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THE INHERITANCE OF MESIODISTAL TOOTH DIAMETER IN TWINS

by
W. Stuart Hunter

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of the requirements for the degree of
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INTRODUCTION

This investigation was planned to determine the influence of heredity on the mesiodistal diameter of certain permanent teeth.

Newman, Freeman, and Holzinger (1937, p. 3) suggest that there are five ways of utilizing twins for studies of heredity and environment: (1) One may study monozygous (MZ) twins only, (2) twins may be studied longitudinally, (3) one may compare unlearned with learned abilities (capacities) in twins, (4) the problem of inheritance may be studied "by comparing the likenesses or differences between identical twins with the likenesses and differences between fraternal twins" and (5) "we may secure more crucial evidence on this question if we can find identical twins who have been separated from early infancy and brought up under diverse environmental conditions."

This paper is concerned with the fourth method—that of comparing likeness and differences in MZ twins with those in dizygous (DZ) twins. A concise statement of the principle is made by Lundstrom (1948):

> If the aim is to analyze the significance of heredity of man as compared to that of environment, one utilizes twin-investigations. It is presupposed that identical twins have the same genes, and therefore the difference between them is conditioned by environmental factors, while the difference between fraternal twins is conditioned by heredity, as well as environmental factors [p. 30].

The method used in this investigation involves the comparison of the variance of the identical twins with the within-pair variance

of the fraternal twins, in a variance or "F" ratio which may be evaluated by reference to a standard "F" table.

REVIEW OF THE LITERATURE

Since the publications on tooth size and on twins are rather extensive, only representative papers in these areas are presented. The topics investigated in the literature include tooth size in general, tooth size in twins, determination of zygosity and factors controlling tooth size.

Among the studies of tooth size, those by Seipel (1946), Selmer-Olsen (1949), and Moorrees et al. (1957) are perhaps representative of the vast amount which has been accomplished in this area.

Seipel studied tooth size, arch dimensions, changes due to tooth loss, arch relationships, the mechanisms of spacing-crowding, and certain cephalometric relationships in three age groups each containing five hundred Swedish children. He measured "the greatest distance between the approximal surfaces of the crown, measured parallel with the occlusal and labial surfaces (along the length axis of the crown)." He presents the errors of measurement involved, both as the standard error of a single determination and as a percentage of the tooth size (Table 7, p. 29). All measures were made directly in the mouth and although left and right sides were measured, Seipel chose to average them for presentation, since he found no significant differences in tooth size between left and right sides. Since a comparison of teeth without proximal fillings versus teeth with proximal fillings showed no significant mean difference between the two groups, Seipel included the measures of filled teeth. His

figures for the mesiodistal diameters of the permanent teeth are shown in Table 1.

Selmer-Olsen's investigation of the teeth of Norwegian Lapps is very detailed with respect to measures useful in racial comparisons. Since the material consisted of archeologic finds, he was able to measure length, width, and height of crowns and roots. In his discussion of measurement of mesiodistal diameters, he notes the problems inherent in a consistent approach to measurement, which are the result of differences in tooth morphology.

Selmer-Olsen defines the distance to be measured as the "points of contact with normal tooth positions" (p. 24). For incisors, it is necessary, he suggests, to attempt to measure this distance in a plane perpendicular to the long axis of the tooth. He states, "The measurement is often determined slightly subjectively and the technique must be taught" (p. 25). He does not present information on the size of his errors.

He presents both left and right side measurements (Table 2) and chose, for the major part of his investigations, to use both sides as though they were independent, thus doubling the number of measures available for any given tooth, although his sample involved 581 crania (p. 19) and 9,675 teeth (p. 14). He explains:

> In spite of differences, there will always be a correlation between the two sides. But I believe that this source of error, so far as the mean is concerned, is more than outweighed [by] having a large number, by the greater accuracy in readings and by the elimination of those drawbacks possessed by other methods" [p. 32].

The mesiodistal diameters of the permanent teeth of Lapps are of interest because they are among the smallest known for any racial group. They are presented in Table 2.

Table 1. Tooth size (in mm.) for Swedes as recorded by Seipel (1946, p. 51). (The values given are mean values for right and left sides combined.)

Tooth Position[a]	Males				Females			
	N	Mean	SD_m	SD	N	Mean	SD_m	SD
				Maxilla				
I_1	483	8.84	0.025	0.55	490	8.62	0.024	0.53
I_2	469	6.81	0.028	0.60	476	6.64	0.026	0.57
C	463	8.10	0.020	0.46	473	7.73	0.019	0.41
P_1	135	7.18	0.033	0.38	124	7.04	0.035	0.39
P_2	125	6.97	0.035	0.39	115	6.85	0.040	0.43
M_1	164	10.69	0.038	0.48	135	10.47	0.045	0.52
M_2	151	10.47	0.053	0.65	176	10.05	0.044	0.58
				Mandible				
I_1	507	5.51	0.016	0.36	491	5.42	0.017	0.37
I_2	507	6.13	0.018	0.40	493	5.94	0.017	0.37
C	503	7.12	0.017	0.39	493	6.69	0.017	0.38
P_1	160	7.27	0.029	0.37	146	7.16	0.033	0.40
P_2	103	7.41	0.040	0.41	117	7.21	0.036	0.39
M_1	145	11.24	0.047	0.57	123	10.98	0.055	0.61
M_2	241	11.15	0.041	0.69	275	10.70	0.039	0.64

[a] I_1, central incisor; I_2, lateral incisor; C, cuspid; P_1, first bicuspid; P_2, second bicuspid; M_1, first molar; M_2, second molar.

Table 2. Tooth size for Norwegian Lapps as recorded by Selmer-Olsen (1949). (Mean values for left and right sides, p. 70, are given at the left and the combined values according to sex on the right, pp. 46–49.)

Tooth Position	Side		Males			Females		
	Left	Right	N	Mean	SD_m	N	Mean	SD_m
				Maxilla				
I_1	8.33	8.29	73	8.4	0.049	85	8.3	0.046
I_2	6.75	6.71	95	6.8	0.057	105	6.7	0.050
C	7.60	7.57	194	7.7	0.031	177	7.5	0.028
P_1	6.66	6.64	221	6.8	0.032	205	6.6	0.028
P_2	6.37	6.40	237	6.5	0.028	208	6.3	0.030
M_1	10.05	10.14	256	10.2	0.037	223	9.9	0.034
M_2	9.08	9.19	267	9.3	0.037	225	8.9	0.037
				Mandible				
I_1	5.26	5.30	76	5.4	0.029	83	5.2	0.032
I_2	5.88	5.87	123	6.0	0.035	124	5.9	0.035
C	6.66	6.65	219	6.8	0.029	186	6.5	0.027
P_1	6.65	6.65	226	6.7	0.029	191	6.6	0.031
P_2	6.65	6.68	232	6.7	0.027	191	6.6	0.028
M_1	10.78	10.81	228	11.0	0.043	192	10.6	0.039
M_2	10.32	10.30	254	10.5	0.041	203	10.1	0.043

The investigation by Moorrees, Thomsen, Jensen, and Yen on mesiodistal crown diameters in 184 North American children utilized plaster casts. They measured

> . . . the greatest distance between the contact points on its [the crown of the tooth] approximal surfaces, using a sliding caliper held parallel both to the occlusal and vestibular surfaces. This technic could be employed only when the teeth were in a "normal" position in the dental arch. Otherwise, the mesiodistal crown diameter was obtained by measuring between the points where contact with the neighboring teeth "normally" should occur.

The error of measurement for single mandibular teeth was calculated to be 0.09 mm. (n = 360). The average diameter of left and right sides was calculated and these are presented in Table 3.

With respect to twin studies, that of Lundstrom (1948) is certainly a standard for such investigations. It is based upon a sample of 100 MZ and 102 DZ twin pairs, whose zygosity was primarily determined by general physical similarity. Color of eyes and ear shape were considered secondarily. From a practical point of view, this is reasonably reliable, and Lundstrom later checked a few of his samples with blood group studies with no conflicting results. Theoretically, however, one is in danger of studying similarity and dissimilarity in physical characters in a sample divided into two groups on the basis of similarity and dissimilarity of physical characters. Probably the correlations between such items as eye color or ear shape and tooth size or dental arch shape are

Table 3. Mesiodistal crown diameter of the permanent teeth of North American white children according to Moorees et al. (1957, p. 41, Table II).

Tooth Position	Males				Females			
	N	Mean	SD_m	SD	N	Mean	SD_m	SD
				Maxilla				
I_1	87	8.78	0.05	0.46	87	8.40	0.06	0.53
I_2	84	6.64	0.07	0.63	86	6.47	0.07	0.62
C	87	7.95	0.05	0.42	85	7.53	0.04	0.37
P_1	87	7.01	0.04	0.38	84	6.85	0.05	0.42
P_2	86	6.82	0.04	0.37	81	6.62	0.05	0.43
M_1	83	10.81	0.06	0.56	85	10.52	0.06	0.51
M_2	65	10.35	0.08	0.63	50	9.81	0.07	0.49
				Mandible				
I_1	85	5.42	0.03	0.31	87	5.25	0.04	0.36
I_2	85	5.95	0.04	0.38	87	5.78	0.04	0.36
C	84	6.96	0.04	0.36	87	6.47	0.04	0.32
P_1	85	7.07	0.04	0.35	87	6.87	0.04	0.38
P_2	82	7.29	0.06	0.52	83	7.02	0.04	0.40
M_1	76	11.18	0.05	0.47	84	10.74	0.06	0.56
M_2	53	10.76	0.10	0.71	53	10.34	0.08	0.62

small, but "general similarity" suggests that size considerations could be involved. However, as far as eye-color and ear shape are concerned, the method would seem to be valid.

Lundstrom's method of measurement was simply to measure from contact point to contact point using a Helios style sliding caliper. Measures were taken directly for the anterior maxillary teeth. Posterior teeth and arch measurements were made on plaster casts. If a tooth could not be measured because of restorations or caries, he used the measure for the opposite tooth, or if this too could not be measured, he extrapolated from the size of adjacent teeth. However, he kept these "estimated" measures in a separate group for more cautious consideration.

In the statistical treatment of his data, he follows the method of Dahlberg (1926) which involves the partitioning of the variabilities connected with internal versus external environment, heredity, measurement, and asymmetry.[1] This procedure is valid only if the various components are independent as Lundstrom points out (p. 66). He suggests elsewhere (p. 99) that there is some reason to expect interaction since indentical twins can be expected to show greater variability than fraternal twins, because of prenatal "internal" environmental differences due to competition for blood supply. Sutton, Vandenberg, and Clark (1957) also discuss the interaction of variability and zygosity.

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[1]The formulations for this partitioning are:
$\sigma^2_{1+2+3} = \sigma^2_1 + \sigma^2_2 + \sigma^2_3$ where σ^2_{1+2+3} is the variance of fraternal twins; σ^2_1 is the variance due to environment; σ^2_2 is the variance due to heredity; and σ^2_3 is the variance due to the method. The variance for identical twins is $\sigma^2_{1+3} = \sigma^2_1 + \sigma^2_2$.

In addition, Lundstrom considers "internal factors" which may be genetic or environmental or both, which are seen in asymmetries of tooth size, for instance. He suggests:

> It is conceivable that, for instance, a slight difference in pH, a difference in temperature due to the intensity of the metabolism between the right and the left side, causes certain dissimilarities which cannot directly be attributed to environment, but which are neither conditioned by heredity. Therefore Dahlberg has suggested a division into three groups of etiological factors, namely, genetical, environmental and internal factors showing random distribution between left and right side, and also between co-twins on their left and right side, respectively. Dahlberg points out that these internal factors are particularly of importance concerning those characters conditioned by genes with a low penetrability [p. 92].

It is to get at these "internal factors" that Lundstrom considers the differences between left and right sides for maxillary incisors and cuspids.

The implications of the comparisons are not at all easy to see, although it is apparent that the variability between first and second measurements is least; between left and right sides, more; between MZ twins, more; and between DZ twins, most. For all teeth, simple variance ratios (DZ/MZ) have been calculated, the purpose of which is to allow one to order the variation according to the level of statistical significance.

Perhaps the most clear-cut statement in the way of general conclusion is that "the genetic factors are of relatively great significance to the variability in the tooth- and jaw-size" (p. 183). He suggests that differences between individuals can be attributed to (1) both environmental and genetic asymmetric factors, (2) environmental factors with symmetric effects, and (3) genetic factors with symmetric effects.

The study of Horowitz, Osborne, and DeGeorge (1958) involved fifty-four pairs of like-sexed twins (average age twenty-seven years), thirty-three of which were monozygous (twenty-one female and twelve male) and twenty-one dizygous (sixteen female and five male). Zygosity was determined primarily through the use of blood-group analysis and secondarily through consideration of eye color, ear form, and dermal pattern. The six anterior maxillary and mandibular teeth were measured (except for restored or carious teeth) with a sliding caliper at the widest mesiodistal diameter parallel to the incisal surfaces of the tooth at the contact points.

Horowitz et al. (1958) note a low "genetic variability" of the canine and found a "sex influence" which operates more strongly on the left side than on the right "which suggests that there may be some general sex-influenced asymmetry mechanism operating at a developmental level" (p. 92).

Osborne et al. (1958) report the errors of measurement to range from 0.003 to 0.008 (units not specified), which they state is significantly less than the MZ differences ($P < 0.001$).

It is interesting to note that in the report of Osborne et al. (1958, p. 352) reference is made to "both Lundstrom's (1948) and Seipel's (1946) twin data" in which "no sex differences were found." It is possible perhaps, that Osborne had in mind Lundstrom's 1944 and Seipel's 1946 population studies which showed, according to Lundstrom "that only very insignificant sex differences in the standard deviation occur in the tooth size" (p. 79).

The report of Osborne et al. (1958) deals at some length with cross twin analysis (comparing I_{1A} with I_{2A} and then I_{1A} with I_{2B} et cetera, where A and B refer to twin A and twin B of a pair),

concluding essentially, that there are general and specific genetic factors controlling tooth size.

The statement that "the maximum size of the maxillary central incisors and mandibular central and lateral incisors is established by 3 to 4 months after birth, approximately one month later in the case of the canines, and not until 10–12 months after birth for the variable lateral incisors" (p. 355) seems to hint at the conclusions reached in this study. They conclude,

> The present analysis now gives evidence that the size of these teeth is under genetic control. It is therefore possible that for these teeth there is an association of time, size and genetic control.

In their discussion of the basis for twin studies, Sutton, Vandenberg, and Clark (1957) state, "A fundamental assumption underlying the estimation of heritability from a comparison of identical and fraternal twins is that the environments of the two members of a set of monozygous twins are neither more, nor less different from one another than are the environments of the two members of a pair of dizygous twins of the same sex." They go on to note that this assumption is open to question since MZ twins may have more dissimilar intrauterine environments than DZ but more similar postnatal environments. These biases may tend to neutralize one another.

Sutton et al. (1957) and Clark (1956) have reported on certain aspects of the twin study, of which the material used for this investigation of tooth size is a part. The sample consisted of forty-four MZ (twenty-three male and twenty-one female) and thirty-seven DZ (fourteen male and twenty-three female) pairs of like-sexed twins. Clark states, "Twins were classified as dizygous if they were discordant in either the ABO, MN Rh, Kell, Duffy or secretor reaction,

the ABO and Rh types being based on the antisera A, absorbed A, and B and C, D, E, c, and e respectively."

A group of twins concordant for blood types may be expected to contain 10 percent DZ twins according to Sutton, Clark, and Schull (1955). The concordant group was therefore examined for similarity. A concordant pair was ruled DZ if there was (1) a difference in color or pattern of the iris observed by three investigators in Kodachrome transparencies of the eyes, or (2) marked difference in facial and head characters including hair color. Studies of fingerprints, carpal films, cephalograms, and casts of the teeth were used to verify the other findings. This procedure may of course, tend to sharpen the difference between MZ and DZ groups unduly by wrongly labelling unlike MZ twins dizygous. It assumes a direct and good correlation between zygosity and phenotypes in fingerprint pattern, pattern and color of the iris, outlines of the bones of the wrist and skull and general appearance. The last criterion is, as we have suggested, not above suspicion, but it appears to have contributed very little.

In an attempt to clarify a problem of this nature, Wise (1958) investigated six sets of like-sexed triplets for whom serologic studies had been performed, not only on the triplets, but also on their parents. Despite this, two sets of the six had to be diagnosed on the basis of characteristics for which the exact genetic control mechanism is unknown. This would suggest, however, that it is possible to classify beyond reasonable doubt some multiple births on the basis of blood types alone, and then to establish for such data whether such items as cranio-facial contours as seen in the cephalograms, can be used completely reliably, as criteria for the diagnosis of zygosity.

Although the evidence for genetic control of tooth size is good, there is also evidence for the effects of environment on tooth size. Paynter and Grainger (1956) have shown that the size of the upper first molar of rats can be influenced by diet. Weanling rats, whose mothers had been fed on a diet deficient in vitamin A, or abnormally high in phosphate or contained fluoride (12 parts per million) had teeth significantly smaller than those of the controls.

Baume, Becks, and Evans (1954) found that thyroidectomy of rats will not only greatly reduce the eruption rate but also results in smaller actual tooth size.

With respect to individual teeth, the phylogenetic field theory of Butler (1939), as interpreted by Dahlberg (1951), is of interest, since it provided a simplifying principle. It was Butler's observation that morphologic variability becomes greater in the more distal teeth of each of the morphologic groups of maxillary incisors, cuspids, and molars, and mandibular cuspids and molars. The mandibular incisors become less variable toward the distal. Dahlberg amended this by separating premolars from molars in man. There are thus four "type" fields to consider, rather than eight teeth in each quadrant.

THE SAMPLE

The material consists of dental plaster casts for thirty-three pairs of like-sexed DZ twins and thirty-seven MZ pairs. The impressions were obtained with alginate (Jeltrate). For twenty-three individual twins there are double sets of dental casts (obtained within an hour of each other) for error control studies. The material was collected during 1953–1955 by J. P. Alderisio in cooperation with the Institute of Human Biology at the University of Michigan.

Distribution of this sample according to sex and zygosity with corresponding ages in months is as follows:

Zygosity	Males		Females		Total No.	Avg. Age
	No.	Avg. Age	No.	Avg. Age		
MZ	20	190.5	17	196.9	37	193.5
DZ	12	200.8	21	195.5	33	197.3
Totals . .	32	194.3	38	196.2	70	195.3

The reduction in numbers from the original sample participating in the Michigan Twin Study is small and proportionate for each group. It will be seen that the small number of DZ males will impose some restrictions upon the analysis. There is no reason to suspect that the reduction in numbers was other than random. It was the result of practical difficulties encountered in processing all the twins in a limited amount of time.

The disparity in average age of ten months between MZ and DZ males should have no effect upon this study since the teeth cannot be expected to change greatly in size with age in such a period.

Mesiodistal diameters were measured for all erupted or existing teeth on both left and right sides, from incisors to and including second molars with certain exceptions as follows:

1. Teeth containing restorations: If a restoration involving the mesial or distal side of a tooth could be detected on the cast, that tooth was not measured. The obvious restorations of this nature numbered 352.
2. Teeth missing (extracted): 109.
3. Teeth obscured by soft tissue: incisors through premolars—35; first and second molars—165; total—200.
4. Teeth having carious mesial or distal surfaces: 27.
5. Teeth having orthodontic bands, completely inaccessible mesial or distal surfaces and chipped teeth: 80.

Of a possible 3,920 measurements, 768 were not made, leaving a total of 3,152 measures of mesiodistal tooth diameter.

METHOD

Measurement

The measuring procedure was made as uniform as possible:

1. Lighting was standardized by using a desk-type fluorescent lamp and a gooseneck tungsten lamp.
2. All measurements were made with the same sliding caliper (Helios) having a vernier scale accurate to 0.1 mm. and sharply pointed beaks.
3. When teeth were in normal close alignment, the points of the calipers were placed at the widest mesiodistal diameter, being inserted from the labial or buccal.
4. When possible, measurements were made with the points of the calipers parallel to the long axis of the tooth on the normal contact areas. This of course, presupposes some spacing or rotation of the teeth.
5. If a tooth was rotated, the mesiodistal diameter that it would have in a normal position was recorded.
6. Within these restrictions, the greatest mesiodistal diameter was recorded.
7. Every effort was made to maintain the light source, the calipers and the eye in a straight line when reading the scale.
8. When the vernier scale gave a reading precisely between two points at the 0.1 mm. level (i.e., precisely between 7.6 and 7.7) the value used (either 7.6 or 7.7) was chosen randomly.

Separate data sheets were used for right side and left side and for A and B twins (four sheets per pair of twins) so that no comparison between sides or twins could occur inadvertently.

The sample was measured in units of ten twin pairs because this was the number which could be measured at one sitting. Left maxillary and mandibular quadrants for ten twin pairs were measured, then the right quadrants for the same ten.

In order to be assured that there were no mistakes in reading the instrument, the complete sample was measured twice. The first series of readings was then compared measure by measure with the second. If the difference between any measures was greater than an arbitrarily chosen 0.9 mm., the correct measure was identified and used. Otherwise, the second series of measures was used for all computations. However, the first series was also used as a check run on the "F" ratios (see p. 68).

The twenty-three replicate casts were measured upon completion of the measurements for the entire first series. The replicate series was then remeasured, so that there were four measurements for each tooth in this series, or two measures on each of two sets of replicate casts.

Only the replicate series was used for the error-of-measurement studies, since a period of several months separated first and second measures on the total sample. Since we are concerned with the differences between Twin A and Twin B in tooth size on casts of twelve to twenty-one subjects, double measures made during the same week on casts of twenty-three subjects provide a more similar control than would the double measures on the entire series.

Statistical Analysis

The major portion of the computations was performed on an IBM Model 650 computer according to the formulas presented in the

Appendix. The programs for the analysis of twin data were written by Steven G. Vandenberg. It might be mentioned here that the use of an electronic computer virtually eliminates computational errors.

FINDINGS

Errors of Measurement

Each second measure was subtracted from its corresponding first measure and the differences assembled according to tooth position into 28 x 2 = 56 cells for a four-way analysis of variance. Since precise tooth size was not of interest here, a number of restored teeth were measured in order to bring the number of differences in each cell up to eighteen and thus provide an orthoganal design. For the same reason, in cells having more than eighteen differences, entries were deleted randomly down to eighteen.

Bartlett's test (for homogeneity of variances; if the cell variances are not homogeneous, the analysis of variance will not be completely valid) on this design revealed that homogeneity did not exist (χ^2 = 330.3; df, 55; prob., less than 0.001).

However, the distribution of the differences between first and second measures for molars (M_1 and M_2) were quite different graphically from those for the other teeth (I_1 to P_2). (See Figs. 1, 2, and 3.) Therefore, Bartlett's test was performed for I_1—P_2. Again, the lack of homogeneity was significant (χ^2 = 102.9, df—39, prob.—less than 0.001). However, it was deemed worth while to perform the analysis of variance for these five teeth as a suggestive procedure.[1]

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[1]The largest within-cell variance was 0.325 mm. and the smallest, 0.051 mm.

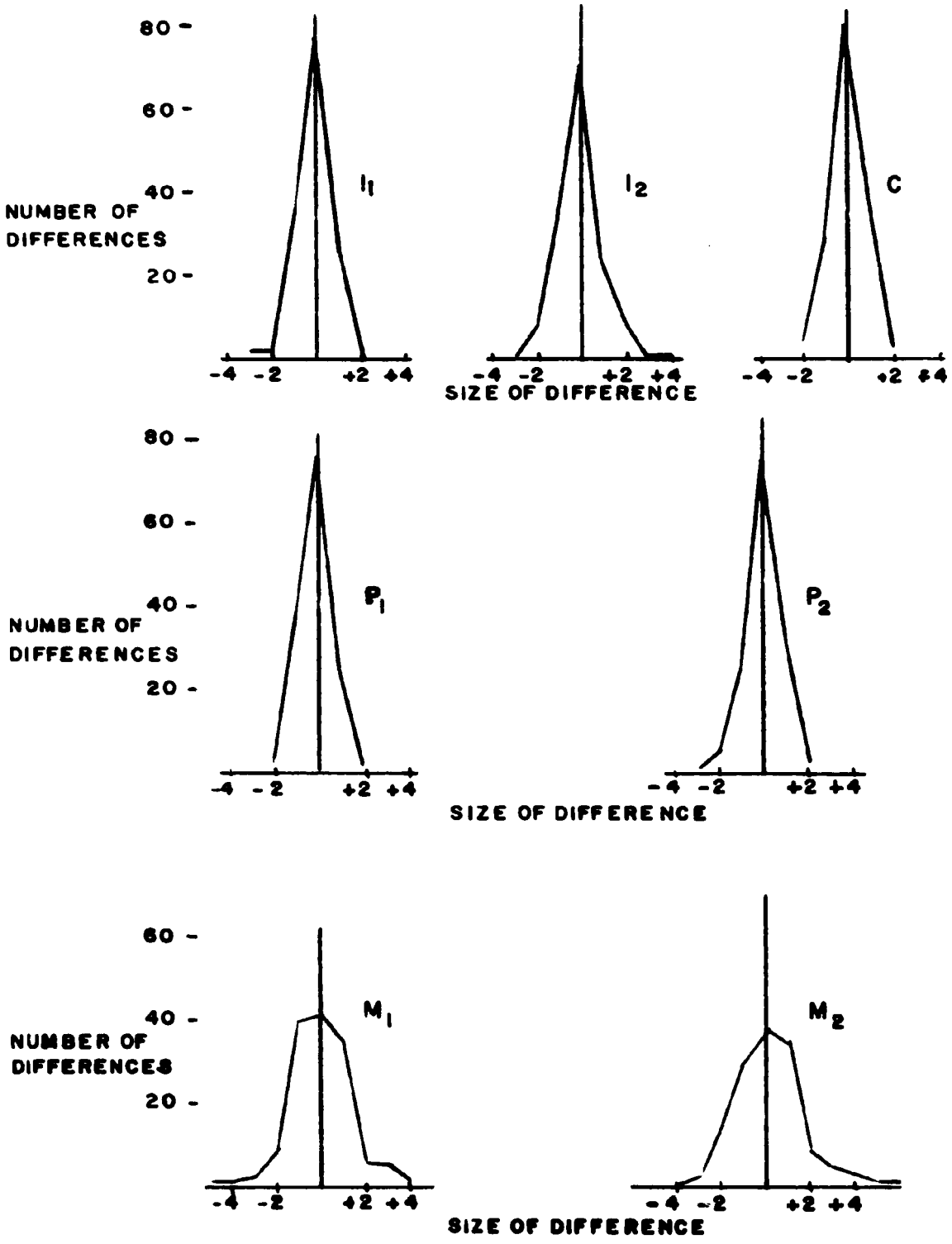

Figure 1. Distribution of differences (first measure – second measure) according to position. (N = 144 for each graph.)

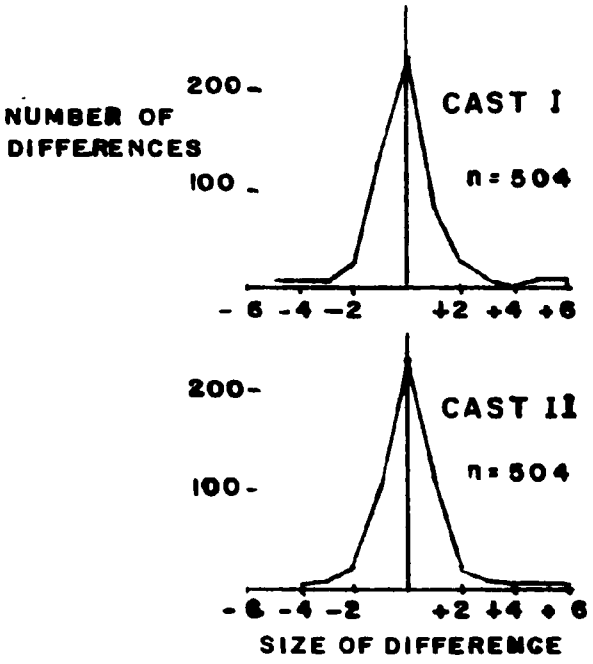

Figure 2. Distribution of differences according to cast.

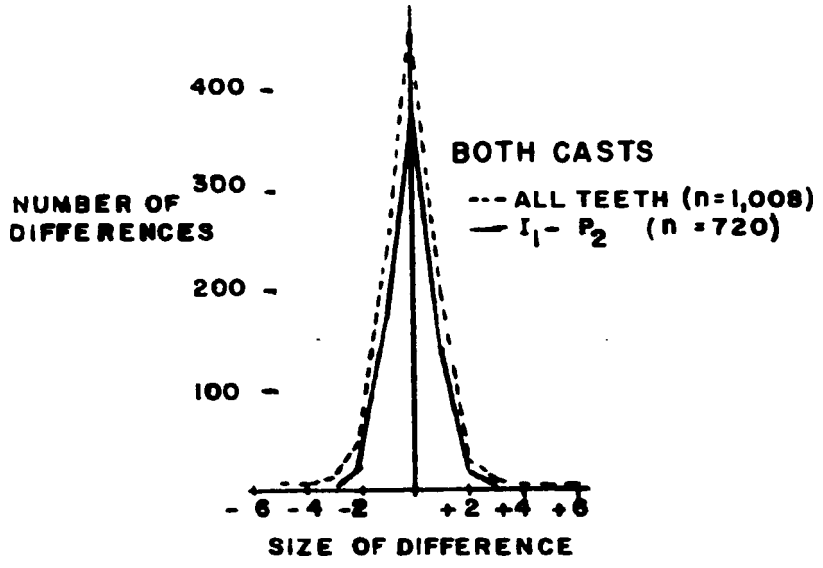

Figure 3. Distribution of first measure minus second measure differences for I_1—M_2 and for I_1—P_2.

Table 4 is a summary of this analysis. The differences between first and second measures are more variable in the Cast I measures than in the Cast II measures. This may be explained by the fact that the first measures on the Cast I series were made as they occurred in the total sample over a two-week period. The second measures on the Cast I series were made after the complete sample had been measured. On the other hand, both measures on the Cast II series were made in the same week. This is substantiated by Table 5 in which the Cast I differences are seen to be larger than the Cast II differences.

The analysis also shows the maxillary differences to be more variable than the mandibular differences. Two explanations are possible for this:

1. The lack of homogeneity of cell variances suggests that the within-cell variance could have been underestimated, thus increasing the significance of "F" ratios in which the within-cell variance is the denominator.

2. The maxillary teeth are actually more difficult to measure. The maxillary laterals, cuspids, and molars would seem to be more difficult to measure than their mandibular counterparts simply on the basis of morphology. These teeth do not, as a rule, have clearly defined parallel proximal surfaces—the maxillary cuspid, for instance, is usually rather conical in terms of a mesiodistal measurement—so that one would expect the maxillary measures to show more variability. However, Table 5 does not bear this out, at least with respect to the mean differences.

The paired differences between Cast I and Cast II (Table 6) were also subjected to Bartlett's test with similar results. For fifty-six cells (I_1—M_2) χ^2 = 447.2, df—55, $P < 0.01$; and for forty

Table 4. Summary of four-way analysis of variance for the differences between first and second measures on each of two sets of casts. ("Tooth type" refers to the incisors, cuspids, and bicuspids only. Number in each cell = 18.)

Source	Sum of Squares	df	Mean Squares	F	Probability
Cast I vs. Cast II	0.05600	1	0.05600	7.943	0.001–0.0001
Right vs. left . . .	0.02112	1	0.02112	2.996	0.20–0.05
Maxilla vs. mandible	0.02812	1	0.02812	3.989	0.05–0.01
Tooth type	0.00520	4	0.00130	0.184	0.20–0.05
Interaction	0.21950	32	0.00686	0.973	0.20 plus
Between cells . . .	0.32994	39	0.00846	1.200	0.20–0.05
Within cells	4.79171	680	0.0705		
Total	5.21165	719			

Table 5. Means of differences between first and second measures, with "t" tests. (Cast I and Cast II separate and together.)

Tooth Position	Maxilla				Mandible			
	Left		Right		Left		Right	
	Mean	"t"	Mean	"t"	Mean	"t"	Mean	"t"
				Cast I (N = 18)				
I_1	-0.039	2.3*	-0.022	1.3	-0.028	1.4	-0.006	0.4
I_2	-0.017	0.2	-0.017	0.6	-0.022	2.2*	-0.006	0.2
C	-0.044	2.6*	-0.017	1.2	-0.050	2.5*	0.006	0.4
P_1	-0.039	2.8*	-0.017	1.2	-0.022	2.2*	0.017	0.8
P_2	-0.033	2.4*	-0.028	1.6	-0.017	0.7	0.006	0.3
M_1	0.006	0.2	0.039	1.0	-0.094	2.7*	0.017	0.8
M_2	0.039	0.8	-0.044	0.8	0.033	0.8	0.044	1.6
				Cast II (N = 18)				
I_1	0.006	0.3	-0.017	0.8	-0.016	0.4	0.028	2.0*
I_2	-0.017	0.5	0.011	0.6	-0.028	1.5	0.017	0.8
C	0.006	0.4	-0.011	0.6	0.028	2.0*	-0.033	1.0*
P_1	0.003	1.9*	-0.033	1.5	-0.011	0.8	-0.022	1.6
P_2	-0.006	0.3	0.011	0.6	0.000	—	0.000	—
M_1	0.011	0.3	0.017	0.4	0.039	1.6	-0.050	1.8
M_2	-0.022	0.6	0.044	1.0	-0.044	1.8	0.011	0.3
				Both Casts (N = 36)				
I_1	-0.017	1.2	-0.019	1.9*	-0.017	1.7*	0.017	1.7
I_2	-0.017	0.8	-0.003	0.2	-0.025	2.5*	0.006	0.4
C	-0.019	1.9*	-0.014	1.4	-0.011	0.8	0.019	1.9*
P_1	-0.003	0.3	-0.025	2.5*	-0.017	1.8*	-0.003	0.3
P_2	-0.019	1.9*	-0.008	0.8	0.008	0.6	0.003	0.2
M_1	0.008	0.4	0.028	1.1	-0.028	1.2	-0.017	1.0
M_2	0.008	0.3	0.000	—	-0.006	0.2	0.028	1.2

*Significant at the 0.05 level.

Table 6. Means of differences between Cast I and Cast II measures with "t" tests. (First measure and second measure separate and together.)

Tooth Position	Maxilla				Mandible			
	Left		Right		Left		Right	
	Mean	"t"	Mean	"t"	Mean	"t"	Mean	"t"
	First Measure (N = 18)							
I_1	-0.028	0.9	-0.011	0.4	-0.044	1.3	-0.017	0.6
I_2	-0.039	0.7	-0.100	2.6*	-0.022	0.8	-0.011	0.5
C	-0.022	0.9	-0.022	1.1	-0.061	2.3*	-0.028	1.1
P_1	-0.094	3.0*	0.000	—	-0.011	0.6	0.027	0.9
P_2	0.006	0.1	-0.072	3.0*	0.006	0.1	0.017	0.6
M_1	0.072	2.1*	0.033	0.9	-0.083	2.2*	0.011	0.4
M_2	-0.072	1.1	-0.072	1.0	0.044	0.8	0.017	0.3
	Second Measure (N = 18)							
I_1	0.017	0.6	-0.006	0.2	-0.022	1.0	0.006	0.3
I_2	-0.039	0.8	-0.072	1.7	-0.028	1.1	0.011	0.6
C	0.028	0.9	-0.017	1.2	0.017	0.6	0.000	—
P_1	-0.022	0.6	-0.017	0.8	0.000	—	-0.011	0.4
P_2	0.033	1.0	-0.033	1.1	-0.011	0.2	0.011	0.5
M_1	0.078	1.7	0.011	0.3	0.050	1.9	-0.056	1.9
M_2	-0.133	2.3*	0.017	0.2	-0.033	0.7	-0.017	0.2
	Both Measures (N = 36)							
I_1	-0.006	0.3	-0.008	0.5	-0.033	1.7	-0.006	0.3
I_2	-0.039	1.0	-0.086	3.1*	-0.025	1.4	0.000	—
C	0.003	0.1	-0.019	1.9*	-0.022	1.1	-0.014	0.8
P_1	-0.058	2.4*	-0.008	0.6	-0.006	0.6	-0.008	0.4
P_2	0.019	0.7	-0.053	3.1*	-0.003	0.1	0.014	0.8
M_1	0.075	2.7*	0.022	0.9	-0.017	0.7	-0.022	1.0
M_2	-0.103	2.4*	-0.028	0.5	0.006	0.2	0.000	—

*Significant at the 0.05 level.

cells (I_1–P_2), χ^2 = 118.6, df—39, P< 0.001. Both of these are quite significant and it was not thought worth while to use the analysis of variance method further. (See also Fig. 4.)

The mean differences between measures on the Cast I series and on the Cast II series is –0.0146 mm., which is larger than the difference between all first measures and all second measures (–0.0051 mm.). There is then, the possibility that there is some actual difference in the casts themselves. On the other hand, the slightly different conditions of the first measure on the Cast I series may be a possible explanation. In this case there may have been a systematic error in measuring rather than a real difference in the casts.

The first-measure versus second-measure differences average less than 0.05 mm. in almost all cells. However, the differences between casts are larger and five of them exceed 0.07 mm. Since these differences include both investigator and cast discrepancies, it might be well to consider them as representative of the measuring error. However, for the sake of comparability, only the first- and second-measure differences are compared with those of Lundstrom and Seipel.

The standard error of the differences and the differences as percentages of the tooth size involved are presented in Table 7 with those of Lundstrom and Seipel for comparison. It is apparent that there is more variability in the measures of anterior teeth in this study than in Lundstrom's, though in general, the premolars and molars were measured with less variability.

Our study of errors also suggests that the data in this study on first and second molars are less reliable than that for the other teeth. Essentially, the measurement errors are distributed differently

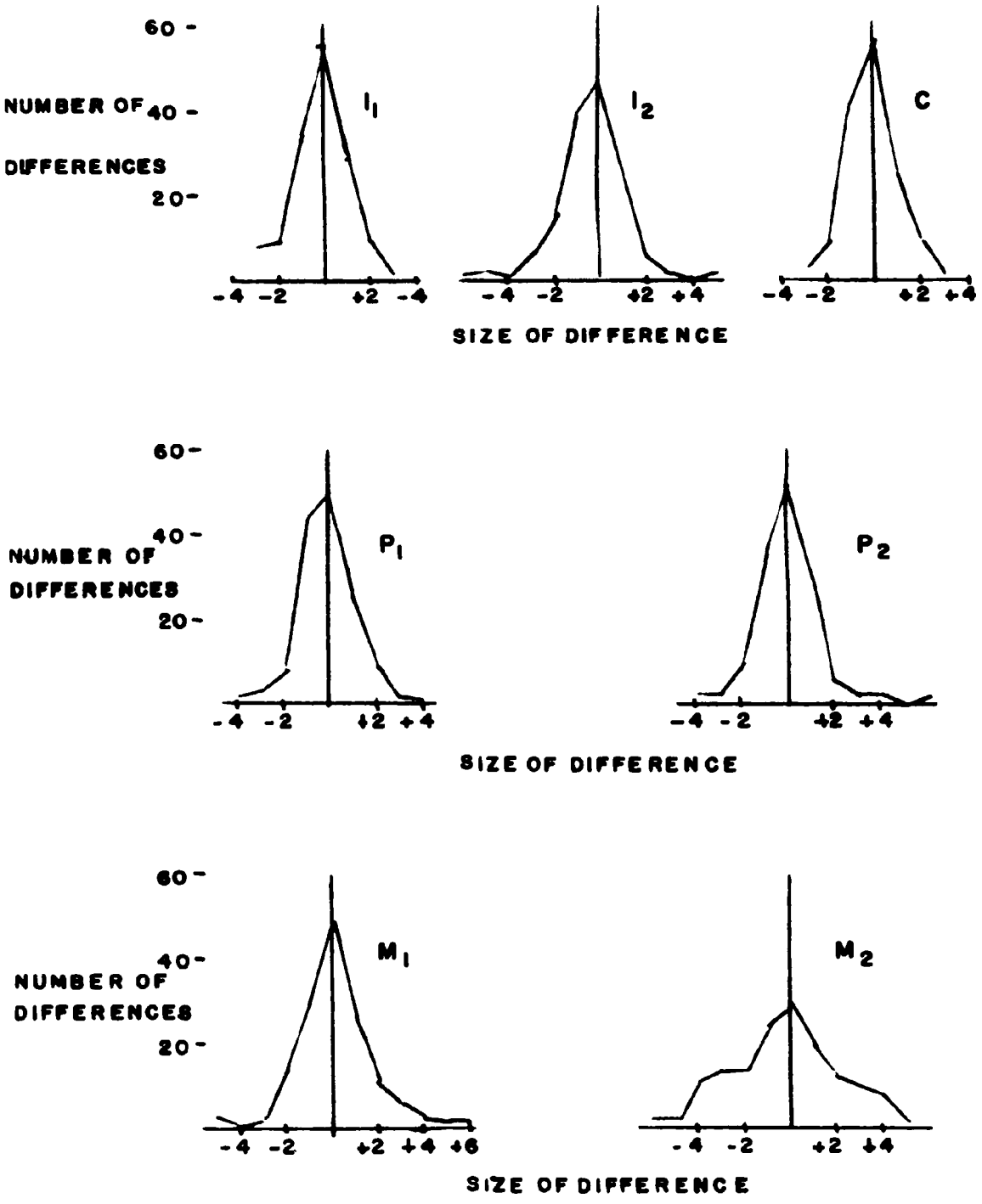

Figure 4. Distribution of paired differences between Cast I and Cast II measures. (N = 144 for each graph.)

Table 7. The errors of measurements (in mm.) for mesiodistal diameter expressed as the standard deviation of the mean difference between two measures on the same individual and as a percentage of the mean of both measures.

Tooth Position	Maxilla			Mandible		
	N	SD_m	SD in Pct. of Mean	N	SD_m	SD in Pct. of Mean
			This Study			
Left:						
I_1	36	0.09	1.09	36	0.08	1.51
I_2	36	0.12	1.85	36	0.07	1.21
C	36	0.07	0.93	36	0.09	1.36
P_1	36	0.08	1.16	36	0.06	0.86
P_2	36	0.08	1.18	36	0.09	1.28
M_1	36	0.14	1.38	36	0.15	1.41
M_2	36	0.19	1.93	36	0.16	1.59
Right:						
I_1	36	0.08	0.95	36	0.07	1.33
I_2	36	0.10	1.53	36	0.10	1.74
C	36	0.07	0.92	36	0.08	1.21
P_1	36	0.08	1.16	36	0.08	1.15
P_2	36	0.08	1.20	36	0.09	1.26
M_1	36	0.17	1.65	36	0.11	1.02
M_2	36	0.22	2.27	36	0.14	1.38

Table 7 (Continued)

Tooth Position	Maxilla			Mandible		
	N	SD_m	SD in Pct. of Mean	N	SD_m	SD in Pct. of Mean
			Lundstrom (1948), p. 60, Table 12)			
Left:						
I_1	40	0.06	0.69	40	0.03	0.61
I_2	39	0.08	1.21	40	0.08	1.34
C	38	0.05	0.72	39	0.05	0.67
P_1	37	0.09	1.33	38	0.11	1.48
P_2	37	0.08	1.16	33	0.15	2.11
M_1	37	0.16	1.54	36	0.16	1.46
Right:						
I_1	40	0.05	0.57	40	0.04	0.79
I_2	39	0.07	1.05	40	0.08	1.41
C	36	0.04	0.56	40	0.07	1.09
P_1	36	0.09	1.24	37	0.10	1.36
P_2	37	0.08	1.15	34	0.11	1.48
M_1	37	0.13	1.25	37	0.14	1.24
			Seipel (1946, p. 27)			
I_1	100	0.08	0.9	99	0.06	1.2
I_2	99	0.08	1.2	100	0.12	2.0
C	90	0.12	1.6	99	0.10	1.5

for the molars than for the other teeth and comparisons between molars and other teeth should be cautious for this reason.

We can also state that the more closely together in time two measures are made, the less will be the error of measurement between them. Thus, while the second measures in the error study were made several days after the first, the A and B twins were invariably measured one after the other. Thus, the estimate of error is maximal, rather than representative.

Table 8 gives the standard deviations for the differences between first and second measures and the within-twin variances. It is immediately apparent that the standard deviations for the molar differences are comparatively high, while those for the other teeth range from 0.07 mm. to 0.12 mm.

A comparison of the variances of the left side first- and second-measure differences and the left side MZ within-twin variances, with the former expressed as a percentage of the latter for I_1 through P_2 was made with the following results:

	I_1	I_2	C	P_1	P_2
Maxilla	14	19	9	13	18
Mandible	20	9	13	6	7

This means that from 7 percent to 20 percent of the left side MZ within-twin variability could be due to measurement errors. Whether this has had an important effect on the study of within-twin variances is discussed at greater length below (p. 68).

Table 8. A comparison of the standard deviations of the differences between first and second measures with the within-twin variances (SD of the within-twin differences).

Tooth Position	Maxilla				Mandible			
	Left		Right		Left		Right	
	N	SD	N	SD	N	SD	N	SD
Differences between First and Second Measures								
I_1	36	0.09	36	0.08	36	0.08	36	0.07
I_2	36	0.12	36	0.11	36	0.07	36	0.10
C	36	0.08	36	0.07	36	0.09	36	0.08
P_1	36	0.08	36	0.08	36	0.06	36	0.08
P_2	36	0.08	36	0.08	36	0.09	36	0.09
M_1	36	0.14	36	0.17	36	0.15	36	0.11
M_2	36	0.19	36	0.22	36	0.16	36	0.15
Within-Twin Differences								
MZ:								
I_1	35	0.24	31	0.26	34	0.18	36	0.16
I_2	36	0.28	34	0.29	35	0.23	35	0.22
C	33	0.26	36	0.19	35	0.25	35	0.24
P_1	28	0.22	26	0.25	35	0.25	35	0.24
P_2	21	0.19	19	0.32	25	0.34	27	0.32
M_1	20	0.18	14	0.32	12	0.30	12	0.28
M_2	18	0.35	13	0.43	10	0.40	13	0.42
DZ:								
I_1	32	0.57	32	0.54	32	0.36	32	0.38
I_2	28	0.54	28	0.64	33	0.43	32	0.41
C	29	0.44	31	0.38	32	0.45	31	0.40
P_1	25	0.32	21	0.38	30	0.37	28	0.37
P_2	15	0.34	13	0.43	18	0.53	21	0.54
M_1	17	0.47	15	0.58	10	0.45	15	0.55
M_2	13	0.58	16	0.59	13	0.61	16	0.65

Nature of the Sample

Missing measures.—Since 19.6 percent of the potential sample of teeth could not be measured, we must ask how the missing measures are distributed and whether they could have an effect on the outcome of the study. This is essentially a consideration of the means of various groupings of the sample. Discussion of the effects of the missing measures on the variance ratios is included in the analysis of variance.

Appraisal of measures not made on teeth (for the reasons cited, p. 16) in this study cannot be more than suggestive with respect to the inheritance of a tendency toward caries susceptibility, for instance, because the investigation was not set up to study this. In addition, for each category the following factors should be considered:

1. Teeth not measured because of restorations detectable on the casts, essentially reflect a somewhat subjective evaluation of the quality of the restorative work, since very good restorations would not be detected. There is no way of demonstrating whether or not the quality of the work was different for MZ and DZ twins.

2. With respect to missing or extracted teeth, although lateral and PA cephalograms were available, the evidence for congenital absence of a tooth, for instance, could not be conclusive (since the study is in no way longitudinal); nor again is there any way of demonstrating whether the exposure to dental care was independent of zygosity. Table 9 presents some evidence that in this sample the MZ twins are more alike with respect to extracted teeth than are the DZ twins. Table 9 is a summary of the answers to the question, "If Twin A has an extracted tooth, does Twin B also have the same

Table 9. Chi-square tests in which the number of concordant MZ missing teeth are tested against the DZ missing teeth. (A significant χ^2 means that there is more agreement among MZ twins with respect to extracted teeth than among DZ twins.)

Source	χ^2	df	Probability Range
Maxilla left	6.465[a]	1	0.02–0.01
Maxilla right	1.721[a]	1	0.20–0.10
Mandible left	0.158[a]	1	0.20 plus
Mandible right	0.303[a]	1	0.20 plus
Maxilla	14.275	3	0.01–0.001
Mandible	5.167	3	0.20–0.10
Maxilla and mandible	20.076	7	0.01–0.001

[a]Yates correction employed.

tooth extracted?" The "yes" answers for MZ twins are compared in Table 8 with the "yes" answers for DZ twins. It was found that the MZ twins had significantly more "concordance" with respect to extracted teeth than did the DZ twins.

3. While the category "obscured by soft tissue" is least influenced by uncontrolled factors, it is an evaluation in terms of tooth surfaces available for measurement (of the mesiodistal diameter), rather than of eruption. Only four DZ and one MZ twin pairs were less than fourteen years of age, so that eruption as such is not an important factor. Most such obscured measures belonged to the second molars,[1] which had erupted into occlusal contact although their distal contact areas were obscured by soft tissue.

4. The presence of caries has again much more to do with the availability of dental services than with zygosity.

5. Finally, the "other" category is the result of attrition of the casts and orthodontic bands, both having no connection with zygosity.

Table 10 shows left and right sides to be almost identical with respect to missing measures. This table also shows that the maxillary teeth differ from the mandibular teeth, in that they contain more restorations (215 vs. 137) but have fewer extracted teeth (26 vs. 73).

The χ^2 analysis of missing measures (summarized in Table 11) distributed according to sex and zygosity shows that the missing measures are unevenly distributed with respect to sex (there are more missing in the female groups) and that there is an interaction

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[1]There was a total of 200 measures not made because of soft-tissue interference, of which 158 were for second molars.

Table 10. Summary of measures not made according to cause. (Measures were made on 3,152 teeth and were not made on 768 teeth [19.6 percent].)

Tooth Position	Restorations	Extractions	Soft Tissue Obscured	Caries	Other	Total
			Left Maxilla			
I_1	1				2	3
I_2	2				4	6
C	4		5		1	10
P_1	19	1		2	1	23
P_2	33	8	6	2		49
M_1	36	7	2	1	6	52
M_2	12	1	37		6	56
	107	17	50	5	20	199
			Right Maxilla			
I_1	1			2	4	7
I_2	3		1	1	3	8
C			3	2		5
P_1	25		2		1	28
P_2	35	7	5	1	2	50
M_1	35	10	2	2	8	57
M_2	9	2	36	2	3	52
	108	19	49	10	21	207
			Left Mandible			
I_1		1	1		3	5
I_2					2	2
C			1		2	3
P_1	5	1	1			6
P_2	22	4	4	4	2	36
M_1	35	26	2	2	5	70
M_2	11	7	43	2	6	69
	73	38	52	8	20	191

Table 10 (Continued)

Tooth Position	Restorations	Extractions	Soft Tissue Obscured	Caries	Other	Total
			Right Mandible			
I_1		1	1		1	3
I_2		1			2	3
C			1		3	4
P_1	5		1		1	7
P_2	16	8	3	2	2	31
M_1	37	18	1	1	5	62
M_2	6	7	42	1	5	61
	64	35	49	4	19	171
			Totals According to Cause			
Left side	180	55	102	13	40	390
Right side	172	54	98	14	40	378
Grand total	352	109	200	27	80	768

Table 11. Summary of a chi-square analysis to test for random distribution of the missing measures according to sex and zygosity.

Source	χ^2	df	Probability
Sex	4.360	1	less than 0.05
Zygosity	1.046	1	
Interaction	15.555	1	less than 0.001
Total	20.961	3	less than 0.001

Table 12. The missing measures distributed according to sex and zygosity.

Measures	Monozygous		Dizygous		Total
	Females	Males	Females	Males	
Missing . . .	233	189	216	130	768
Total	952	1,120	1,176	672	3,920
Ratios	0.245	0.169	0.184	0.194	0.196

between sex and zygosity with MZ females having the most missing measures, DZ males less, DZ females less, and MZ males least (Table 12).

Symmetry.—A check of left-right differences showed a high degree of symmetry with no differences approaching significance.

Males versus females.—Very definite sex differences in the means, significant at the 0.001 level for both maxillary and mandibular cuspids, exist in the DZ group (Table 13). This group also demonstrates very significant sex differences in maxillary second molars. Both MZ and DZ groups together (Table 15) demonstrate these sex differences, significant at the 0.001 level; but the MZ group (Table 14), while showing a similar trend, have only one position—the mandibular left cuspid, which has a sex difference significant even at the 0.10 level. The smaller difference in the MZ group is real and actual, since the standard errors are very much the same as those in the DZ group. The lack of differences appears to be the result of a concentration of rather large teeth amongst the females in the MZ group. It is this group which has the largest number of missing measures. There would therefore, seem to be a distinct possibility that the missing measures are not randomly distributed, but rather, contain an unexpected number of small teeth.

A further consideration of this problem in terms of variability seemed indicated. Table 16 presents a comparison of MZ variabilities with the variabilities for MZ and DZ groups together, and the same for DZ variabilities. The general pattern which emerges is that as a group, the MZ twins contribute more to the over-all variability than

Table 13. Summary of "t" tests of sex differences in mean mesio-distal tooth diameter for the dizygous twins.

Tooth Position	Left					Right				
	Female		Male		"t"	Female		Male		"t"
	N	$\bar{x}$	N	$\bar{x}$		N	$\bar{x}$	N	$\bar{x}$	
					Maxilla					
I_1	41	8.4	24	8.6	1.0	42	8.4	23	8.6	1.0
I_2	39	6.5	22	6.7	1.5	38	6.6	23	6.6	0.4
C	38	7.4	22	7.9	4.7*	40	7.5	22	7.8	3.5*
P_1	36	6.7	20	7.0	3.0*	36	6.8	16	7.0	2.2*
P_2	28	6.6	14	6.8	1.8	29	6.7	13	6.9	2.0*
M_1	28	10.1	16	10.5	3.4*	30	10.1	14	10.5	2.8*
M_2	24	9.7	16	10.1	3.6*	27	9.6	17	10.3	4.3*
					Mandible					
I_1	41	5.3	24	5.4	1.2	41	5.2	24	5.3	1.1
I_2	42	5.8	24	5.8	0.1	41	5.8	24	5.8	0.2
C	41	6.5	24	6.8	3.7*	40	6.5	24	6.9	4.9*
P_1	41	6.9	22	7.1	2.2*	39	6.9	22	7.1	1.2
P_2	30	7.1	16	7.2	0.8	29	7.1	19	7.2	0.9
M_1	23	10.4	12	11.1	3.2*	26	10.5	15	10.9	1.8
M_2	24	10.0	14	10.4	2.3*	26	10.1	16	10.5	1.9*

*Significant at the 0.05 level.

Table 14. Summary of "t" tests of sex differences in mean mesio-distal diameter for the monozygous groups.

Tooth Position	Left					Right				
	Female		Male		"t"	Female		Male		"t"
	N	$\bar{x}$	N	$\bar{x}$		N	$\bar{x}$	N	$\bar{x}$	
					Maxilla					
I_1	34	8.6	38	8.5	1.0	32	8.5	36	8.5	0.7
I_2	33	6.8	40	6.6	1.0	31	6.7	40	6.7	0.4
C	33	7.7	37	7.8	1.2	33	7.8	40	7.8	0.1
P_1	24	7.0	37	6.9	1.2	23	7.1	37	7.0	1.0
P_2	20	6.7	29	6.7	0.3	18	6.9	30	6.7	1.5
M_1	15	10.3	29	10.3	0.4	14	10.4	25	10.3	0.4
M_2	23	9.8	21	10.0	1.2	19	9.8	25	10.0	1.4
					Mandible					
I_1	34	5.4	36	5.4	0.1	34	5.4	38	5.4	0.1
I_2	34	5.8	38	5.8	0.3	34	5.8	38	5.8	0.1
C	33	6.6	39	6.8	1.9	33	6.7	39	6.8	1.1
P_1	31	7.0	40	7.0	0.7	33	7.1	39	7.0	1.1
P_2	23	7.1	35	7.1	0.8	24	7.2	37	7.1	0.8
M_1	11	10.9	24	10.8	0.5	10	11.0	27	10.9	0.1
M_2	17	10.3	16	10.3	0.3	16	10.5	21	10.4	0.8

Table 15. Summary of "t" tests of sex differences in mean mesio-distal tooth diameter for all twins.

Tooth Position	Left					Right				
	Female		Male		"t"	Female		Male		"t"
	N	$\bar{x}$	N	$\bar{x}$		N	$\bar{x}$	N	$\bar{x}$	
					Maxilla					
I_1	75	8.5	62	8.5	0.0	74	8.5	59	8.5	0.2
I_2	72	6.6	62	6.7	0.4	69	6.6	63	6.6	0.1
C	71	7.6	59	7.8	4.1*	73	7.6	62	7.8	3.3*
P_1	60	6.8	57	6.9	1.2	59	6.9	53	7.0	1.0
P_2	48	6.6	43	6.7	1.1	47	6.8	43	6.8	0.2
M_1	43	10.1	45	10.3	1.9*	34	10.6	36	10.9	1.8
M_2	47	9.7	37	10.1	3.1*	46	9.7	42	10.2	3.8*
					Mandible					
I_1	75	5.3	60	5.4	0.9	75	5.3	62	5.3	0.9
I_2	76	5.8	62	5.8	0.2	75	5.8	62	5.8	0.1
C	74	6.5	63	6.8	4.1*	73	6.6	63	6.8	4.1*
P_1	72	6.9	62	7.0	1.0	72	7.0	61	7.0	0.1
P_2	53	7.2	51	7.2	0.9	53	7.1	56	7.1	0.1
M_1	34	10.6	36	10.9	1.8	36	10.7	42	10.9	1.8
M_2	41	10.1	30	10.4	1.9*	42	10.3	37	10.4	1.0

*Significant at the 0.05 level.

Table 16. Summary of the number of times the dizygous or monozygous variability exceeds the variability for DZ and MZ together. (This table presents a count of the number of times the variability of the MZ twins and the DZ twins, separately, exceeds the variability of both together. Six comparisons were made in each category.)

Zygosity	Females		Males	
	Left	Right	Left	Right
Maxilla				
Dizygous	3	3	0	1
Monozygous	1	2	6	5
Mandible				
Dizygous	2	1	0	0
Monozygous	3	2	5	6

Table 17. Mesiodistal crown diameters of the teeth of the sample of twins used in this study. (Only one twin from each pair has been used in this compilation.)

Tooth Position	Males				Females			
	N	Mean	SD_m	SD	N	Mean	SD_m	SD
			Maxilla—Left Side					
I_1	32	8.48	0.12	0.65	38	8.45	0.08	0.50
I_2	31	6.62	0.09	0.52	35	6.62	0.09	0.54
C	29	7.84	0.07	0.40	36	7.52	0.06	0.35
P_1	28	6.90	0.06	0.35	30	6.71	0.07	0.39
P_2	19	6.72	0.10	0.44	22	6.62	0.08	0.37
M_1	22	10.30	0.12	0.55	19	10.01	0.09	0.41
M_2	19	10.15	0.12	0.51	24	9.71	0.11	0.55
			Mandible—Left Side					
I_1	30	5.35	0.06	0.37	37	5.30	0.06	0.37
I_2	31	5.80	0.08	0.47	38	5.76	0.05	0.34
C	31	6.80	0.08	0.45	37	6.45	0.06	0.35
P_1	30	7.00	0.08	0.45	37	6.87	0.06	0.39
P_2	25	7.18	0.07	0.36	26	7.16	0.07	0.39
M_1	18	10.88	0.19	0.80	17	10.48	0.16	0.66
M_2	16	10.35	0.15	0.60	20	10.14	0.16	0.69
			Maxilla—Right Side					
I_1	29	8.42	0.12	0.65	38	8.44	0.08	0.50
I_2	31	6.62	0.10	0.55	33	6.72	0.09	0.54
C	31	7.83	0.07	0.38	36	7.58	0.07	0.41
P_1	25	6.98	0.08	0.40	27	6.82	0.08	0.41
P_2	22	6.71	0.09	0.41	22	6.74	0.08	0.39
M_1	19	10.42	0.14	0.60	17	10.09	0.11	0.44
M_2	22	10.26	0.13	0.59	23	9.68	0.13	0.61
			Mandible—Right Side					
I_1	31	5.34	0.07	0.38	37	5.25	0.07	0.43
I_2	31	5.81	0.09	0.48	38	5.73	0.05	0.34
C	31	6.82	0.08	0.43	36	6.50	0.06	0.34
P_1	30	6.98	0.09	0.47	36	7.01	0.06	0.38
P_2	28	7.13	0.09	0.49	24	7.14	0.08	0.39
M_1	22	10.81	0.14	0.68	19	10.60	0.14	0.62
M_2	17	10.41	0.12	0.51	17	10.37	0.15	0.63

do DZ twins, except in the maxillary quadrant for females. This suggests that the missing measures have indeed reduced the variability of the MZ female group, and would seem to confirm the above suggestion that there was indeed an underrepresentation of the MZ female small teeth.

On the other hand, it should be remembered that most of the missing measures are for M_1 and M_2. The difference in pattern of variability is obviously not restricted to these teeth. Therefore, we must conclude that the missing measures are not responsible for the comparatively small over-all variability of the MZ females, but rather, that the MZ female group had actually less variability as a group than the other categories.

Comparison with other samples.—Table 17 contains the summary of tooth size in this sample which may be compared with data recorded by Seipel for Swedes (Table 1), by Selmer-Olsen for Lapps (Table 2), and by Moorrees et al. for Americans (Table 3). The summary for this sample of twins is for one of each pair only. Both males and females have smaller teeth than those recorded for Swedes by Seipel and for Americans by Moorrees et al. and larger teeth than those recorded for Lapps by Selmer-Olsen. The differences are not great and could be racial or due to sampling. The variability of all samples seems to be about the same.

Finally, we must ask whether any of the comparisons of means discussed above could influence the within-twin differences. Possibly a paucity of small teeth resulting in the equivalent of an excess of large teeth could produce slightly greater within-twin differences. This does not seem to have occurred as shown by the comparisons made in Table 18. This table gives a comparison of the within-twin

Table 18. A comparison of the standard deviations for the within-twin differences for this study with those found by Lundstrom and by Horowitz et al.

Tooth Position		Maxilla				Mandible			
		MZ		DZ		MZ		DZ	
		N	SD	N	SD	N	SD	N	SD
		This Study							
Left:	I_1	35	0.24	32	0.57	34	0.18	32	0.36
	I_2	36	0.28	28	0.54	35	0.23	33	0.42
	C	33	0.26	29	0.44	35	0.25	32	0.45
	P_1	28	0.22	25	0.32	35	0.25	30	0.37
	P_2	21	0.19	15	0.34	25	0.34	18	0.53
	M_1	20	0.18	17	0.47	12	0.30	10	0.45
	M_2	18	0.35	13	0.58	10	0.40	13	0.61
Right:	I_1	31	0.26	32	0.54	36	0.16	32	0.38
	I_2	34	0.29	28	0.64	35	0.22	32	0.41
	C	36	0.19	31	0.38	35	0.24	31	0.40
	P_1	26	0.25	21	0.38	35	0.24	28	0.37
	P_2	19	0.32	13	0.43	27	0.32	21	0.54
	M_1	14	0.32	15	0.58	12	0.28	15	0.55
	M_2	13	0.43	16	0.59	13	0.42	16	0.65
		Lundstrom (1948, p. 102)							
	I_1	91	0.19	93	0.52	93	0.14	91	0.32
	I_2	90	0.30	98	0.58	95	0.15	94	0.40
	C	87	0.17	87	0.39	93	0.16	95	0.34
	P_1	62	0.17	73	0.43	80	0.18	95	0.40
	P_2	53	0.22	60	0.43	62	0.26	67	0.45
	M_1	45	0.30	45	0.53	43	0.34	47	0.64
		Horowitz et al. (1958, p. 89)							
Left:	I_1	31	0.14	16	0.28	27	0.08	18	0.26
	I_2	31	0.20	16	0.33	28	0.16	15	0.22
	C	26	0.15	14	0.18	26	0.21	21	0.25
Right:	I_1	30	0.18	18	0.34	26	0.12	15	0.29
	I_2	29	0.17	18	0.59	29	0.11	17	0.33
	C	29	0.15	18	0.26	29	0.14	17	0.24

variances (as represented by the standard deviations of the differences between twins) for this study with those found by Lundstrom and by Horowitz et al. Some of the variances for this study are larger than those found by Lundstrom and by Horowitz et al. A larger error of measurement might explain these differences. However, since the error of measurement applies equally to MZ and to DZ, it would not affect the comparison of MZ and DZ within-twin variances.

Analysis of Variance

Consideration of the variance of MZ as opposed to DZ groups (Table 19) suggests a bias of some sort, since the MZ standard deviations are larger than the DZ standard deviations for twenty-six out of twenty-eight positions for the males, but for only sixteen out of twenty-eight positions for the females.

A check of the distributions suggested that the DZ males have less variability than the MZ males, possibly because of the smaller, and perhaps less representative, sample of only twelve pairs. Therefore, each of the MZ and DZ females groups was reduced randomly to twelve pairs and a check run performed. Under these conditions, the standard deviations for MZ males were larger than for DZ males nineteen out of twenty-eight times, and for females, seven out of twenty-eight times. This is the same pattern, but rather less pronounced. (See Table 20.)

The "F" ratios of DZ-within versus MZ-within variances are listed in Table 21, Column A. These "F" ratios are ratios of within-twin variances expressing the comparative heritability of each tooth and may be thought of as a ratio of E plus H plus M and E plus M, where E is the variance due to environment, H the variance

Table 19. Means and standard deviations (sample) for the twins, with zygosity, side, jaw, and sex separate.

Tooth Position	Males						Females					
	DZ			MZ			DZ			MZ		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
					Maxilla—Left Side							
I_1	24	8.6	0.44	38	8.5	0.64	41	8.4	0.53	34	8.6	0.42
I_2	22	6.7	0.44	40	6.6	0.55	39	6.5	0.52	33	6.8	0.52
C	22	7.9	0.35	37	7.8	0.42	38	7.4	0.36	33	7.7	0.29
P_1	20	7.0	0.30	37	6.9	0.42	36	6.7	0.38	24	7.0	0.41
P_2	14	6.8	0.28	29	6.7	0.42	28	6.6	0.35	20	6.7	0.33
M_1	16	10.5	0.30	29	10.3	0.57	28	10.1	0.42	15	10.3	0.44
M_2	16	10.1	0.31	21	10.0	0.55	24	9.7	0.47	23	9.8	0.57
					Mandible—Left Side							
I_1	24	5.4	0.25	36	5.4	0.38	41	5.3	0.33	34	5.4	0.42
I_2	24	5.8	0.25	38	5.8	0.52	42	5.8	0.34	34	5.8	0.35
C	24	6.8	0.38	39	6.8	0.47	41	6.5	0.36	33	6.6	0.30
P_1	22	7.1	0.36	40	7.0	0.45	41	6.9	0.36	31	7.0	0.40
P_2	16	7.2	0.33	35	7.1	0.45	30	7.1	0.43	23	7.2	0.35
M_1	12	11.1	0.65	24	10.8	0.87	23	10.4	0.55	11	10.9	0.54
M_2	14	10.4	0.63	16	10.3	0.52	24	10.0	0.54	17	10.3	0.66
					Maxilla—Right Side							
I_1	23	8.6	0.44	36	8.5	0.63	42	8.4	0.53	32	8.5	0.46
I_2	23	6.6	0.53	40	6.7	0.59	38	6.6	0.54	31	6.7	0.51
C	22	7.8	0.41	40	7.8	0.35	40	7.5	0.38	33	7.8	0.33
P_1	16	7.0	0.25	37	7.0	0.45	36	6.8	0.35	23	7.1	0.38
P_2	13	6.9	0.35	30	6.7	0.48	29	6.7	0.39	18	6.9	0.39
M_1	14	10.5	0.42	25	10.3	0.65	30	10.1	0.43	14	10.4	0.47
M_2	17	10.3	0.42	25	10.0	0.61	27	9.6	0.58	19	9.8	0.54
					Mandible—Right Side							
I_1	24	5.3	0.31	38	5.3	0.41	41	5.2	0.37	34	5.4	0.42
I_2	24	5.8	0.33	38	5.8	0.51	41	5.8	0.32	34	5.8	0.36
C	24	6.9	0.40	39	6.8	0.44	40	6.5	0.28	33	6.7	0.30
P_1	22	7.1	0.32	39	7.0	0.49	39	6.9	0.39	33	7.1	0.41
P_2	19	7.2	0.44	37	7.1	0.48	29	7.1	0.40	24	7.2	0.35
M_1	15	10.9	0.59	27	10.9	0.81	26	10.5	0.56	10	11.0	0.33
M_2	16	10.5	0.47	21	10.4	0.53	26	10.1	0.58	16	10.5	0.59

Table 20. Results of computations of twelve pairs of MZ males, twelve pairs of MZ females, twelve pairs of DZ males, and twelve pairs of DZ females.

Tooth Position	Males						Females					
	DZ			MZ			DZ			MZ		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
					Maxilla—Left Side							
I_1	24	8.6	0.45	23	8.7	0.59	24	8.4	0.58	24	8.5	0.42
I_2	22	6.7	0.44	24	6.8	0.61	22	6.5	0.56	23	6.7	0.47
C	22	7.9	0.35	23	8.0	0.26	23	7.4	0.39	24	7.6	0.27
P_1	20	7.0	0.30	23	7.1	0.35	22	6.7	0.37	17	6.9	0.37
P_2	14	6.8	0.28	17	6.9	0.22	16	6.5	0.39	15	6.7	0.35
M_1	16	10.5	0.30	17	10.4	0.57	19	10.0	0.38	11	10.2	0.37
M_2	16	10.1	0.31	13	10.1	0.65	16	9.6	0.40	16	9.7	0.54
					Mandible—Left Side							
I_1	24	5.4	0.25	23	5.5	0.35	24	5.2	0.34	24	5.4	0.45
I_2	24	5.8	0.31	23	6.0	0.54	24	5.8	0.37	24	5.8	0.33
C	24	6.8	0.38	24	6.9	0.45	24	6.4	0.33	23	6.6	0.31
P_1	22	7.1	0.36	24	7.1	0.38	24	6.8	0.34	21	6.9	0.30
P_2	16	7.2	0.33	21	7.3	0.36	17	7.1	0.48	18	7.1	0.35
M_1	12	11.1	0.65	13	11.1	0.96	12	10.2	0.54	7	10.6	0.28
M_2	14	10.4	0.63	10	10.5	0.44	16	9.8	0.56	13	10.1	0.56
					Maxilla—Right Side							
I_1	23	8.6	0.44	21	8.6	0.62	24	8.4	0.62	24	8.5	0.43
I_2	23	6.6	0.53	24	6.9	0.59	22	6.5	0.54	23	6.9	0.42
C	22	7.8	0.40	24	8.0	0.25	24	7.4	0.42	24	7.6	0.30
P_1	16	7.0	0.25	23	7.2	0.38	21	6.8	0.38	16	7.0	0.40
P_2	13	6.9	0.35	18	6.9	0.43	18	6.6	0.41	13	6.9	0.37
M_1	14	10.5	0.42	15	10.6	0.69	18	10.0	0.39	8	10.2	0.52
M_2	17	10.3	0.42	15	10.3	0.58	15	9.4	0.35	13	9.7	0.41
					Mandible—Right Side							
I_1	24	5.3	0.31	24	5.5	0.38	24	5.2	0.41	24	5.3	0.45
I_2	24	5.8	0.33	23	5.9	0.55	24	5.8	0.35	24	5.8	0.35
C	24	6.9	0.40	24	6.9	0.42	23	6.5	0.27	23	6.7	0.28
P_1	22	7.1	0.32	23	7.1	0.38	23	6.9	0.39	23	6.9	0.32
P_2	19	7.2	0.44	23	7.3	0.39	17	7.0	0.42	18	7.1	0.27
M_1	15	10.9	0.59	14	11.4	0.84	16	10.4	0.58	9	10.9	0.33
M_2	16	10.5	0.47	12	10.5	0.45	15	9.9	0.48	10	10.2	0.40

Table 21. Summary of the over-all "F" ratios together with the "F" ratios for each sex separately and a test of sex differences. ("w" means "within"; "m" means "male"; "f" means "female"; "sx" means "sex.")

Tooth Position	N		$F_{\frac{w_{DZ}}{w_{MZ}}}$ (A)	N		$F_{f\ \frac{w_{DZ}}{w_{MZ}}}$ (B)	$F_{m\ \frac{w_{DZ}}{w_{MZ}}}$ (C)	$F_{sx\ \frac{w_f}{w_m}}$ (D)
	DZ	MZ		f	m			
				Maxilla—Left Side				
I_1	32	35	5.8**	37	30	13.6**	2.0	2.2*
I_2	28	36	3.9**	34	30	3.1*	4.8**	1.7
C	29	33	2.8**	34	28	3.9**	2.2	1.0
P_1	25	28	2.8**	27	26	4.2**	1.3	2.1*
P_2	15	21	3.3**	18	18	2.9	4.5*	0.9
M_1	17	20	6.6**	17	20	4.4*	8.9**	1.8
M_2	13	18	2.9	17	14	4.0*	2.2	0.7
				Mandible—Left Side				
I_1	32	34	4.0**	37	29	4.9**	2.6*	1.9*
I_2	33	35	3.1**	38	30	3.4**	2.6*	1.3
C	32	35	3.5**	36	31	4.7**	2.0	1.8*
P_1	30	35	2.3**	35	30	1.7	2.5*	2.3**
P_2	18	25	2.4*	21	22	1.5	4.2**	1.3
M_1	10	12	2.9*	11	11	13.1*	1.6	1.7
M_2	13	10	2.3	13	10	1.7	3.1	0.7

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

Table 21 (Continued)

Tooth Position	N		$F_{\frac{w_{DZ}}{w_{MZ}}}$ (A)	N		$F_{f\,\frac{w_{DZ}}{w_{MZ}}}$ (B)	$F_{m\,\frac{w_{DZ}}{w_{MZ}}}$ (C)	$F_{sx\,\frac{w_f}{w_m}}$ (D)
	DZ	MZ		f	m			
				Maxilla—Right Side				
I_1	32	31	4.7**	36	27	5.0**	3.4*	2.1*
I_2	28	34	4.8**	31	31	4.2**	5.8**	1.0
C	31	36	4.0**	36	31	2.4*	7.7**	1.2
P_1	21	26	2.3*	23	24	3.1	1.6	1.5
P_2	13	19	1.8	16	16	1.3	0.3	3.6**
M_1	15	14	3.2*	15	14	6.3*	3.5*	0.7
M_2	16	13	2.1	15	14	1.5	3.1	0.6
				Mandible—Right Side				
I_1	32	36	5.4**	37	31	5.6**	4.0**	2.5**
I_2	32	35	3.8**	37	30	4.5**	2.4	2.0*
C	31	35	3.2**	35	31	4.4**	2.8*	0.9
P_1	28	35	2.6**	34	29	3.0*	1.9	1.6
P_2	21	27	2.8**	22	26	5.4**	2.0	1.1
M_1	15	12	6.4**	11	16	20.2*	5.7**	1.6
M_2	16	13	2.2	14	15	1.9	1.3	3.0*

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

due to heredity and M the variance due to measurement. The variance of the DZ within-twin differences is divided by the variance of the MZ within-twin differences. This comparison of MZ and DZ within-pair variances may be evaluated by reference to a standard table of "F." It will be seen that with the exception of the maxillary right first and second bicuspids and mandibular left second bicuspid, all teeth except the second molars have significant ratios, which means that the DZ differences are greater than the MZ differences at a statistically significant level. The maxillary left and mandibular right first molars have the highest ratios with the centrals, laterals, and cuspids coming next.

Column B (Table 21) gives the same ratio for the female twins alone, and Column C shows the ratios for males alone. Column B, for females, is of considerable interest because of its similarity with the general "F" test. The centrals, laterals, cuspids, and molars have significant ratios in all quadrants, while for the males, no tooth has a significant ratio in all four quadrants (i.e., many are significant in three quadrants, but none in all four). A comparison of the female within-twin variability with male within-twin variability is shown in Column D. It suggests that a significant sex difference in variability can affect the zygosity ratios, since the highest value here, for the maxillary right second bicuspid, corresponds with a nonsignificant "F" ratio in Column A.

Table 22 shows a series of consistency checks. These demonstrate that the between-pairs versus within-pairs variance ratios in MZ twins in Column E are very high (since MZ twins are alike), and that the between versus within ratios in DZ twins in Column F are close to unity (since DZ twins are not as alike). The value for the maxillary right first molar is less than one, which means that

Table 22. A compilation of various combinations of sex and zygosity ratios which provide validity checks for the over-all "F" ratio. ("f" means "female"; "m" means "male"; "b" means "between"; "w" means "within.")

Tooth Position	N				$F = \frac{b_{MZ}}{w_{MZ}}$ (E)	$F = \frac{b_{DZ}}{w_{DZ}}$ (F)	$F = \frac{b_{both}}{w_{both}}$ (G)	$F = \frac{w_{f_{MZ}}}{w_{m_{MZ}}}$ (H)	$F = \frac{w_{f_{DZ}}}{w_{m_{DZ}}}$ (I)
	MZ		DZ						
	f	m	f	m					
Maxilla—Left Side									
I_1	17	18	20	12	17.0**	2.0*	4.4**	0.4	2.7
I_2	16	20	18	10	14.2**	2.1*	5.2**	1.9	1.2
C	16	17	18	11	7.2**	1.8	3.6**	0.6	1.0
P_1	11	17	16	9	12.4**	2.1*	5.5**	0.8	2.5
P_2	8	13	10	5	17.6**	3.6**	7.7**	0.8	0.5
M_1	7	13	10	7	31.8**	1.4	6.6**	2.2*	1.1
M_2	10	8	7	6	12.2*	0.4	4.5**	0.5	0.9
Mandible—Left Side									
I_1	17	17	20	12	18.4**	1.8*	5.4**	1.0	1.9
I_2	17	18	21	12	13.6**	1.4	4.5**	0.9	1.2
C	16	19	20	12	9.0**	1.5	3.4**	0.8	1.9
P_1	15	20	20	10	11.1**	2.5**	5.5**	2.5	1.7
P_2	10	15	11	7	5.7	1.4	2.9**	2.1	0.7
M_1	3	9	8	2	37.0**	2.5	12.9**	0.2	1.5
M_2	5	5	8	5	6.5	3.1*	3.8**	1.0	0.6

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

Table 22 (Continued)

Tooth Position	N				$F_{\frac{b_{MZ}}{w_{MZ}}}$ (E)	$F_{\frac{b_{DZ}}{w_{DZ}}}$ (F)	$F_{\frac{b_{both}}{w_{both}}}$ (G)	$F_{\frac{w_{f_{MZ}}}{w_{m_{MZ}}}}$ (H)	$F_{\frac{w_{f_{DZ}}}{w_{m_{DZ}}}}$ (I)
	MZ		DZ						
	f	m	f	m					
					Maxilla—Right Side				
I_1	15	16	21	11	15.7**	2.1*	4.4**	1.2	1.8
I_2	14	20	17	11	12.8**	1.8	4.0**	1.0	0.7
C	16	20	20	11	12.2**	3.4**	5.8**	2.3	0.7
P_1	8	18	15	6	11.8**	1.4	5.2**	0.8	1.4
P_2	6	13	10	3	6.2**	3.0*	4.9**	2.6	11.1*
M_1	5	9	10	5	10.0**	1.0	3.1**	0.3	0.5
M_2	5	8	10	6	3.9	2.2	2.6**	0.9	0.4
					Mandible—Right Side				
I_1	17	19	20	12	24.3**	2.3**	6.2**	1.5	2.1
I_2	17	18	20	12	14.5**	1.4	4.3**	1.1	2.0
C	16	19	19	12	9.5**	1.5	3.8**	0.5	0.8
P_1	16	19	18	10	14.0**	2.8**	6.5**	1.0	1.6
P_2	10	17	12	9	6.0**	1.6	3.0**	0.4	1.2
M_1	2	10	9	6	19.3**	1.8	4.0**	0.3	1.0
M_2	4	9	10	6	4.8	2.4*	3.6**	2.0	3.1

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

for this tooth, the samples of DZ twins are less alike with respect to variability than samples of randomly paired individuals would have been.

Column G provides a check on the reliability of the measurements as a whole, since values less than one would suggest no similarity in twins. The values in this column have, in general, a level of significance similar to those for the within comparisons in Column A (Table 21).

Columns H and I in Table 22 compare sex variabilities within MZ and DZ groups respectively. The maxillary right second bicuspid shows a significant sex difference, so that we can say that the sex difference seen in Column D is due to the DZ group and this in turn, to the presence of only three DZ male pairs in the comparison.

Tables 23 and 24 contain the same information for the reduced sample, in which there were twelve pairs each of MZ males and females and DZ males and females.

Table 23. "F" ratios for sample reduced to forty-eight pairs with twelve pairs in each of the sex and zygosity categories. ("w" means "within"; "m" means "male"; "f" means "female"; "sx" means "sex.")

Tooth Position	N		$F_{\frac{w_{DZ}}{w_{MZ}}}$ (J)	N		$F_{f\ \frac{w_{DZ}}{w_{MZ}}}$ (K)	$F_{m\ \frac{w_{DZ}}{w_{MZ}}}$ (L)	$F_{sx\ \frac{w_f}{w_m}}$ (M)
	DZ	MZ		f	m			
				Maxilla—Left Side				
I_1	24	23	3.9**	24	23	12.1**	1.7	1.2
I_2	20	23	3.8**	21	22	3.8*	3.8*	1.0
C	22	23	5.0**	23	22	6.3**	4.1*	0.9
P_1	19	19	1.8	18	20	2.1	1.4	1.4
P_2	11	13	2.9*	12	12	2.8	3.2	0.7
M_1	14	12	3.6*	12	14	1.2	7.7**	0.5
M_2	11	12	3.3*	12	11	7.3*	1.9	0.6
				Mandible—Left Side				
I_1	24	23	5.5**	24	23	5.9**	5.0**	1.4
I_2	24	23	4.8**	24	23	5.5**	4.1*	1.0
C	24	23	3.2**	23	24	2.8*	3.7*	1.1
P_1	22	22	2.4*	22	22	2.2	2.3	2.3*
P_2	13	17	2.1	14	16	1.1	4.5*	1.1
M_1	5	7	2.6	5	7	8.1	1.8	1.2
M_2	11	8	2.4	11	8	1.9	3.0	0.6

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

Table 23 (Continued)

Tooth Position	N		$F_{w_{DZ}/w_{MZ}}$ (J)	N		$F_{f\ w_{DZ}/w_{MZ}}$ (K)	$F_{m\ w_{DZ}/w_{MZ}}$ (L)	$F_{sx\ w_f/w_m}$ (M)
	DZ	MZ		f	m			
				Maxilla—Right Side				
I_1	23	21	6.0**	24	20	9.3**	3.2*	1.7
I_2	21	23	5.4**	21	23	3.4*	8.0**	0.7
C	23	24	4.4**	24	23	2.5	11.3**	1.1
P_1	15	16	2.7*	14	17	3.7	2.4	1.2
P_2	10	11	0.8	11	10	0.6	0.3	2.8
M_1	11	8	2.0	9	10	8.3	2.1	0.3
M_2	11	8	2.4	11	8	1.9	3.0	0.6
				Mandible—Right Side				
I_1	24	24	5.9**	24	24	7.7**	4.1**	1.7
I_2	24	23	5.6**	24	23	8.9**	3.2*	1.6
C	23	23	3.8**	22	24	4.5**	3.5*	0.5
P_1	21	22	3.3**	22	21	2.6	5.7**	2.1*
P_2	16	19	2.4*	15	20	4.6*	1.8	0.7
M_1	11	7	4.0*	7	11	22.5**	3.0	1.1
M_2	11	8	1.4	7	12	1.0	1.4	2.3

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

Table 24. "F" ratios for sample reduced to forty-eight pairs which provide validity checks on sex and zygosity for the over-all "F" ratio. ("f" means "female"; "m" means "male"; "b" means "between"; "w" means "within.")

Tooth Position	N				$F_{\frac{b_{MZ}}{w_{MZ}}}$	$F_{\frac{b_{DZ}}{w_{DZ}}}$	$F_{\frac{b_{both}}{w_{both}}}$	$F_{\frac{w_{f_{MZ}}}{w_{m_{MZ}}}}$	$F_{\frac{w_{f_{DZ}}}{w_{m_{DZ}}}}$
	MZ		DZ						
	f	m	f	m	(N)	(O)	(P)	(Q)	(R)
					Maxilla—Left Side				
I_1	12	11	12	12	16.5**	3.6**	6.2**	0.2	1.8
I_2	11	12	10	10	16.5**	2.7**	5.9**	0.9	1.0
C	12	11	11	11	6.8**	2.0*	3.0**	0.7	1.0
P_1	8	11	10	9	8.7**	3.7**	5.6**	1.0	1.5
P_2	6	7	6	5	4.9**	3.5*	4.0**	0.7	0.7
M_1	5	7	7	7	27.1**	2.1	7.0**	2.0	0.3
M_2	7	5	5	6	14.7**	0.4	4.0**	0.2	0.9
					Mandible—Left Side				
I_1	12	11	12	12	35.7**	2.6**	7.7**	1.2	1.4
I_2	12	11	12	12	22.7**	1.9*	5.5**	0.8	1.1
C	11	12	12	12	13.1**	2.6**	5.1**	1.3	1.0
P_1	10	12	12	10	6.6**	2.0	3.3**	2.2	2.1
P_2	8	9	6	7	2.9*	1.8	2.2*	2.8	0.7
M_1	2	5	3	2	43.6**	1.0	15.2**	0.3	1.2
M_2	5	3	6	5	5.5*	3.0*	3.4**	1.0	0.6

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

Table 24 (Continued)

Tooth Position	N				$F_{\frac{b_{MZ}}{w_{MZ}}}$ (N)	$F_{\frac{b_{DZ}}{w_{DZ}}}$ (O)	$F_{\frac{b_{both}}{w_{both}}}$ (P)	$F_{\frac{w_{f_{MZ}}}{w_{m_{MZ}}}}$ (Q)	$F_{\frac{w_{f_{DZ}}}{w_{m_{DZ}}}}$ (R)
	MZ		DZ						
	f	m	f	m					
					Maxilla—Right Side				
I_1	12	9	12	11	20.3**	2.5*	4.8**	0.7	2.1
I_2	11	12	10	11	14.1**	1.9	4.0**	1.4	0.6
C	12	12	12	11	7.4**	3.3**	4.4**	3.8*	0.8
P_1	5	11	9	6	15.5**	1.7	5.6**	0.7	1.0
P_2	4	7	7	3	3.3*	6.4**	4.8**	2.9	6.4
M_1	3	5	6	5	7.2**	0.9	2.4*	0.1	0.4
M_2	3	5	5	6	1.6	0.4	0.8	0.8	0.6
					Mandible—Right Side				
I_1	12	12	12	12	30.9**	3.2**	7.4**	1.0	1.9
I_2	12	11	12	12	28.7**	1.9*	5.9**	0.7	1.9
C	11	12	11	12	11.2**	1.9*	4.0**	0.4	0.5
P_1	11	11	11	10	9.6**	2.7*	4.4**	3.9*	1.7
P_2	8	11	7	9	3.3**	2.1	2.5**	0.3	0.9
M_1	2	5	5	6	2.0	1.8	3.3**	0.1	1.1
M_2	2	6	5	6	3.3	2.8*	3.3**	2.8	2.0

*Ratio significant at the 0.05 level.
**Ratio significant at the 0.01 level.

DISCUSSION

The pattern which emerges in this study is one of decreasing heritability from central incisors to cuspids, with first molars next and bicuspids and second molars in that order. It is rather puzzling that in three of the four quadrants, the second bicuspid has a larger heritability ratio than the first bicuspid. Also, with the exception of the mandibular right quadrant, there is a sex difference here since the females have a larger value for the first bicuspid, while the males have a larger value for the second bicuspid in three out of four quadrants.

In terms of Dahlberg's (1951) modification of Butler's (1939) field concept (p. 14), one might expect the more medial tooth in each morphologic group of incisors, bicuspids, and molars to show a higher heritability ratio than the corresponding distal tooth, except for mandibular incisors. Indeed, this is so for the females, with the exception of the mandibular right bicuspids. The mandibular central incisors, however, have higher ratios than the mandibular laterals. The males, on the other hand, show the opposite trend as often as not. The tests of sex difference in variability (Column D) are significant for the groups in which the males have a higher heritability ratio for the more distal tooth, only at the 0.05 level.

There would seem, then, to be some evidence for a relationship between morphologic variability and heritability ratios to the extent that in the females, the less morphologically variable the tooth, the greater the heritability ratio.

When the DZ female and MZ male and female groups are reduced to twelve pairs to match the DZ male group, no great changes in the results of the analysis of variance occur. Since the sample is smaller, significance declines generally and the "F" tests of within-DZ variance versus within-MZ variance show significant differences for incisors and cuspids only. On the other hand, the male pattern approximates the female pattern more closely in the reduced group than it does in the total sample. Indeed, cuspids and lateral incisors show significant ratios in all four quadrants in the reduced sample for the males (Column L). It is unfortunate, then, that the number of DZ males is so small. The evidence neither supports nor refutes a theory of sex differences in the variability of within-twin differences.

In general, the evidence of this study suggests a pattern of declining heritability from central incisor to cuspid. Although the first molars have similarly high values, the lack of reliability of measurement suggests that this similarity be viewed with a little caution. However, since they show higher ratios in all four quadrants than do the bicuspids, we might conclude that heredity exerts a stronger influence on the first molars than on the bicuspids. The second molars show uniformly low ratios which are smaller than those for the other teeth. The pattern, then, is of declining heritability from I_1 to P_2, with M_1 having quite significant ratios and M_2, quite nonsignificant ratios.

Since Butler's (1939) field concept did not prove to be particularly useful in explaining this pattern, the development of the crowns of the permanent teeth was considered.

According to Logan and Kronfeld (1933) and Kronfeld (1935) the incisor crowns are completed between ages four and five, the cuspids at

approximately six to seven years, the bicuspids at about age six, the first molar crowns at two and one-half, and the second molar crowns at seven to eight years of age. These estimates are based on histologic studies of thirty specimens.

A recent radiographic study by Nolla (1952) which is based on twenty-five males and twenty-five females would seem to give a more accurate picture of crown completion. Since it is radiographic, it gives later estimates of crown completion. It is a serial study with almost two hundred readings of degree of crown completion at each age, as opposed to perhaps five or six at each age in the histologic study of Logan and Kronfeld (1933). According to Nolla, mandibular crowns are completed about six months earlier than maxillary crowns. Maxillary crown completion is seen radiographically for I_1 through P_2 at ages four and one-half, five and one-half, six and one-half, seven and one-third, and eight and one-third years respectively. For the first molars it is four and one-half years and for the second molars, eight and one-third years. Girls are slightly ahead of boys. Ages at which calcification should be seen radiographically were extrapolated.

The findings of Garn et al. (1958) for mandibular premolars and molars are in agreement with those of Nolla for the ages at which calcification is first seen, but seem to be four to eighteen months later for age of crown completion, possibly because of a different definition of crown completion.

This pattern is illustrated in Figure 5 in which times of initiation are taken from Logan and Kronfeld and times of crown completion from Nolla.

If this sequence of crown completion is compared with the significance patterns of the "F" tests, a distinct similarity may be

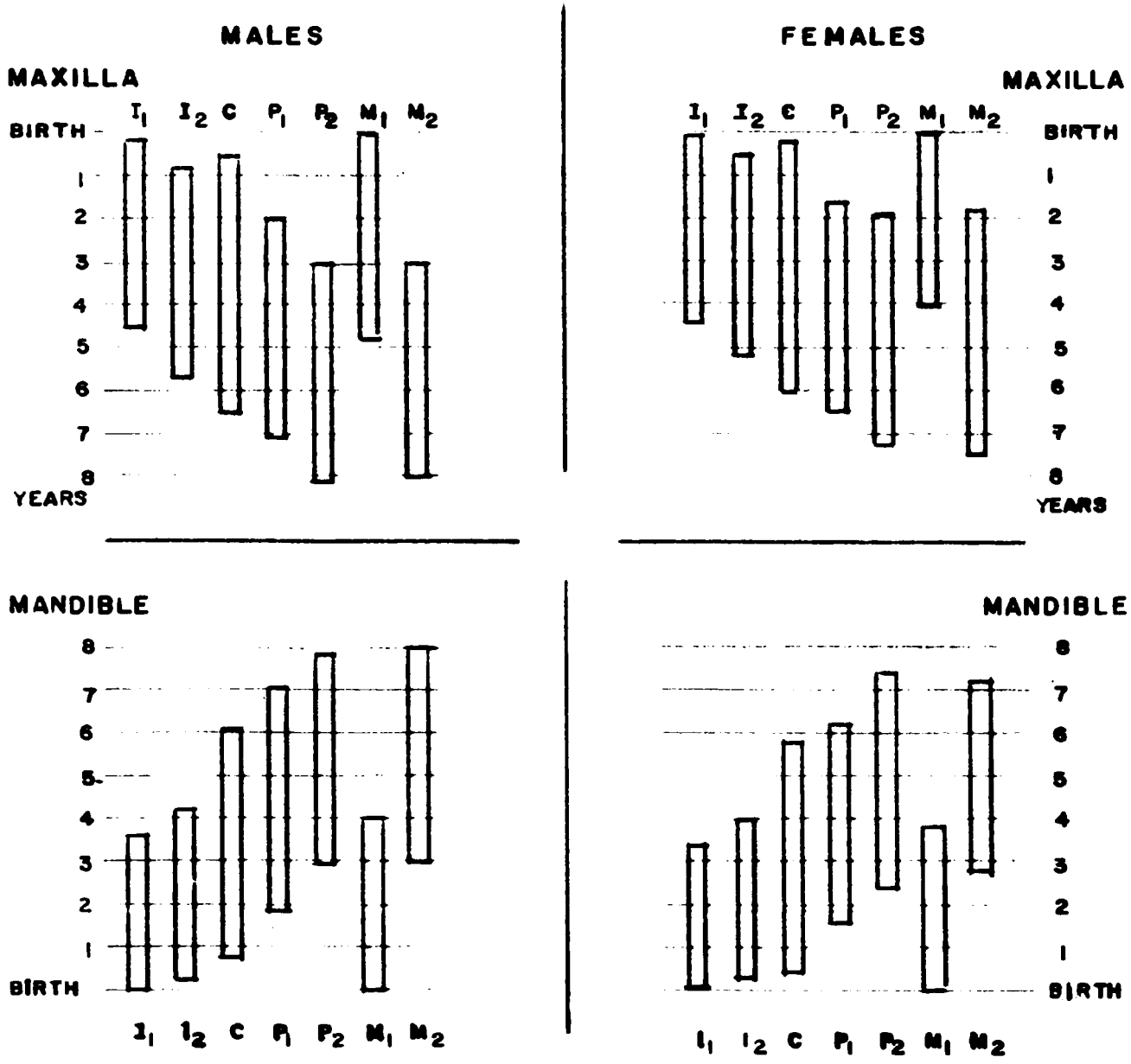


Figure 5. Duration of development of the crowns of the permanent teeth. Initiation after Logan and Kronfeld, and completion after Nolla.

seen. A scattergram of this relationship is shown in Figure 6, in which time of completion is plotted against the heritability as reflected in the corresponding "F" ratio from Table 20, Column A. The two lowest and two highest values at the extreme left of the distribution belong to the four first molars. If these were excluded from consideration, a rather straight line relationship becomes apparent. Figure 6 would seem to indicate that the later in life the crown of a tooth is completed, the greater the influence of environment will be on it and hence, the smaller will be its heritability.

Unfortunately, the information on crown initiation is as yet inadequate to warrant a stronger statement. If, however, this information does become available, it seems likely that a good correlation between time of completion of the crown, and duration of crown formation and heritability will emerge.

In the meantime, it is well to remember that the older a child is, the more severe are the effects of environment upon its development, or indeed, the older a child is, the more it is exposed to environmental changes. Thus, the very young child has a relatively uniform diet, is relatively inactive, and is much better protected from diseases than the child of four years of age, particularly in the American culture. Thus, the tooth which has completed its crown formation by four years of age should show less variability due to environment than the tooth whose crown is not completed until eight years of age.

We might now ask, "Can these findings be duplicated?" Table 25 is a compilation of data available on this. It can be shown that an "F" ratio obtained by dividing the variance of the DZ within-twin differences by the variance of the MZ within-twin variances will produce the same pattern as the machine method formulas used to

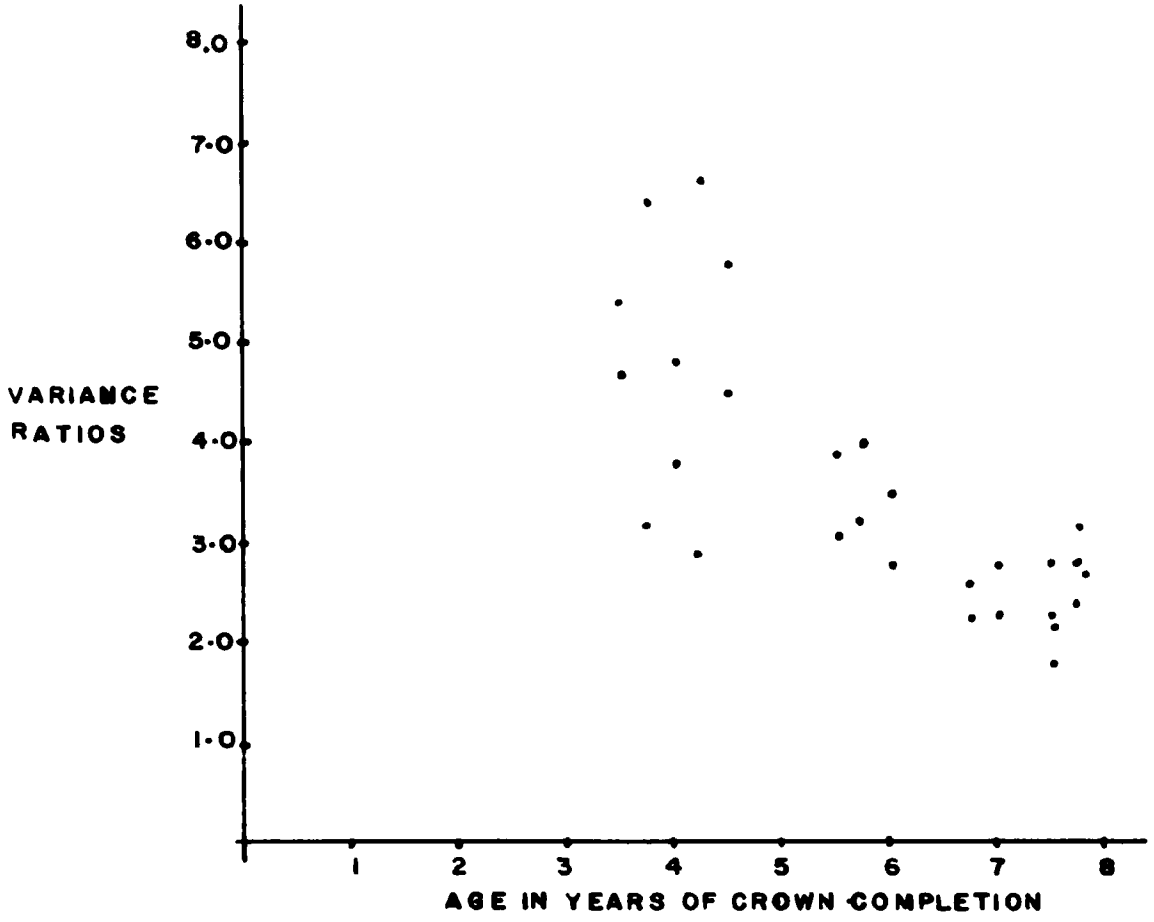


Figure 6. Scattergram showing the relationship between age of crown completion and the heritability variance ratios ("F"). Each dot represents one tooth position. There are twenty-eight positions shown.

Table 25. Comparison of "F" ratios computed for this study and for others. (The first column has the "F" ratios as given in Column A, Table 21. The second column contains those computed on the same casts by the author as a check. Column 3 contains the "F" ratios resulting from yet another set of measures made by another investigator [W. R. Priest]. Column 4 has been computed from the standard deviations presented by Horowitz et al. [1958], and Column 5 has been computed from Lundstrom's [1948] data.)

Tooth Position	This Study		W.R.P.	Horowitz	Lundstrom
	A	Check			
		Maxilla—Left Side			
I_1	5.8	5.4	6.9	4.0	7.5
I_2	3.9	5.8	6.2	2.7	3.7
C	2.8	3.0	3.3	1.4	5.3
P_1	2.8	4.1	2.7		6.4
P_2	3.3	2.9	2.3		3.8
M_1	6.6	3.3	2.8		3.1
M_2	2.9	0.9			
		Mandible—Left Side			
I_1	4.1	2.0	4.6	10.6	5.2
I_2	3.1	2.3	2.6	1.9	7.1
C	3.5	2.8	3.2	1.4	4.5
P_1	2.3	3.8	3.5		4.9
P_2	2.4	1.9	2.0		3.0
M_1	2.9	0.9	3.1		3.5
M_2	2.7	3.3			

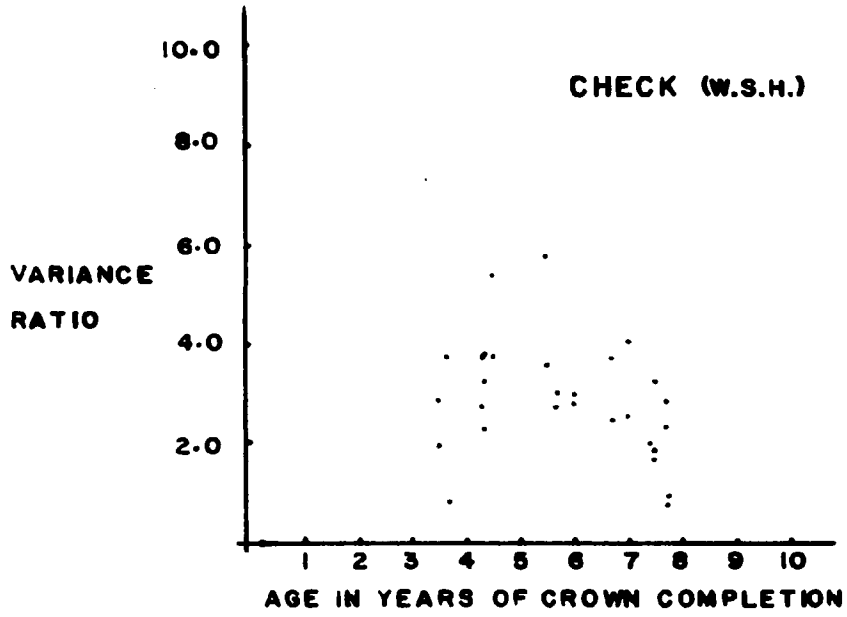
Table 25 (Continued)

Tooth Position	This Study		W.R.P.	Horowitz	Lundstrom
	A	Check			
		Maxilla—Right Side			
I_1	4.7	3.8	5.0	3.9	
I_2	4.8	3.6	4.4	12.7	
C	4.0	2.9	2.0	3.0	
P_1	2.3	2.6	4.0		
P_2	1.8	2.4	2.7		
M_1	3.2	3.8	1.9		
M_2	2.1	0.9			
		Mandible—Right Side			
I_1	5.4	2.9	5.7	5.9	
I_2	3.8	2.8	3.0	9.0	
C	3.2	3.1	2.4	3.9	
P_1	2.6	2.5	3.9		
P_2	2.8	1.8	3.0		
M_1	6.4	3.8	4.5		
M_2	2.2	2.0			

compute the "F" ratios as presented in Tables 21 to 24. This has been done for the data presented by Horowitz et al. (1958) and by Lundstrom (1948).

In addition, "F" ratios were computed for the first series of measurements (p. 18) as a check, and the computations from yet a third set of measures on this material by another investigator (W. R. Priest). The five series of "F" ratios available are presented in Table 25. The corresponding scattergrams are shown in Figures 7 and 8. The check run by the author shows a similar pattern in the right quadrants but does not give the decreasing values from I_1 to P_2 with the increase for M_1 in the left quadrants. The computations from W.R.P.'s measurements show the expected pattern in all but the maxillary right quadrant. The data of Horowitz et al. show a decrease from I_1 to C in the left quadrants but not in the right quadrants. The computations from Lundstrom's data agree completely with his conclusions, but not with those of this study. However, it should be remembered that he averaged the left and right side measures before making any computations. This might be expected to reduce the variability a trifle, but if such reduction occurs, it should be fairly uniform for all positions.

A further consideration of the "F" ratio reveals that the differences which contribute to a high or low "F" ratio are very slight. A difference of 0.1 mm. in the standard deviation of the DZ differences in one direction and those of the MZ differences in the other direction will completely change the resultant "F" ratio. It would seem possible, then, that a difference in the pattern of the errors of measurement (which has been shown to exist between this study and that of Lundstrom—Table 7, p. 29) could quite change the pattern of the "F" ratios. Certainly this must be the reason for the differences in the "F" ratio patterns computed by the author for the principal



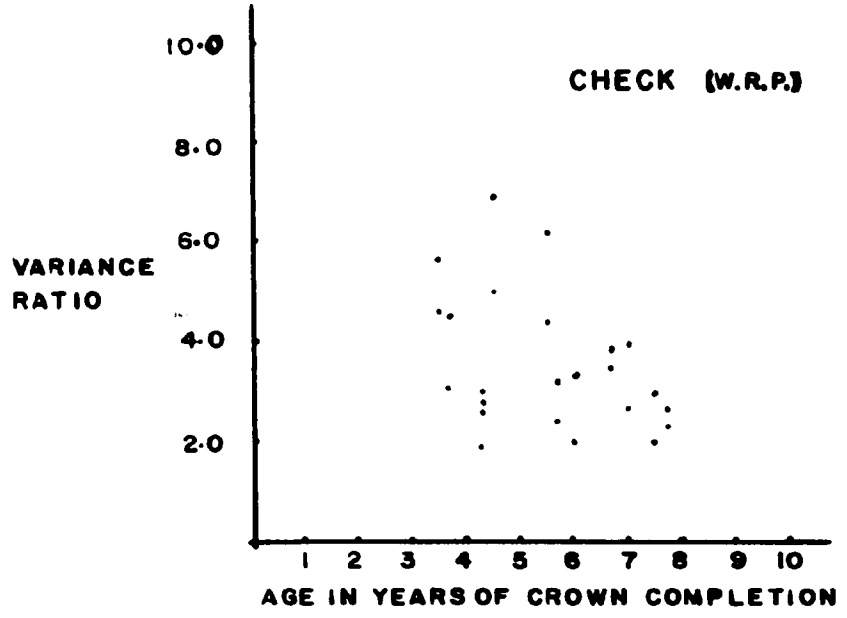


Figure 7. Scattergram showing the relationship between age of crown completion and heritability ratios for two sets of check measurements on the materials used in this study.

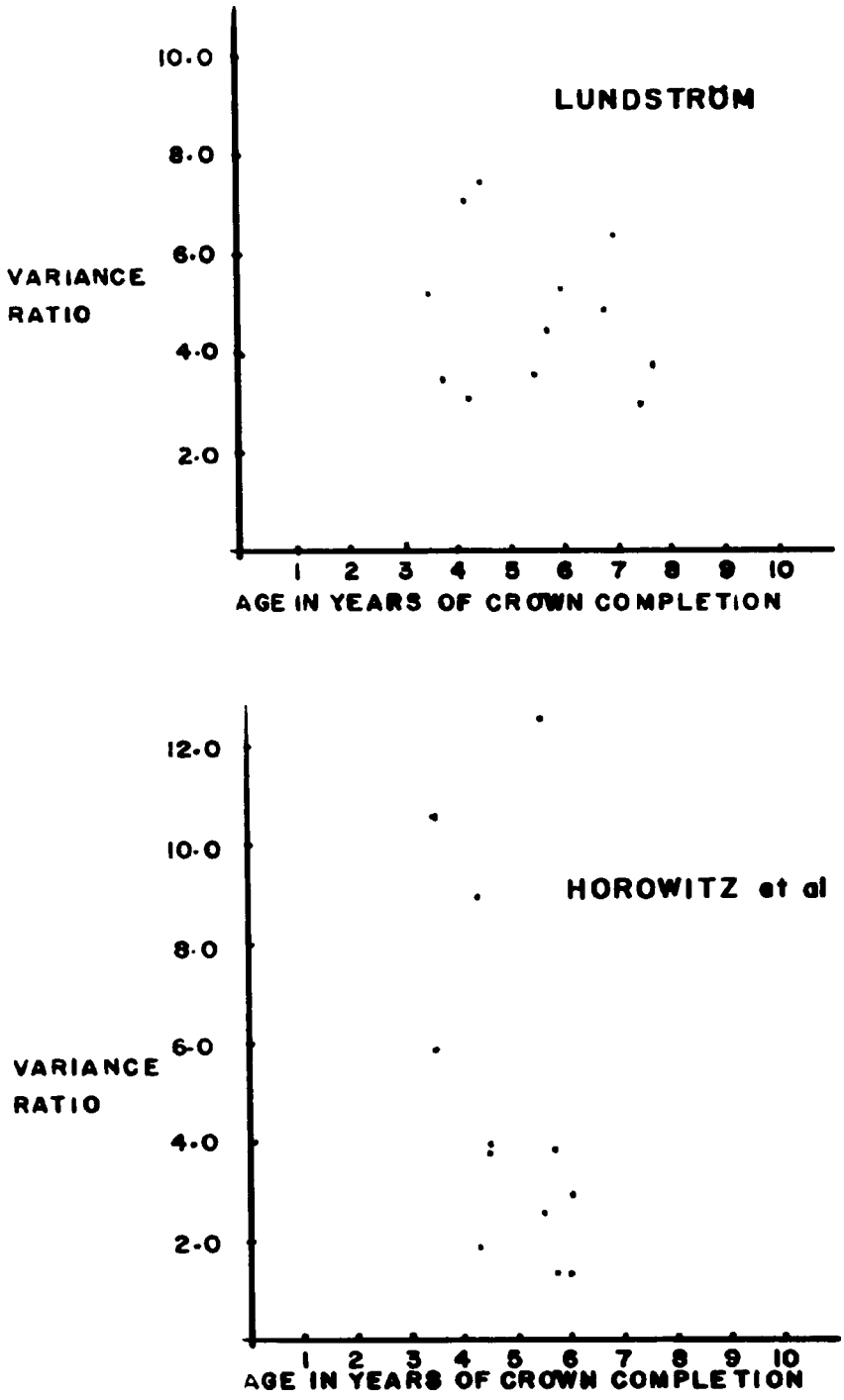


Figure 8. Scattergram showing the relationship between age of crown completion and variance ratios computed from the data of Lundstrom and Horowitz et al.

portion of this investigation and the check computations. It would also explain the differences between these computations and the computations on the same material by the other investigator; and probably those seen between this study and those of Lundstrom and Horowitz et al. Of course, in the case of Lundstrom's study, we have the additional factor of averaged left and right sides to begin with.

The analysis of variance of the errors of measurement (p. 24) gave a very significant difference in variability between casts. This might well be a partial explanation for the differences between the results of this study and those computed for the work of Lundstrom and of Horowitz et al. The analysis of variance for the errors also suggested a difference in variability between maxilla and mandible. Since the "F" ratio patterns are essentially similar for maxilla and mandible, however, this tendency does not seem to have been responsible for any major differences in results.

The fact that tooth type variabilities in the error study were found to be more alike than should be expected, though not significantly so, suggests that considerable confidence may be placed in the pattern of decreasing heritability from central incisors to second premolars. Since the molar variabilities could be altered by errors, we cannot place such confidence in the high heritability ratios for the first molars.

We can therefore conclude that within very definite limits—principally having to do with accuracy of measurement—these findings can be duplicated. There seems to be no valid reason for suspecting a basic difference in the samples themselves, although this is always a possibility. The fact that the computations on the reduced sample (Table 23) produced a similar pattern also suggests that differences in samples are not the critical factors.

We are, then, left with the conclusion that the rather heterogeneous pattern of heritability seen in this sample of twins is probably for the most part real. It would seem reasonable to assume that the genetic control of tooth size is rather uniform for all teeth and that it is the influence of environment which gives us the heterogeneous heritability pattern. This heterogeneous pattern does not seem to be systematic until we compare the heritability ratios with the times of crown completion. While the agreement is not perfect, it does seem to be quite suggestive. The concept suggested earlier in this discussion—that during the period of development of the tooth crowns, the influence of environment becomes greater, in that there could well be a more variable environment as the child's age increases—could not be substantiated in the literature, perhaps because it is so self-evident.

In terms of the purpose of this investigation, stated at the beginning, we can conclude that the central incisors and first molars show the greatest influence of heredity or conversely, the least influence of environment. We can go further and state that there appears to be a direct relationship between the time of crown completion and the heritability ratios. In other words, the later a tooth crown completes its development, the more it manifests the influences of environment as seen in the comparison of within-twin differences in monozygous and dizygous twins.

SUMMARY

Mesiodistal tooth diameter was studied on plaster casts of the teeth of seventy pairs of like-sexed twins, of whom thirty-seven were monozygous and thirty-three dizygous. Their average age was 16.3 years. Twenty-eight teeth were measured for each twin, where possible. The purpose of the study was to determine which teeth showed the greatest influence of heredity.

An analysis of the errors of measurement on replicate casts of twenty-three individual twins demonstrated that slight but significant differences in variability could be traced to the method of measurement and specifically, the time interval between any measures being repeated. The shorter the time interval, the more reliable was the comparison between such measures. The error study also suggested that less confidence could be placed in the measures on the first and second molars than in the measures on the other teeth.

In the consideration of missing (extracted) teeth, the monozygous twins were found to have significantly more agreement than the dizygous twins. This may be indirectly suggestive of an inherited component in factors leading to tooth loss.

The statistical comparisons of within-twin differences produced a sequence of heritability similar to the sequence of crown completion. It is therefore postulated that the size of all permanent teeth is controlled genetically to approximately the same extent, but that environment exerts a greater influence the later the tooth crown is completed. Thus, a tooth whose crown is completed at three

years of age shows the influence of heredity more than a tooth whose crown is completed at six years of age.

years of age shows the influence of heredity more than a tooth whose crown is completed at six years of age.

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APPENDIX

STATISTICAL ANALYSIS

Error Study

Differences between first and second measures were assembled according to cast, jaw, side, and tooth type for a four-way analysis of variance and Bartlett's test for homogeneity of variances performed using the ratio M/C where

$$M = -\Sigma_k[n_k \log_\epsilon (\frac{S_k}{n_k})] + n \log_\epsilon \frac{S}{N}$$

$$\text{and } C = 1 + \frac{1}{3(b-1)} (\Sigma\frac{1}{n_k} = \frac{1}{n})$$

in which S_k = cell S.S.; $S = \Sigma$ cell S.S.; $n = \Sigma_{nk}$; $n_k = N_{k-1}$(cell); and b = number of cells.

Nature of the Sample

Means, standard deviations, and standard deviations of the means were calculated for various groupings of the data to elicit as completely as possible the nature of the sample. Formulas used were:

$$\text{Mean} = \frac{\Sigma x}{n}$$

$$S.D._s = \sqrt{\frac{N \cdot \Sigma x^2 - (\Sigma x)^2}{N(N-1)}}$$

$$S.D._m = \frac{S.D._s}{\sqrt{N}}$$

These were also computed for various paired differences such as Twin A minus Twin B measures.

The significance of differences between means was tested using the Student-Fisher formula:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left[\frac{N_1 \cdot \Sigma x_1^2 - (\Sigma x_1)^2}{N_1} + \frac{N_2 \cdot \Sigma x_2^2 - (\Sigma x_2)^2}{N_2}\right]\left[\frac{1}{N_1} + \frac{1}{N_2}\right]}{(N_1 + N_2) - 2}}$$

Analysis of Variance

"F" ratios were calculated for various combinations of the sample such as $F = \frac{\text{within MZ variance}}{\text{within DZ variance}}$ which was computed using the following machine formula:

$$F = \frac{\frac{a_{DZ} - 1/2(b_{DZ})}{N_{DZ}}}{\frac{a_{MZ} - 1/2(b_{MZ})}{N_{MZ}}}$$

where $a = \Sigma x_A^2 + \Sigma x_B^2$ $b = \Sigma(x_A + x_B)^2$ $c = \Sigma x_A + \Sigma x_B$

Similarly, for instance, the formulation for

$$F = \frac{\text{between MZ variance}}{\text{within MZ variance}}$$

is

$$F = \frac{\dfrac{b_{MZ/2} - c^2_{MZ/2N_{MZ}}}{N_{MZ} - 2}}{\dfrac{a_{MZ} - b_{MZ/2}}{N_{MZ}}}$$