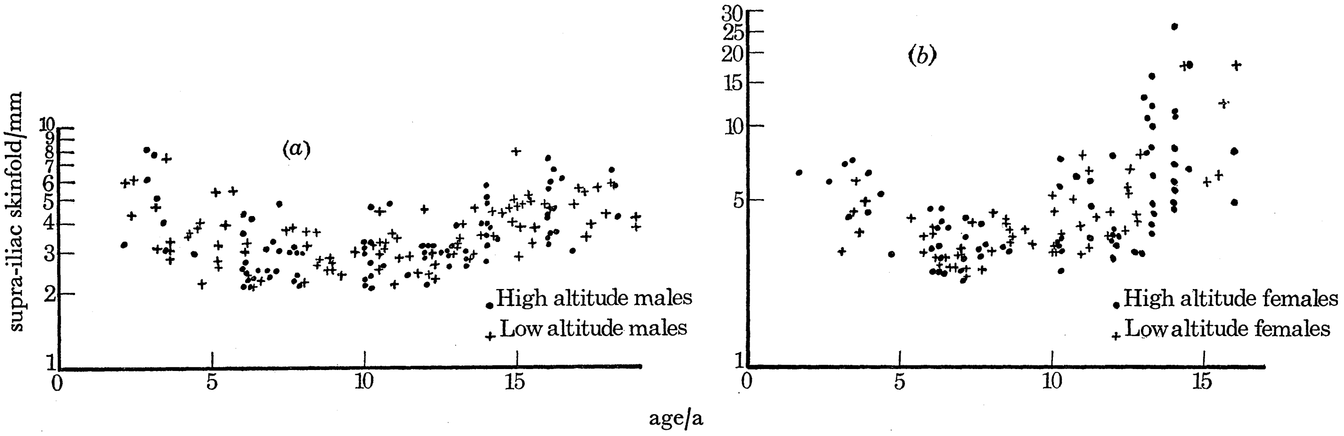

Figure 9. Age distribution of supra-iliac skinfold thickness of Ethiopian children. (*a*) Boys; (*b*) girls.

*Cormic index.* Highlanders of both sexes show a steeper fall in the index in relation to chronological age, although only in males is the difference significant. The fall is also steeper in males than females at either altitude.

*Schreider's index.* This shows changes essentially similar to those of the cormic index in between-altitude comparisons. In between-sex comparisons, however, females show a steeper fall at either altitude.

Table 12. Adjusted mean values of indexes and their regression coefficients on age. Between-altitude comparison of similar sexes

| | males | | | | | | females | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | adjusted means | | | regression coefficients | | | adjusted means | | | regression coefficients | | |
| index | high altitude | low altitude | *P* | high altitude | low altitude | *P* | high altitude | low altitude | *P* | high altitude | low altitude | *P* |
| | | | | | (*a*) Independent variable, chronological age | | | | | | | |
| brachial index, % | 87.60 | 93.95 | $< 0.001$ | $-0.069 \pm$ 0.158 | $-0.293 \pm$ 0.104 | NS | 86.57 | 93.79 | — | $0.281 \pm$ 0.168 | $-0.294 \pm$ 0.134 | $< 0.05$ |
| cephalic index, % | 78.02 | 77.38 | NS | $-0.069 \pm$ 0.079 | $-0.087 \pm$ 0.076 | NS | 80.24 | 76.96 | $< 0.001$ | $-0.020 \pm$ 0.092 | $-0.215 \pm$ 0.123 | NS |
| nasal index, % | 75.76 | 80.88 | $< 0.001$ | $-0.833 \pm$ 0.219 | $-0.069 \pm$ 0.322 | NS | 75.82 | 82.20 | $< 0.001$ | $-0.839 \pm$ 0.266 | $-0.411 \pm$ 0.357 | NS |
| cormic index, % | 55.88 | 55.40 | — | $-0.564 \pm$ 0.064 | $-0.396 \pm$ 0.055 | $< 0.05$ | 55.73 | 55.47 | NS | $-0.301 \pm$ 0.075 | $-0.154 \pm$ 0.071 | NS |
| Schreider's index, % | 8.88 | 9.23 | — | $-0.470 \pm$ 0.030 | $-0.400 \pm$ 0.020 | $< 0.05$ | 9.33 | 9.73 | NS | $-0.620 \pm$ 0.040 | $-0.550 \pm$ 0.050 | NS |
| surface area, m² | 1.024 | 0.961 | — | $0.077 \pm$ 0.003 | $0.061 \pm$ 0.003 | $< 0.05$ | 0.965 | 0.928 | $< 0.05$ | $0.078 \pm$ 0.003 | $0.068 \pm$ 0.005 | NS |
| haemoglobin g, % | 14.16 | 12.41 | — | $0.344 \pm$ 0.052 | $0.120 \pm$ 0.039 | $< 0.001$ | 14.17 | 12.84 | — | $0.337 \pm$ 0.001 | $0.152 \pm$ 0.072 | $< 0.01$ |
| | | | | | (*b*) Independent variable, skeletal age | | | | | | | |
| brachial index, % | 87.55 | 94.00 | $< 0.001$ | $-0.090 \pm$ 0.181 | $-0.291 \pm$ 0.233 | NS | 86.37 | 93.14 | $< 0.001$ | $0.184 \pm$ 0.164 | $-0.304 \pm$ 0.208 | NS |
| cephalic index, % | 78.01 | 77.64 | NS | $-0.042 \pm$ 0.086 | $-0.059 \pm$ 0.134 | NS | 80.14 | 76.41 | $< 0.001$ | $-0.037 \pm$ 0.091 | $-0.114 \pm$ 0.170 | NS |
| nasal index, % | 75.64 | 81.32 | — | $-1.034 \pm$ 0.239 | $0.405 \pm$ 0.481 | $< 0.05$ | 75.72 | 80.09 | — | $-0.405 \pm$ 0.271 | $0.980 \pm$ 0.442 | $< 0.01$ |
| cormic index, % | 55.72 | 56.10 | NS | $-0.544 \pm$ 0.072 | $-0.351 \pm$ 0.076 | NS | 55.63 | 55.44 | NS | $-0.222 \pm$ 0.080 | $-0.201 \pm$ 0.094 | NS |
| Schreider's index, % | 8.78 | 8.54 | — | $-0.460 \pm$ 0.030 | $-0.300 \pm$ 0.030 | $< 0.01$ | 9.14 | 9.17 | NS | $-0.500 \pm$ 0.030 | $-0.400 \pm$ 0.050 | NS |
| surface area, m² | 1.041 | 1.031 | — | $0.072 \pm$ 0.002 | $0.056 \pm$ 0.003 | $< 0.001$ | 0.989 | 0.992 | — | $0.069 \pm$ 0.003 | $0.056 \pm$ 0.005 | $< 0.05$ |
| haemoglobin g, % | 14.16 | 12.18 | $< 0.001$ | $0.261 \pm$ 0.054 | $0.215 \pm$ 0.050 | NS | 14.34 | 12.88 | $< 0.001$ | $0.299 \pm$ 0.059 | $0.156 \pm$ 0.098 | NS |

TABLE 13. ADJUSTED MEAN VALUES OF INDEXES AND THEIR REGRESSION COEFFICIENTS ON AGE. BETWEEN-SEX COMPARISONS AT SIMILAR ALTITUDES

| | high altitude | | | | low altitude | | | |
|---|---|---|---|---|---|---|---|---|
| | adjusted means | | | significance of differences between regression coefficients | adjusted means | | | significance of differences between regression coefficients |
| index | male | female | *P* | *P* | male | female | *P* | *P* |
| (*a*) Independent variable, chronological age | | | | | | | | |
| brachial index, % | 87.55 | 86.62 | NS | NS | 94.13 | 93.53 | NS | NS |
| cephalic index, % | 78.03 | 80.18 | $< 0.001$ | NS | 77.45 | 76.89 | NS | NS |
| nasal index, % | 76.04 | 75.19 | NS | NS | 81.08 | 81.02 | NS | NS |
| cormic index, % | 56.00 | 55.42 | — | $< 0.01$ | 55.63 | 55.29 | — | $< 0.05$ |
| Schreider's index, % | 9.03 | 8.87 | — | $< 0.05$ | 9.52 | 9.62 | — | $< 0.01$ |
| surface area, $m^2$ | 0.989 | 1.026 | NS | NS | 0.915 | 0.954 | $< 0.05$ | NS |
| haemoglobin g, % | 14.11 | 14.50 | NS | NS | 12.27 | 12.80 | NS | NS |
| (*b*) Independent variable, skeletal age | | | | | | | | |
| brachial index, % | 87.57 | 86.35 | NS | NS | 93.92 | 93.20 | NS | NS |
| cephalic index, % | 78.04 | 80.13 | $< 0.001$ | NS | 76.35 | 77.59 | NS | NS |
| nasal index, % | 75.90 | 75.61 | NS | NS | 80.84 | 76.70 | NS | NS |
| cormic index, % | 55.90 | 55.44 | — | $< 0.01$ | 55.78 | 55.21 | NS | NS |
| Schreider's index, % | 8.97 | 9.16 | NS | NS | 8.25 | 8.66 | NS | NS |
| surface area, $m^2$ | 0.997 | 0.988 | NS | NS | 1.078 | 1.060 | NS | NS |
| haemoglobin g, % | 14.09 | 14.36 | NS | NS | 12.23 | 13.02 | NS | NS |

*Surface area.* The rate of increase is greater in highlanders, although only in males is the difference significant. The adjusted mean is greater in females in the between-altitude comparison; in between-sex comparisons only the adjusted mean at low altitudes shows a significant difference, the female value being greater than the male.

*Haemoglobin.* The slope of the regression on chronological age is greater in both high-altitude groups. Between-sex comparisons show no significant differences.

### (ii) *Regressions on skeletal age* (tables 12*b*, 13*b*)

*Brachial index.* In both males and females there are significant between-altitude differences in adjusted means, the low-altitude groups having the higher value. There are no significant between-sex differences.

*Cephalic index.* As with regressions on chronological ages, high-altitude females have a higher index than either high-altitude males or low-altitude females.

*Nasal index.* In both sexes the slope of the regression line is significantly steeper in high-altitude children. Between-sex comparisons show no significant differences.

*Cormic index.* There are no significant between-altitude differences. At high altitudes males show a significantly greater rate of fall in the index as age advances than do females.

*Schreider's index.* The only significant finding is that the slope of the regression line is greater in high-altitude than in low-altitude males.

*Surface area.* In between-altitude comparisons, rates of increase of surface area with age are greater in highlanders of either sex. There are no significant between-sex differences.

*Haemoglobin.* Adjusted means are much higher in both highland groups, although there are no significant differences between sexes.

### (*f*) *Puberty ratings*

Genital development in males and breast development in females alone have been considered as measures of pubertal change. Although all girls above the age of 10 were asked whether they had begun to menstruate, their embarrassment and reluctance to answer the question made us doubt the truth of many of their answers. However, it was noted in both villages that girls almost invariably began to wear underclothes at the age of 12 and from this we conclude that menarche does not often occur before this age. Data collected by recall in women of mean age 29.3 years (Harrison *et al.* 1969) suggests that the mean age of menarche, irrespective of altitude, was about 14.5 years.

It was impossible to obtain data on the growth of pubic hair because of the custom of shaving this region.

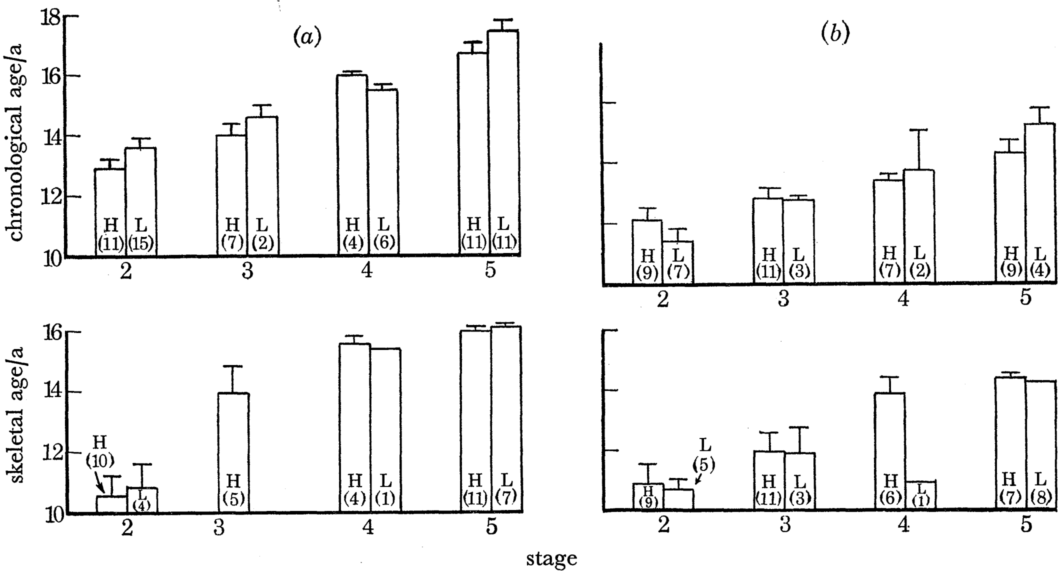

Figure 10. Mean ages (chronological and skeletal, ± s.e.m.) of children in the various stages of genital (*a*) and breast (*b*) development. Figures in brackets refer to the number of children in each group. H, High altitude; L, low altitude.

#### (i) *Genital development in boys*

Measures of this feature in highland and lowland groups are shown in figure 10*a*. It will be seen that there are only small and non-significant differences between groups at different altitudes, although there is a tendency for the mean ages at stages 2 and 3 to be slightly less in the highlanders.

Figures 10*a* and 11 also show that the skeletal ages of the children at the different stages are considerably less than the chronological ages. The discrepancy is most marked at Stage 2 and becomes less as genital development proceeds. Again, between-altitude differences are never significant. The number of boys showing signs of pubertal development (67) was too small to obtain probit estimates of the mean ages of entering all the different stages. However, an estimate of the mean age of entering Stage 2 was computed. This was 12.16 years, with 95 % confidence limits of 11.59 to 12.76.

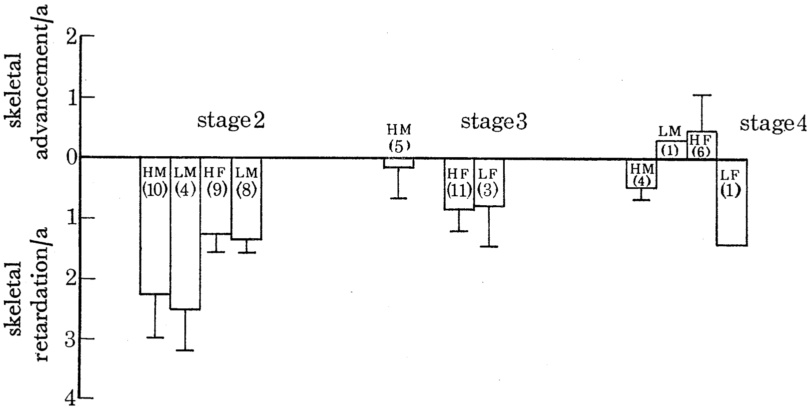

FIGURE 11. Mean degree (± S.E.M.) of retardation of skeletal development of Ethiopian children in the various stages of genital or breast development. Figures in brackets refer to the number of children in each group. HM, High-altitude males; LM, low-altitude males; HF, high-altitude females; LF, low-altitude females.

(ii) *Breast development in girls*

The findings are essentially similar to those relating to genital development in boys. Figure 10*b* shows that differences between highlanders and lowlanders are not statistically significant. Figures 10*b* and 11 also show that girls at Stage 2 of breast development are retarded in their skeletal development to a significant extent. As with boys, this retardation becomes less marked with increasing sexual maturity. Probit estimations of the mean age of entering Stage 2 of breast development gave a value of 10.76 years with 95 % confidence limits of 10.35 to 11.19 years, for the 52 girls showing some degree of breast development.

## 4. DISCUSSION

The results of this investigation may be considered in two ways: first, an internal comparison between the different altitude or sex groups; and secondly, an external comparison with other highland populations. In practice this usually means a comparison with Amerindian groups living at high altitudes in the Andes, as virtually no information is available for other high-altitude peoples. It must be remembered that all Ethiopian–Andean comparisons must be interpreted with caution, since not only are there genetic differences between the populations, but also the environments may differ in many ways (for example, ambient temperature and terrain), despite the fact the reduced atmospheric pressure is common to both.

Despite the extent of the data and analyses, results in each of the six sections can be summarized concisely, and point to a number of simple conclusions.

### (*a*) *Developmental age*

Skeletal development is retarded in all Ethiopian groups, compared with the Greulich–Pyle American White standards. However, the retardation is relatively short-lived – it is maximal during middle and late childhood but the increased rate of maturation during the early years of puberty means that by the age of 16 to 18 most Ethiopians seem to have 'caught up' to the Greulich–Pyle standards.

Comparisons between highland and lowland children are generally consistent, highlanders being more advanced skeletally for any given chronological age. This difference is much more marked in boys than in girls. In between-sex differences at each altitude the girls are always closer to the Greulich–Pyle standards (i.e. less retarded) than the boys; the greater sex difference is found at low altitude.

This internal comparison suggests that children of either sex growing up in the highland environment are less subject to environmental stress than those in the lowland. The fact that males show greater between-altitude differences than females may indicate the greater homeorhetic stability of the latter. This is also suggested by the closer approximation of females than males to the Greulich–Pyle standards, particularly at low altitudes.

Data on skeletal maturation of Amerindian (Quechua) children living at high altitudes have been given by Frisancho (1969*a*). He found that skeletal age fell behind chronological age after the age of 6 years, the maximum retardation (1.5 to 2 years) occurring at the twelfth and fourteenth years in girls and boys respectively. Subsequently there was a slow catch-up, but considerable retardation was still evident as late as the 20th year.

Unfortunately, no data appear to be available for lowland Quechua populations, so that it is uncertain to what extent the retardation is due to genetic differences between Quechua and American White children or to environmental factors. It is undoubtedly consistent with the late onset of the adolescent growth spurt in Quechua children at high altitude (Frisancho 1966, 1969*a*, *b*; Frisancho & Baker 1970), and it contrasts with the transient skeletal retardation and lack of delay in the onset of the development of the secondary sexual characters found in the present study. Clearly, the explanation of these differences between Ethiopian and Quechua children may be due to environmental and/or genetic factors and at present we are unable to estimate the relative importance of either. However, we can probably exclude hypoxia as a cause of the marked retardation seen in Ethiopian children, as both lowland and highland groups are affected. Other East African data (Mackay 1952) indicates that while in early life there is skeletal advancement of African children over Europeans, this is later replaced by retardation, so that from 5 years onwards, maturation proceeds at about the same rate as in Europeans, but is constantly less until at least the age of 17. Similar results have been found in West Africa (Weiner & Thambipillai 1952; Hunt & Massé 1963). Thus it appears that Ethiopian children have a pattern of skeletal development qualitatively different from that seen in the small number of other African groups which have been studied. Possibly the present findings are in part artefactual, in that they reflect the selective 'drop-out' of poorer and worse-fed children with increasing age, which was referred to on p. 406. As a result the very rapid improvement in skeletal maturation seen in older children may be simply because they are the better-fed ones. Because of the rapid improvement in skeletal development in children above the age of 12, this hypothesis seems to necessitate a fairly sudden and massive withdrawal of poor children from school at about that age. We have no evidence for or against such an occurrence.

In dental development, Ethiopian children are ahead of Europeans, at least until about the ninth year of life. This finding is consistent with those in other East African groups studied (Mackay & Martin 1952; Welbourn 1956). The internal comparison shows that as with skeletal maturation, dental eruption is more advanced in highlanders than in lowlanders. The difference appears to be more marked in boys than in girls and, again, it suggests that the highland environment is a more suitable one for growth. Eveleth (1966*b*) found that the permanent teeth of American White children living in a tropical environment (Rio de Janeiro) erupted earlier than children of fairly similar socio-economic status in the United States itself and she suggests that temperature differences may have some bearing on this result. The present findings of increased dental maturity in the colder environment do not support this hypothesis, but as Eveleth herself suggests, factors other than increased environmental temperature may influence growth, and there is no reason to suppose that they are the same in the Ethiopian as in the American comparisons.

### (*b*) *Regressions of measurements on chronological and skeletal ages and the results of canonical analysis*

Since these parts of the study are essentially complementary, they are best considered together.

Canonical analysis (tables 4, 5; figure 4) indicates that overall between-altitude differences in each sex are of the same order as between-sex differences at each altitude. Thus altitude differences exert a considerable effect on phenotype, but not to the extent that any individual can unequivocally be placed in any one altitude/sex group.

Among the different measurements, some contribute disproportionately to the total variation (table 6). The most important of these are bicondylar femoral diameter, nose height and body weight. Inspection of tables 2 and 3 reveals that the bicondylar femoral diameter contributes importantly to between-sex differences, while the other two contribute to between-altitude differences.

As far as the individual regressions on chronological age are concerned, table 2 shows that for many measurements highlanders are either bigger for a given age (greater adjusted mean) or faster-growing (greater regression coefficient). This is particularly true for males, but while in females significant differences in adjusted means are always in favour of highlanders, the reverse is generally true for regression coefficients. Between-sex comparisons show male adjusted means to be more often greater than female at high altitude; but at low altitude this position is reversed. Regression coefficients are greater in females, irrespective of altitude.

These findings suggest that at low altitudes children of both sexes are growing more slowly, and that the greater retardation is in males. In part this may be associated with the reduced rate of skeletal or dental maturation described above and to some extent the regressions on skeletal age (table 3) confirm this, for example the fact that at both altitudes males always have greater adjusted means than females for a given skeletal age. However, the greater regression coefficients on skeletal age of highlanders, whether male or female, suggests that even when differences in rates of skeletal maturation have been taken into account, highlanders are faster growing than lowlanders.

The results of this study thus extend into the childhood period the observations of Harrison *et al.* (1969) that adult highlanders are in general bigger than lowlanders. However, in one respect, that of chest dimensions, the results of this investigation differ somewhat from those in adults. Harrison *et al.* (1969) found that all chest dimensions were significantly greater in highland males (measurements were not made in female subjects). In the present study the results are less clear-cut. While mean chest circumference and transverse diameter are increased in highland males, chest depth is not; and in females none of the between-altitude differences in adjusted means are significant. While the evidence is on balance therefore in favour of an increased chest size in highland children, it is less clear-cut than in adults and it might be suggested that the demands on the respiratory organs at an altitude of 3000 m are not so severe during childhood as they are during adult life. It is clear, however, from Frisancho's (1966) data on males that where the hypoxic stress is greater, as at Nuñoa (4360 m), in the Andes, mean chest dimensions are considerably increased over lowland values, even during childhood. Where the high-altitude location is at a lower level (3096 m) means are still increased over sea-level values although to a lesser extent.

The explanation of the overall superiority of highlanders over lowlanders in general body size may be concerned more with temperature differences in the two environments than with differences in atmospheric pressure (see below). Perhaps it may be regarded as an altitudinal, rather than latitudinal expression of Bergmann's (1847) rule.

### (*c*) *Stature and body-weight relationships*

The results of covariance analysis of the regressions on chronological age (table 2) indicate that in the between-altitude comparisons highland children of either sex have either a greater adjusted mean stature (males) or a greater rate of increase in stature (females). For body weight the situation is reversed, males showing a greater rate of increase and females a higher adjusted mean. In between-sex comparisons females have a higher mean adjusted body weight at high altitude and greater stature and body weight at low altitude.

These differences are also shown in figure 5 for stature and figure 6 for body weight, in which individual measurements are plotted on the different percentile curves for European children (Tanner *et al.* 1966). Table 7 shows the numbers of Ethiopian children in each group falling into the different European percentile ranges of stature; the frequency distributions are significantly different in the comparisons between high- and low-altitude males, highlanders being more often in the higher percentile ranges. In comparisons between lowland males and females, females are more often in the higher percentile ranges. For body weight (table 8) significant differences are found in both the between-altitude comparisons, in each case the highlanders being in the higher percentile ranges.

Figures 5 and 6 show clearly that Ethiopian children are very much shorter and lighter for any given age than are European children, very few being above the 50th percentile lines. It is of interest to note, though, that older girls, particularly those at high altitude, show a greater tendency to approach the European norms for body weight, suggesting perhaps a 'catch-up' period at the onset of puberty or alternatively a genetically determined difference in the pattern of growth. An explanation based on selective 'drop-out' of poorer children (p. 406) may apply here. However, if 'drop-out' were contributing significantly it might be expected to affect height as well as weight and to be at least as marked in boys as in girls. We conclude therefore that it cannot be of major importance.

Figures 5 and 6 show also the mean statures and body weights of children of both sexes in Gondar, the capital of the Begemder province of which the Simien mountains form a part (Dellaportas 1968) and, for girls only, of Baganda children from Uganda (Burgess & Burgess 1964). Comparison with the Baganda shows Ethiopian girls to be both shorter and lighter, although as in the comparison with European children, older girls at high altitude tend to approach the Baganda means. It is not possible to apportion these differences between genetic and environmental factors.

The comparison with Gondar children is more interesting, since it is unlikely that genetic differences between the various groups are significant. Environmental differences, however, are considerable, Gondar being a sizeable town situated at an altitude of 2100 m. Health and educational facilities are considerably better than in either Debarech or Adi Arkai.

Table 14 shows the numbers of individuals in each group above or below a line joining the mean values of Gondar children at each age. Significant deviations are found only for low-altitude males, both in stature and body weight. Since the altitude of Gondar is only slightly greater than that of Adi Arkai, it seems unlikely that this is the factor causing this difference in size of males. Other environmental variables, for example, nutrition, hygiene and sanitation and better standards of medical care may be important. Such a result underlines the finding in many parts of the world that urbanization can often have an apparently beneficial effect on the rate of maturation of children (see Schreider 1964*b*; Valsik 1965).

Table 14. The distribution of highland and lowland Ethiopian children above or below Dellaportas's (1969) mean values for Gondar, and values of $\chi^2$ for heterogeneity of distribution in each group

| | | numbers of individuals | | | |
|---|---|---|---|---|---|
| measurement | group | > Gondar mean | < Gondar mean | $\chi^2$ | *P* |
| stature | h.a.m. | 41 | 32 | 0.5548 | NS |
| | l.a.m. | 21 | 48 | 6.0942 | $< 0.02 > 0.01$ |
| | h.a.f. | 23 | 34 | 1.0614 | NS |
| | l.a.f. | 24 | 23 | 0.0106 | NS |
| body weight | h.a.m. | 41 | 32 | 0.5548 | NS |
| | l.a.m. | 18 | 51 | 7.8914 | $< 0.01 > 0.001$ |
| | h.a.f. | 30 | 27 | 0.2193 | NS |
| | l.a.f. | 18 | 29 | 1.2872 | NS |

Table 15. Adjusted mean values of body surface areas and their regression coefficients on $\log_{10}$ body weight

*** $0.01 > P > 0.001$; **** $P < 0.001$

| comparison | adjusted means ($\hat{y}$, surface area/m$^2$) | | regression coefficients *b* | |
|---|---|---|---|---|
| | h.a.m. | l.a.m. | h.a.m. | l.a.m. |
| h.a.m./l.a.m. | 0.9920 | 1.0173*** | 1.6115 | 1.5588 |
| | h.a.f. | l.a.f. | h.a.f. | l.a.f. |
| h.a.f./l.a.f. | 0.9440 | 0.9538*** | 1.4904 | 1.4497 |
| | h.a.m. | h.a.f. | h.a.m. | h.a.f. |
| h.a.m./h.a.f. | — | — | 1.6115 | 1.4904**** |
| | l.a.m. | l.a.f. | l.a.m. | l.a.f. |
| l.a.m./l.a.f. | — | — | 1.5588 | 1.4497**** |

Table 9 shows the regression coefficients of $\log_{10}$ body weight upon stature for the Ethiopian groups in the present study. While the coefficients themselves do not differ significantly the mean logarithms of body weight, after covariance adjustment, are greater in the highlanders – that is for a given stature highlanders are heavier than lowlanders or as Harrison *et al.* (1969) found, highlanders have a less linear build.

Since there are considerable thermal differences between the two villages it is interesting to consider whether these differences in physique would be appropriate to the particular temperature conditions. Table 15 shows the regressions of $\log_{10}$ surface area, calculated by Dubois's formula, on body weight. In both the between-altitude comparisons lowlanders have a significantly increased adjusted mean surface area – they have a greater surface area per unit body weight. Thus in the different altitude groups the physique does seem appropriate to the thermal environment, but whether the factors which determine this difference are thermal or whether other important environmental variables such as disease, nutrition etc., are significant, cannot be determined from the present data.

### (*d*) *Skinfolds*

The results (figures 7 to 9) show that Ethiopian children, whether highland or lowland, have in general much thinner skinfolds than Tanner's & Whitehouse's (1962) European children. The figures also show that the pattern of growth of at least the triceps and subscapular folds is qualitatively as well as quantitatively different from the European standards. While young children have folds not too dissimilar in thickness from Europeans, the fall in thickness in early childhood is more marked and from the low level reached at age 6 to 8, the prepubertal rise in both limb and trunk fat is very small in both sexes.

At puberty boys show a slight increase in trunk fat, but most values are below the European 25th percentile. Limb fat shows very little change from prepubertal values, the proportions between the different percentile lines varying very little. In girls, however, particularly at high altitudes, there is a very pronounced rise in both trunk and limb fat beginning at age 12 to 13. By the age of 14 to 16 there are slightly more girls above the 50th percentile values than below (figures 7*b*, 8*b*). This change occurs at the same time as the marked increase in body weight discussed above.

In view of this marked pubertal rise in skinfold thicknesses in females, it seems unlikely that inadequate nutrition can explain the reduced thicknesses before puberty in these children, unless the finding is biased by large-scale withdrawals from school of children of low socio-economic status. While other environmental factors must be taken into account, genetic causations for the differences from European growth patterns must be considered. Unfortunately there appears to be little published information on skinfold thicknesses in African populations. What there is derives from American Negro groups of varying socio-economic status (Malina 1966; Rauh & Schumsky 1968). Malina gives data for growth in triceps, subscapular and mid-axillary skinfold thickness in White and Negro children between the ages of 6 and 12. In general, the patterns of growth in the two groups are similar, but Negro thicknesses are always less than those of White children. Even in Negro children of high socio-economic status skinfolds are thinner than in Whites. Rauh's & Schumsky's (1968) data refer to the triceps skinfold only and their figures 13 and 14 show the mean values for Negro children. They indicate clearly the existence of a pre-adolescent fat spurt in both sexes, with the expected sexual dimorphism appearing at puberty – males gradually acquiring thinner and females thicker triceps folds.

These results are different from those of the present investigation. Ethiopian values are generally less than Rauh's and Schumsky's means and evidence for a pre-adolescent fat spurt in Ethiopians is, as stated above, very poor. Clearly the Ethiopian pattern is different from the American Negro one but again, on the basis of our present knowledge, the differences cannot be explained as being due solely to genetic or solely to environmental factors. The fact that the sudden increase in the thickness of skinfolds in older children is largely confined to girls suggests that the progressive elimination from the sample with age of poorer children (p. 406) is not a complete explanation for the pattern of growth observed.

Differences between the various Ethiopian groups show few pronounced trends. In overall comparisons of children of the same sex at the two altitudes (tables 10*a*, 11*a*) there are few significant heterogeneities in their distributions in the different percentile ranges. However, if the populations are divided arbitrarily into those less than 8 years old and those 8 years old or more (i.e. into those in whom the pre-adolescent fat spurt cannot be expected to have started and those in whom it can), differences become apparent in limb fat distribution (triceps skinfold). Males of the younger group at low altitude are significantly more often in the higher percentile ranges for both skinfolds than are highlanders, while females show no very marked between-altitude differences (table 10*b*).

The situation is reversed in children aged 8 years or more (table 10*c*). Males show no significant differences but there is a greater frequency of high altitude girls in the higher percentile range. For trunk fat (subscapular skinfold) there are no significant differences, but the general pattern of variation is similar to that for limb fat (tables 11*a*–*c*).

Percentile values are not available for the supra-iliac skinfold, but inspection of figure 9*a* suggests that in males less than 8 years old the skinfolds are higher in lowlanders, while after 8 years there is little difference. For females (figure 9*b*) there is little difference before 8 years, but older girls in the highlands have thicker folds.

Thus the general pattern seems to be one of increased velocity of skinfold growth in the highlanders, so that males from having thinner folds during early childhood, reach lowland values after puberty; highland females, who show no differences from lowland girls in early childhood, have thicker folds after puberty.

An obvious explanation of this difference in skinfold growth is that nutrition is better in the highlands. Miller & Rivers (1972) found extremely low calorie intakes in both adults and children in the two villages. Between-village differences in intake were very small, so that to explain the observed variations in the patterns of skinfold growth, other environmental factors, such as for example thermal differences between the two environments, have to be considered.

### (*e*) *Regressions of the various indexes and of haemoglobin on chronological and skeletal age*

Between-altitude comparisons (tables 12*a*, *b*) show some interesting differences in both regression coefficients and adjusted means. Lowlanders, whether male or female, have significantly longer forearms in relation to upper arm length, as indicated by the brachial index. Why this should be so is not clear. Conceivably it could be a somewhat bizarre expression of Allen's (1877) rule that 'in warm-blooded species there tends to be an increase in the relative size of protruding organs such as the ears and tail with increasing temperature of the habitat', but the patterns of growth of other distal portions of the limbs do not support this suggestion.

Differences in cephalic index also defy explanation. Highland girls are significantly more round-headed than lowland girls, no matter whether chronological or skeletal age is the independent variable. It seems unlikely that this difference is a systematic one, since males, whose phenotype varies to a greater extent with altitude, show no significant difference in this particular case.

With nasal index, on the other hand, differences are clear-cut and consistent. When chronological age is the independent variable, adjusted means are significantly higher in both high-altitude groups and when skeletal age is the independent variable, high-altitude children show a significant fall with age, while lowlanders show no significant trend. Weiner (1954) found a strong correlation between nasal index and atmospheric water-vapour pressure and it is tempting to explain the differences found in this investigation on these terms – i.e. that the highland environment is less humid than the lowland. It is necessary to be cautious in accepting such an interpretation: first, because there is little or no information on meteorological conditions in this region; secondly, because it is difficult to envisage the mechanism of a direct action of atmospheric humidity on the growth of the skeletal and soft tissues of the nose, rather than a genetic adaptation arising as a result of natural selection (Wolanski & Cherzewska 1967) and thirdly because data on adults (Harrison *et al.* 1969, table 7), while only giving mean values for nose height and breadth suggests that differences between Adi Arkai and Debarech are minimal. However, in the village of Geech (3700 m) noses are significantly longer than at either Adi Arkai or Debarech, so that the nasal index here is probably significantly lowered.

The regressions of cormic index and of Schreider's index show greater rates of fall in both males and females at high altitudes when chronological age is the independent variable, but differences are less marked using skeletal age, high-altitude males having a greater rate of fall in Schreider's index only. This suggests that while delay in maturation in lowlanders is responsible for most observed differences, there is a true altitude effect on the relative rates of increase in limb lengths and body weight.

Surface area has been largely dealt with in the discussion on the relationships between stature and body weight. Generally highlanders tend to have either a greater adjusted mean or regression coefficient, but as shown above, the surface area for a given body weight is greater in lowlanders.

Haemoglobin levels in highlanders show a more rapid rise with age than in lowlanders when the regression is on chronological age. Regressed on skeletal age the regression coefficients do not differ significantly but the adjusted means in both highland groups are significantly increased. This result is what might be expected in highland–lowland comparisons. It differs from that found by Harrison *et al.* (1969) and was briefly mentioned by them. Possible reasons for the differing results of the two investigations are discussed in their paper.

In general haemoglobin levels are high, even in lowland children, and to some extent this observation seems incompatible with the poor nutritional levels (Miller & Rivers 1962) and the appreciable incidence of malaria and intestinal parastic infections (Harrison *et al.* 1969). As we have already noted, it may be that the children attending school are atypical of the child population as a whole, especially in the older age groups, but it seems that among the Amhara as a whole, dietary intake of iron is high (C. S. Leithead & J. Rivers, personal communications), so that the effects of haemolytic disease and calorie malnutrition may be to some extent mitigated.

Between-sex differences (table 13*a*, *b*) need little discussion. Differences in cephalic index are found only at high altitude. Males have higher rates of decline of the cormic index. This is presumably due to greater prepubertal lower limb growth in males and their reduced rate of fall of Schreider's index may be due to the same factor. Haemoglobin values do not seem to differ between the two sexes in any significant way.

### (*f*) *Puberty ratings*

Figures 10*a* and 10*b* indicate that altitude has little or no effect on the ages at which the various landmarks of reproductive development are reached. The pooled data from highland

TABLE 16. DATA ON THE PUBERTAL DEVELOPMENT OF ETHIOPIAN BOYS AND GIRLS, TOGETHER WITH THE RESULTS OBTAINED BY OTHER WORKERS

(*a*) The mean chronological ages of reaching the various stages of genital development of boys. Ethiopian data have been obtained as follows: Stage G2 by probit analysis (with 95% confidence limits); other stages by assuming that all children at a particular stage are at its mid-point. For other results the mean ages of reaching the different stages are the authors' values. Durations of stages (except for Reynolds & Wines (1951) and Marshall & Tanner (1970)) and ages at mid-points have been derived by interpolation.

| study | age at reaching stage G2, years | duration G2–G3, years | age at mid-point G2–G3 years | age at reaching stage G3, years | duration G3–G4, years | age at mid-point G3–G4, years | age at reaching stage G5, years | duration G4–G5, years | age at mid-point G4–G5, years | age at reaching stage G5, years |
|---|---|---|---|---|---|---|---|---|---|---|
| Reynolds & Wines (1951), | 11.5 ± 0.9 | 1.3 | 12.2 | 12.7 ± 0.8 | 0.6 | 13.0 | 13.4 ± 0.7 | 3.9 | 15.4 | 17.3 ± 0.8 |
| U.S. White | (9.5 – 13.5) | (0.5 – 3.0) | — | (11.0 – 14.5) | (0.3 – 1.8) | — | (11.5 – 15.5) | (2.5 – 5.0) | — | (15.5 – 19.3) |
| Barton & Monk (1962), | 11.9 | — | — | — | — | — | — | — | — | 14.6 |
| U.S. White | | | | | | | | | | |
| Nicolson & Hanley (1953), | 11.8 ± 1.0 | 1.3 | 12.5 | 13.1 ± 1.0 | 0.7 | 13.5 | 13.8 ± 1.0 | 1.4 | 14.5 | 15.2 ± 1.0 |
| U.S. White | (9–15) | — | — | (10–17) | — | — | (11–17) | — | — | (12–19) |
| Chang *et al.* (1966), | 13.2 ± 0.2 | — | 13.5 | 13.7 | — | 14.2 | 14.6 | — | 15.5 | 16.5 |
| Chinese | | | | | | | | | | |
| Van Wieringen *et al.* (1968), | 11.0 | — | — | 13.2 | — | — | 14.1 | — | — | 15.8 |
| (Dutch) | | | | | | | | | | |
| Marshall & Tanner | 11.6 ± 0.1 | 1.1 | 12.3 | 12.9 ± 0.1 | 0.8 | 13.4 | 13.8 ± 0.1 | 1.0 | 14.4 | 14.9 ± 0.1 |
| (1970), U.K. | | | | | | | | | | |
| present study (pooled data) | 12.2 | — | 13.3 ± 1.2 | — | — | 14.2 ± 0.6 | — | — | 15.7 ± 0.4 | — |
| Ethiopian | (11.6 – 12.8) | — | (10.1 – 15.5) | — | — | (13.2–16.0) | — | — | (15.1–16.1) | — |

(*b*) Mean chronological ages at which girls reach the various stages of breast development. Data on the different stages derived as in table 16*a*. Ethiopian menarcheal age estimated from Harrison *et al.* (1969) with correction for a possible secular trend.

| study | age at reaching stage B2, years | duration B2–B3, years | age at mid-point B2–B3, years | age at reaching stage B3, years | duration B3–B4, years | age at midpoint B3–B4, years | age at reaching stage B4, years | duration B4–B5, years | age at mid-point B4–B5, years | age at reaching stage B5, years | age at menarche, years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reynolds & Wines | 10.8 ± 1.1 | 0.6 | 11.1 | 11.4 ± 1.0 | 0.8 | 11.8 | 12.2 ± 0.9 | 1.5 | 13.0 | 13.7 ± 0.3 | 12.9 ± 1.4 |
| (1948), U.S. White | (8.5–13.0) | — | — | (9.0– ) | — | — | (9.5– ) | — | — | (12.5– | — |
| Nicolson & Hanley | 10.6 ± 1.2 | 0.6 | 10.9 | 11.2 ± 1.1 | — | — | — | — | — | 13.9 ± 0.9 | 12.8 ± 1.1 |
| (1953), U.S. White | (8–13) | — | — | (8–15) | — | — | — | — | — | (12–16) | (10.5–15.5) |
| Lee *et al.* (1965), | 10.7 ± 1.2 | — | — | — | — | — | — | — | — | — | 12.9 ± 1.0 |
| Chinese | (6.3–14.4) | — | — | — | — | — | — | — | — | — | (9.4–14.4) |
| Marshall & Tanner | 11.2 ± 1.1 | 0.9 ± 0.5 | 11.7 | 12.2 ± 1.1 | 0.9 | 12.7 | 13.1 ± 1.2 | 2.0 | 14.1 | 15.3 ± 1.7 | 13.5 ± 1.0 |
| (1969), U.K. White | — | (0.25–2.50) | — | — | (0.25–2.50) | — | — | (0.25–4.00) | — | — | — |
| present study | 10.8 | — | 11.8 ± 1.2 | — | — | 12.8 ± 1.3 | — | — | 13.5 ± 0.8 | — | 14.0–14.5 |
| (pooled data), | | | | | | | | | | | |
| Ethiopian | (10.4–11.2) | — | (9.8–14.0) | — | — | (10.1–14.0) | — | — | (12.4–15.0) | — | — |

and lowland groups are shown in tables 16*a* (boys) and 16*b* (girls), together with the results of observations on some other populations. Ethiopian boys appear to be advanced over Chinese boys in the age at which they reach Stage 2 of genital development, while girls show no differences from other populations in breast development. However, they seem to have a greater age of menarche.

In terms of skeletal development Ethiopian children of both sexes appear less mature than European children when secondary sexual development begins. Figure 11 shows that at Stage 2 of either genital or breast development there is pronounced skeletal retardation, more marked in boys. At later stages of pubertal development, the degree of retardation becomes much less.

It might be concluded from these results that in this population the onset of puberty is more closely tied to chronological than to skeletal age. To some extent this is confirmed by the fact that if the chronological ages of children in Stage 2 of either genital or breast development are approximated into the same classes as are their skeletal ages, the variability of the latter is greater than of the former. For boys the mean chronological age is 13.0 ± 0.41 years (coefficient of variation 9.54 %) while mean skeletal age is 10.6 ± 0.54 years (coefficient of variation 19.01 %). For girls the mean chronological age is 12.0 ± 0.28 years (coefficient of variation 8.65 %) while mean skeletal age is 10.8 ± 0.37 (coefficient of variation 12.09 %). Caution must be used in interpreting this difference, because of the cross-sectional nature of the data used, but it accords with Nicolson's & Hanley's (1953) finding of relatively low correlations, particularly in boys, between the ages of reaching Todd skeletal standards of 9.75 years (girls) and 11.25 years (boys) and the ages of attaining Stage 2 of breast and genital development respectively. It contrasts with the fact that at the time of menarche the variability of chronological age is greater than that of skeletal age (Simmons & Greulich 1943).

The data of Harrison *et al.* (1969) given in table 18*b* suggest that menarche is delayed in Ethiopian girls. While no other data on this event in Ethiopian populations appear to be available, Dellaportas (1969) suggests that in his Gondar children puberty occurs relatively early. It might be argued that the mean age of 14.5 years given in table 10*b* is unreliable because of the recall method of ascertainment used. However, Damon, Damon, Reed & Valadian (1969) have shown that while the error of recall of menarcheal age in any individual is considerable, it is unbiased in direction so that a population mean obtained by this method is reasonably accurate. Since the mean age of the women involved in the recall was only 29.3 years, the effects of a secular trend towards earlier menarche, if one is present, could not be expected to reduce present-day mean menarcheal age to much less than 14 years, a figure comparable with those of most of the rural populations given by Marshall & Tanner (1968). While the lack of data on menarche in the present study does not permit any examination of the relationship between chronological and skeletal age at the time of this event, it is interesting to observe that in 14-year-old girls the mean degree of skeletal retardation was not statistically significant (0.05 ± 0.52 years). Menarche is known to be highly correlated with the attainment of particular stages of general maturation, such as the ages of reaching Todd skeletal age standards of 12.75 years, or of 90 % of mature height (Nicolson & Hanley 1953), and the present findings do not run counter to this concept.

It seems then, that in comparison with European girls, the period of pubertal growth in Ethiopians is extended at its upper end. Both genetic and environmental factors may be involved in this difference, but it is not possible to assess their relative importance. The suggestion by Dellaportas (1969) that girls in Gondar have an early puberty suggests that differences between urban and rural environments may be important, but the lack of definite data from other groups of Amhara makes it impossible to come to any firm conclusions. In the Ethiopian–European comparisons the association between prolonged pubertal reproductive development and an initial retardation in skeletal development is interesting. If environmental factors are causal, chronic malnutrition may well be invoked, as it is known to retard skeletal growth and delay menarche (Dreizen, Spirakis & Stone 1967). Also, there is possibly an effect of increased environmental temperature in delaying menarche (Eveleth 1966*b*), but in the absence of Ethiopian populations living in a totally European-type environment, no firm conclusions can be drawn as to the interplay of genetic and environmental factors in causing these differences.

### (*g*) *General discussion*

In considering the results of this investigation the question is posed as to whether, given the apparent genetic homogeneity of the high- and low-altitude populations which are being compared, it is possible to relate particular phenotypic differences to particular environmental differences.

The short answer to this question is 'No'. While we can point to gross environmental differences between our two villages, such as atmospheric pressure, temperature – at least at certain times of the day or seasons of the year, rainfall (probably) and disease incidence (Harrison *et al.* 1969), there must be many other factors which can only be revealed by detailed study, meteorological, epidemiological and demographic. Hence we can only suggest connexions between major phenotypic and major environmental differences and even at this simple level the only clear-cut correspondences are first, that between the linearity of physique and environmental temperature – a relationship similar to that found by Eveleth (1966*a*) in American White children living in tropical and temperate environments; and secondly, the expected increase in haemoglobin levels in high-altitude children.

At a lesser level of certainty the differences in nose-shape may correspond to differences in atmospheric humidity, but without detailed knowledge of meteorological conditions it is impossible to be certain on this point. The greater rate of increase in subcutaneous fat thickness in highland children might point to nutritional differences, but, as has been pointed out, there is no evidence of major variation in nutritional standards between the two environments.

Perhaps the major phenotypic difference is the reduced rate of maturation of lowlanders as evidenced by skeletal development and numbers of teeth erupted. Hence it might be expected that lowlanders would tend to be smaller than highlanders in most physical dimensions and this is confirmed to some extent by the fact that differences in the parameters of regression of the various measurements tend to be less when skeletal age is the independent variable. Nevertheless, variability is not abolished and it seems reasonable to suppose that over and above an effect of environmental conditions on rates of maturation, life at low altitude exerts a direct inhibitory effect on increase in size *per se*.

Paradoxically, therefore, the highland environment in this part of Ethiopia appears the more favourable for the growth of children, a finding at variance with the results of studies of Andean populations living at much higher altitudes (Baker 1969; Frisancho 1966, 1969*a*). Here highlanders have much reduced rates of growth and maturation. The reason for the difference between Andean and Ethiopian results may be connected with the relatively mild degree of hypoxia in the Ethiopian highlands, which may exert only small inhibitory effects on the growth of children who survive the hazards of pregnancy and the early period of post-natal life (see

Harrison *et al.* 1969; Clegg, Harrison & Baker 1970; Clegg & Harrison 1971). Coupled with these mild effects of hypoxia at high altitudes are the more severe effects of disease incidence (particularly malaria and intestinal parasitism, Harrison *et al.* (1969)) and possibly increased environmental temperature acting at low altitudes. Both disease and high environmental temperatures reduce growth rates; in particular Hiernaux (1963) found malaria to be an important factor in causing body weights of lowland Hutu to be less than those of highlanders.

Comparisons between the sexes illustrate the greater stability of girls in their growth patterns. In almost all characters they show less between-altitude variation than boys and the widening of between-sex differences at low altitude suggests that if we assume the greater somatic fitness of girls, then the low-altitude environment is the less healthy.

Both Adi Arkai (*k'olla*) and Debarech (*dega*) lie in altitudinal zones regarded by the Amhara as less than ideal. Other than Dellaportas's (1969) data on children from Gondar, there appears to be no information on the growth of children in the *weyna dega* (grape highland), the zone, intermediate between *k'olla* and *dega*, which is regarded as being the most healthy. As mentioned above, contrasts between the urban and rural environments may account for some of the differences found in comparisons of the present results with those from Gondar and growth data from rural areas in the *weyna dega* would be of considerable interest, were they available.

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