I. PREFACE

Studies on growth and development of children occupy a considerable part of the contents of journals devoted to human biology. The ontogeny of man has been, figuratively speaking, minutely examined under a magnifying glass. Thus thousands of articles have appeared in print, covering various aspects of the subject, from the standpoint of genetic-environmental influences, such as ethnic origin, racial intermixing, family structure, population structure, diseases, twins, child-parent relationships, sex, age, social origin, psychological state, economic status, nutrition, society, migration, urbanization, climate, topography, geography and numerous other factors. The methodology of evaluating human ontogeny has improved over time, and so also have the statistical tools which assess the effects of various genetic-environmental factors on the growth process.

And yet, one aspect of the subject seems to have been overlooked, namely, the connection between the genetic structure of the population and development of the child. It is indeed a fact that the four major tomes in the field, which comprise landmarks in the study of human development and which summarize most of the publications on growth, namely, the books by Tanner (1962), Eveleth and Tanner (1976), Johnston et al. (1980), and Faulkner and Tanner (1986) make no mention whatsoever of this topic, which would seem to testify either to the difficulty of undertaking such a study and/or a lack of suitable investigational models at the time.

In the present study, we shall concentrate on two central aspects of inbreeding, namely: (a) methods used by anthropologists and biologists to measure the degree of inbreeding; and (b) the possible consequences of inbreeding in a population on child growth.

First, however, a fairly extensive review of the relevant literature will be presented.

Structure of the population from a genetic standpoint

Broadly defined, population structure deals with the relationships between the gene and the frequency of the genotype in particular populations (Relethford, 1980). Such relationships are reflections of the social structure with its multifarious aspects (e.g. economy, religion, etc.) and each deviation from the panmixia is a side-effect of these social aspects. Various models have here been designed to describe populations, as indicated below.

(1) The Genealogical model was developed by Wright (1921) and pertains to intermarriage of relatives either by chance inbreeding (for example in cases of small populations), or by non-random inbreeding (endogamy and the like). This model is known as a "Path Coefficient" and its main measure is the Inbreeding Coefficient F. The larger the value of F, the smaller the frequency of heterozygotes and the higher the frequency of homozygotes in the population. A Hardy-Weinberg equilibrium in a population is attained only when F=0.

(2) The Partitioned model, developed by Wahlund (1928), demonstrates that division of a population into sub-populations which randomly interbreed will itself lead to a deviation from the genotypic relationship of Hardy-Weinberg in the total population. This phenomenon, usually designated the "Wahlund Effect", is tantamount to inbreeding within the sub-populations. Wahlund demonstrated that the increase in homozygotes owing to sub-division of a population is on the order of the variance of the gene frequency within the subdivisions.

(3) The Hierarchical model, also developed by Wright (1943, 1965, 1973), attempts a merging of the two aforementioned models in order to incorporate various hypothetical situations in populations, such as non-random inbreeding in large populations, random inbreeding in sub-populations with mating by chance, and further secondary division of a population into randomly inbreeding sub-populations. Thus a more generalized model would encompass most accountable hypothetical situations beyond the two mentioned. The hierarchical model is characterized by a series of parameters known as "Wright's F-statistics", and assumes that a number of sub-populations may interlink by a branching process and that the interrelations between such sub-populations are historical. In other words, the implication is that all sub-populations derive from a common founding population.

(4) The Spatial model (Yasuda and Morton, 1967) is a conglomerate of models intended to provide answers to questions left unresolved by the other models. It is called "spatial" because the model depends on geographic isolation, albeit other factors which lead to isolation cannot be excluded (e.g. religious and social customs, social class, etc.). The most familiar models in this spatial

conglomerate are: a) Wright's "island" model; b) "Isolation by distance" model; and c) "Migration matrix" model(s). The first two were proposed by Wright (1943, 1951, 1965), the third by Cannings and Cavalli-Sforza (1973). Wright's models have undergone various expansions which need not be dealt with here.

Factors which seem to us highly significant in influencing the genetic structure of the population being studied are: (1) the effective population size, and (2) the manner in which mating partners are selected, the so-called Mating Types. Both of these factors can be measured by the genetic variability in the population. As already mentioned, it was Wright who coined the concept of F as the Coefficient of Inbreeding, defining it as the probability that two alleles at each given locus of an individual will be identical owing to a provenance from a common ancient ancestor. In a population of a finite size, even if the choice of a mate is random, the increase of homozygotes will be noticeable.

In the absence of migration and mutation in a population, genetic drift will lead to an increased number of homozygous individuals in an increasing number of loci, more than would be found in a large, randomly inbreeding population. Inter alia, this will result in recessive traits showing up more frequently, and in retardation of growth and diminution in body size with inbreeding.

Inbreeding and morphometric traits in man

The connection between inbreeding and morphometric traits is one of the biological problems that is still unclear. Prominent among the first to collect data on the depressive effect of inbreeding on growth were Neel and his co-workers (1949), Sutter and Tabah (1952) and Sutter (1958). Neel et al. studied for many years the impact of the atomic bombing of Hiroshima and Nagasaki on the Japanese people, delving concurrently into basic problems of that society, e.g. intermarriage and inbreeding level, and their effect on various biological variables. The first pertinent article on the subject was by Neel et al. (1949). Subsequently Morton (1955) investigated the effect of inbreeding on the weight of neonates; he found that a 10% increase in inbreeding resulted in an average drop of 43 grams in weight of the newborn. In a later study, Morton (1958) examined possible links between inbreeding and the duration of the gestation period, as well as the influence of inbreeding on bodily stature, body weight and chest circumference in the same Japanese children at birth and at 8-10 months of age. He found that inbreeding had no effect on length of gestation or head circumference, but that it did significantly decrease newborn body weight (120 gm/10% F) and newborn body length (2.8 mm/10% F).

In 1960 appeared the book by Falconer on quantitative genetics in which there is an attempt to build a model depicting the connection between inbreeding and body size. Falconer's working formula is based on expressing in percent the ratio 10 bF/outbred mean, which designates the extent of change in the mean value of a certain variable upon 10% increase in the coefficient of inbreeding. The term bF is a component of the vector of the regression coefficient of those measurements which typify the growth process on the inbreeding coefficient, i.e., bF is the regression coefficient on F of such measures as weight, stature, etc. Attempts of Falconer to apply his model to laboratory animals, and attempts of other investigators to apply the model to human populations (e.g. Schork, 1964) have yielded only partial agreement. As Schork (1964, p.298) points out:

> *Concerning the growth data, these results indicate that a 10% increase in inbreeding would decrease weight only by about 1% and head and chest girths would be changed even less.*

Most papers that have appeared in the 1960's (Slatis and Hoene, 1961; Barrai et al., 1964; Schork, 1964; Schull and Neel, 1965) have propounded that the mean weight at birth of neonates to parents who are first cousins, is lower, albeit not significantly,than the mean weight of neonates of non-related parents. Schork (1964) pointed out that his findings, based on 230 Japanese children from consanguineous marriages (part of a large sample of 2314 children), supported the conclusions of Morton (1955) in manifesting a suppressive effect of inbreeding on rate of growth, which was taken as the difference in measures at birth and 9 months later, in body weight, head circumference, and chest circumference. It should be emphasized, however, that Schork's (1964) results were not statistically significant. Indeed he sums up his findings in the following words:

> *Although statistically significant results were not obtained in considering inbreeding effects for the growth variables investigated, this is not to be considered as indicating that the effects of inbreeding on growth are nonexistent. While the results show that inbreeding does not greatly affect these growth measures, there is a consistent pattern of retardation in growth and diminution in size in the inbred group* (p.298).

Schork's conclusions may have been influenced by the studies of his colleague Komai (1963) who carried out a parallel investigation on elementary school children in Japan. Komai did report a small, and statistically significant, suppressive effect of inbreeding on morphometric variables such as stature, weight, shoulder breadth, chest circumference, etc.

Another study, by Barrai et al. (1964), unlike those previously mentioned which were all on young children, was carried out on a population of adolescents in Northern Italy. The sample involved 35,000 individuals of which 1556 were from provenances in which inbreeding was known to be prevalent. This study examined the influence of inbreeding on only two features, namely, stature and chest circumference. A suppressive effect of inbreeding was found only in chest circumference.

The study of the two American geneticists Schull and Neel (1965) on Japanese populations, perhaps more than any other, has made its imprint on the connection between inbreeding and morphometric traits, as well as the association between inbreeding and psychotechnic, psychological and some other traits which are outside the scope of the present study. They showed a generally small (ca. 0.5%) but significant suppressive effect of inbreeding on bodily dimensions (10 anthropometric traits). To quote Schull and Neel:

> *Though statistically significant and undoubtedly real, the effect is modest, and amounts, on the average, to a depression of less than 2% of the outbred mean per 10% inbreeding* (p.210-211).

Numerous subsequent studies by these authors and their collaborators became offshoots of the aforementioned pioneering research.

Of interest also is that Schull and Neel's findings indicated that the influence of inbreeding is generally greater for the behavioral than for the body size variables. We also learn from their study that investigations suggesting a possible influence of inbreeding on growth and development were initially actually undertaken by Japanese workers in the mid-fifties who reported a clear tendency for diminution of body dimensions as a result of inbreeding (Ichiba, 1953, 1954; Shiroyama, 1953).

In brief, there is general agreement as to the effects of inbreeding on morphometric traits, although the extent of the impact is still debated. Thus Hulse (1958) reported a significant effect of endogamy on body weight and stature, the offspring of exogamous marriages being on average taller by about 2 cm than the offspring of endogamous marriages. This study was carried out on a rural population in Switzerland. Hulse defined endogamy as marriage between individuals of the same village and exogamy as one between individuals from different villages. Steinberg (1963) likewise reported a significant `inbred' depression of about 60 mm/10% F in stature among males of the Hutterite group in the USA and Canada. Mange (1963), in his doctoral dissertation, considered the various effects of inbreeding on stature and weight. For stature Mange reported:

> *Thus a male whose parents were first cousins ($F'_0=62 \times 10^{-3}$)* is expected to be (0.014)(62)=0.9 inch shorter than a male whose parents were not related ($F'_0=0$). A female so inbred would be expected to be 1.9 inches shorter. The genetic mechanism by which this effect occurs might be in the*

> *corresponding increase in homozygosity which accompanies inbreeding* (p.54).

For body weight Mange also observed that:

> *With no apparent explanation, at all, is the highly significant effect of the inbreeding coefficient of the father on the weight of both males and females. This effect amounts to -0.24 pound per unit of F'f on sons' weights, and -0.23 pounds per unit of F'f on daughters' weights* (pp.55-57).

In a subsequent summarizing article, Mange (1964) claims that the findings of Schull (1962) on 151 Japanese children from Hiroshima and Nagasaki, albeit not statistically significant, nevertheless show a distinct tendency towards an inverse correlation between inbreeding and morphometric traits. He also restated his findings of the previous year, perhaps more effectively, to wit:

> *The multiple regression analysis, by sex, of height on the inbreeding levels of an individual, his mother, and his father indicated that a first cousin marriage, say, would produce sons who were, on the average, about two cm shorter than non-inbred males; daughters from first cousin marriage would be about five cm shorter than non-inbred females* (p.131).

By the end of the 1960's, another comprehensive study in this field made its appearance, that of Krieger (1966, 1969), whose findings were based on a sample of 3465 children from Northern Brazil. In Krieger's investigation, unlike that of Mange, the effect of inbreeding on body height and weight was not statistically significant. According to Krieger, the inbreeding depression is very tightly linked with dominance, hence, for additive loci, no inbred effect can be detected with regard to the mean phenotypic value (Krieger, 1966, p.2). This would explain the fact that for a trait such as stature, no depressive effect of inbreeding was detected. As for body weight, Krieger (1966, p.27) argues that the environment has a central role in its definition and that the available investigative methods are incapable of isolating and separately assessing the effect of inbreeding on it.

According to Krieger, the statistically significant results obtained by Mange (1964) on the depressive effect of inbreeding stemmed from the fact that Mange incorrectly assumed an identical environment for consanguineous families but not for non-consanguineous families. In the same context of environmental effects, Krieger also refutes the statistically significant results obtained by Hulse (1958).

The beginning of the 1970's marked the appearance of a new series of articles, some supporting and some refuting in one way or another the correlation between inbreeding and morphometric traits. An interesting study in this series was that of Wolanski et al. (1970) which examined the influence of internal migration of Polish populations on the development of their children in the post-WWII era. One of the pertinent findings of this study was that a definite increase in stature occurred in children, with increased distance between birthplace of their parents. Wolanski and associates reasoned that this finding was not linked to the bodily metric traits of the parents, nor to variables such as father's or mother's age or the differences between these ages, nor to economic or social factors, but rather to inbreeding.

The same year also marked the appearance of an article by Neel et al. (1970) on the Japanese child population of Hirado Island, among whom the inbreeding effect seemed negligible:

There were no significant effects from consanguinity or inbreeding (p.286).

The ongoing "controversy" regarding effects of inbreeding on morphometric traits is summarized in a paper by Martin et al. (1973). Here we read that:

> *Results of various human population studies to date have indicated small effects, if any, of inbreeding, and conflicting estimates of the strength of the genetic component in continuous traits. This may reflect the true estimation or may reflect deficiencies in the type of data available* (p.581).

The study of Martin and his associates dealt with S-leut populations in the USA and Canada, and as noted above, they stress the inability to define precisely the F-range, especially because of the paucity of information on the early ancestry of the investigated social unit. Yet their results, at least for some of the S-leut groups, were positive. They affirmed that:

> *In general the effect of inbreeding on S-leut anthropometric measurements involves a decrease in skeletal measurements and an increase in fatty measurements* (p.590-591).

Indeed the authors seem to cast doubt on the significance of their own findings, remarking that:

> *Many small but significant changes were found with F, but the biological meaning of these is debatable* (p.592).

In the mid-1970's and there after, this topic of the relationship between inbreeding and morphological traits seemed largely to disappear from the literature, albeit an occasional paper appeared, pointing, for example, to a correlation between inbreeding and blood pressure, blood pulse and hematocrit (e.g. Barbosa and Krieger, 1979), but none dealt directly with the subject of an association between inbreeding and morphometric traits.

---

*F'_0 = Inbreeding coefficient for the offspring based on pedigree which generally had no ancestry omission back to the second cousin generation.

The Present Study

A primary goal of the present study, as previously indicated, was to evaluate the influence of inbreeding, as well as other possible factors, on the physical development of children within the Bedouin society. Hence the present study comprises the following main components:

a) The first part conveys information on the genetic structure of a Bedouin tribe, expressed mainly as the probabilities of kinds of mating of individuals within the population. The stochastic process here is a derivative of the cultural structure into terms and numbers pertaining to effective size of the population, frequency and nature of consanguineous marriages, sex ratio and age structure, social and geographic isolation, etc. Four main topics are considered, as indicated below.

The first deals with the history of the Bedouin tribes. On the basis of archaeological evidence, we delve into the geographic and ethnic origins of the various Bedouin tribes in South Sinai, and attempt to determine who were their founders, and from whence they arrived. Herein the possibility of a Founder effect is also evaluated.

The second main topic examines various cultural aspects and deals extensively with the tribal infrastructure and social components of which it is comprised. Mating patterns and rates of migration are here emphasized, and the definition and the significance of kinship are considered.

The third topic is related to the demography. Information is provided on patterns of mortality and fecundity, sex ratio, family size, tribe size, polygamy and other variables. The demographic evolution of the Bedouin tribes over time is considered.

The fourth and final topic is a summary of what seem to us the factors liable to influence the genetic structure of the Bedouin population. Here we define the infrastructures of the Bedouin tribes with respect to nuclear biological unit, the social unit within which most marriages take place (i.e., the sub-tribe, tribe, or conglomerate of several tribes). For each of the social units we also compute the corresponding F value.

b) The second part of our study considers, first, the growth-development of Bedouin boys vis-à-vis other comparable child populations. We present data also on the differences in child development within social sub-units of the same tribe. Here we also relate various factors which may be responsible for morphologic variability, e.g. topographical environment, (elevation), diet, ethnic origin, inbreeding.

c) The third and final part of the study explores the feasibility of a tribal morphologic identity and the main morphometric variables which could characterize such. In addition, attention is devoted to the relationship between the historical and biological evidence presented in the present study.

The present study is of the cross-sectional type. A longitudinal study of growth in the children was not feasible because of:

a) frequent movements or migrations of families in South Sinai; and

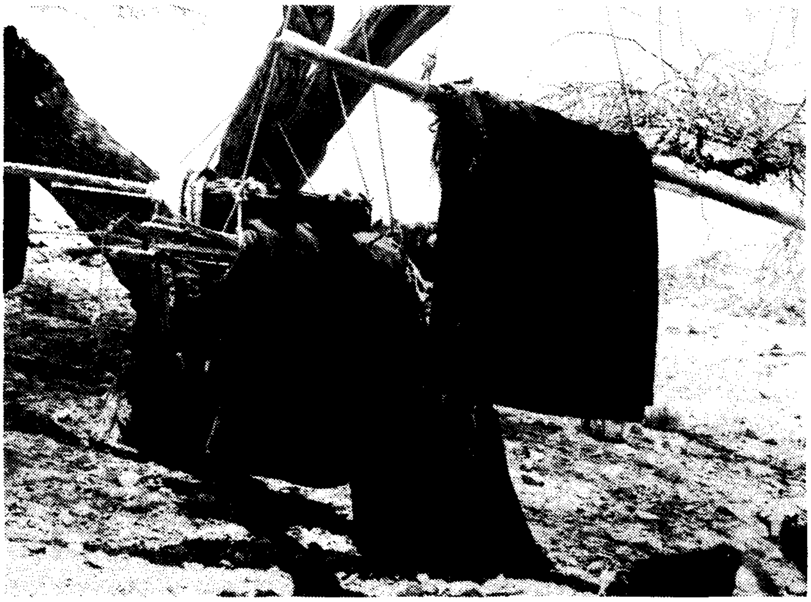
b) the political instability of the region, and hence, uncertainty as to time available for our study.

We believe that even a cross-sectional study of growth and development is perforce closely linked to biological, cultural and economic considerations.

Bedouin camps where children were examined

Measurements took place at 17 sites within the territorial limits of each of the following South Sinai tribes (see Fig. 1): Gebeliya tribe at Santa Katharina, Tarfat Qiderein, and Feiran; Gerarsha tribe at Um-Gsur, Ilianes and Feiran; Aleigat tribe at Bir-Beida; the Hamada tribe at Bir-Nasib and Sheik Hashash; Haweitat tribe at Wadi Tar; Sawalcha tribe - Abu-Raraged and Nasrin; Ahali Et-Tur and Beni-Wassal tribes at Et-Tur and El-Wadi; Muzeina tribe at Hereize, Dahab, Nuweiba and Bir Sa'al; Awlad Said tribe at Bir Sulaf.

Each station was visited three times in the course of the study at intervals of approximately every half-year, from 1978-1980.



Winter tents hanged on the *Acacia* tree

FIGURE 1: Population Centers in South Sinai Where Children Were Examined