Discrimination Between Normal and Class II Individuals Using Steiner's Analysis

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When a number of different measurements is available on individuals who have been classified into a number of groups, it is often useful to know (1) the extent to which the grouping is reflected in the measurements, (2) which of the measurements are most useful in discriminating between the groups, (3) how to combine the (useful) measurements to produce an objective rule for classifying a new individual into one or another of these groups and (4) the amount of error to be expected if this rule is used to allocate new individuals into the existing groups. Answers to these questions can be obtained by use of the statistical technique known as *stepwise discriminant function analysis.* In this paper we employ this technique to investigate the extent to which normal and Class II individuals can be distinguished using the cephalometric variables proposed by Steiner[1] for use in orthodontic diagnosis, case assessment and treatment planning. Only the variables for which normative values have been established are included in this investigation since, presumably, only these are of diagnostic value in practice. The variables considered, along with the normative or "ideal" values for these variables as suggested by Steiner, are given in Table I. Nine angular and four linear variables are included. We distinguish between these kinds of variables by using, e.g., $\underline{1}$/NA° to denote an angular variable (measured in degrees) and $\underline{1}$ to NA mm to denote a linear measurement (measured in millimeters). Walker's[2,3] two-dimensional coordinate model of the skull is depicted in Figure 1. Thus, e.g., the SNA angle is the angle formed by connecting the points No. 95, No. 58 and No. 133 in Figure 1. For a useful summary of, and a precise definition of the variables included in, the Steiner analysis, see Krogman and Sassouni.[4]

Methods and Materials

The present investigation is based on cephalometric data obtained from the Philadelphia Center for Research in Child Growth through the courtesy of Dr. W. M. Krogman, Director. Two groups of children are involved: The first group consists of ninety-six children between 10 and 12 years of age having normal dental occlusions; the second consists of sixty-three children in the same age range who were classified as Class II. The thirteen Steiner variables (Table 1) were extracted from our model of craniofacial morphology (Fig. 1) for subsequent statistical analysis, in particular, for the computation of descriptive statistics and for a stepwise discriminant function analysis. For a detailed discussion of this process of variable extraction see Walker and Kowalski.[3]

The technique of discriminant function analysis was originated by Fisher[5] and was first applied by Barnard.[6] Two useful and detailed summaries of more recent work in discriminant analysis were given by Hodges[7] and Tatsuoka and Tiedeman;[8] both of these papers include extensive bibliographies. The appropriate situation for the application of a discriminant function analy-

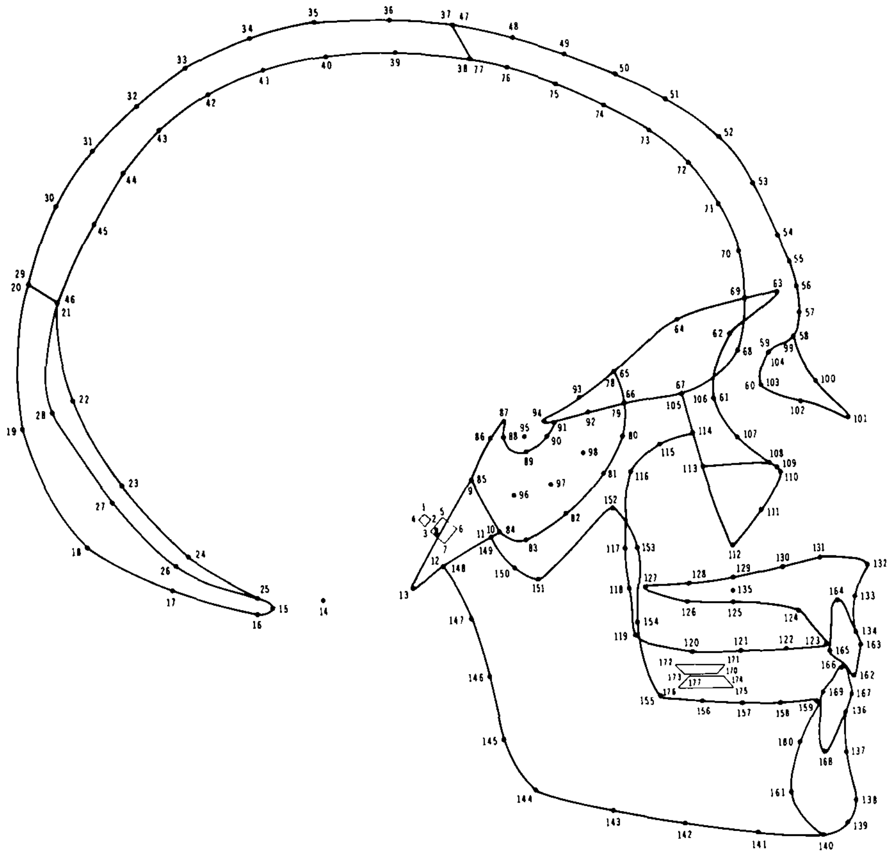

Fig. 1 The 177 coordinate points comprising Walker's model of craniofacial morphology.

TABLE I

Normative values for the variables included in the Steiner cephalometric analysis.

Variable ,	Norm
SNA	82°
SNB	80°
ANB	2°
GoGn/SN	32°
Occl./SN	14.5°
$\underline{1}/\overline{1}$	130°
$\underline{1}$ to NA	4 mm.
$\underline{1}$/NA	22°
$\overline{1}$ to NB	4 mm.
$\overline{1}$/NB	25°
$\overline{1}$/GoGn	93°
$\underline{6}$ to NA	27 mm.
$\overline{6}$ to NB	23 mm.

sis is one in which there are several groups of individuals, several measurements having been made upon each individual. A new individual is presented and it is required to construct optimally weighted combinations of the measurements (the discriminant functions), by means of which the new individual can be allocated to his group. In our application we have two groups (normals and Class II's), thirteen measurements (the Steiner variables) having been made on each individual. If we denote the values of these thirteen variables by X_1, X_2, . . ., X_{13} the discriminant function analysis consists of finding two sets of weights, say

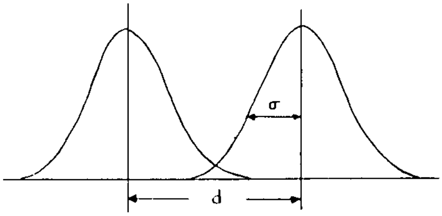

Fig. 2 Discrimination between two Gaussian populations.

$u_1, u_2, \ldots u_{13}$ for the normals

and

$w_1, w_2, \ldots w_{13}$ for the Class II's

such that we will classify an individual as normal if and only if

$$u_1X_1 + u_2X_2 + \ldots + u_{13}X_{13} + u_0 >$$
$$w_1X_1 + w_2X_2 + \ldots + w_{13}X_{13} + w_0$$

where the constants u_0 and w_0 and the weights are chosen to minimize the probabilities of misclassification or, equivalently, to minimize the amount of overlap between the two populations with respect to the ranges of values of the Steiner variables for the two groups. A good discussion of the method is given by Rao.[9] If we ignore methodological complications, the principle upon which this analysis is based is quite simple and can readily be illustrated.[10] Figure 2 shows the frequency functions of two Gaussian (or "normal" in the technical sense of Chilton)[11] populations with a common standard deviation, σ. Think of these two frequency distributions as representing the distributions of the values of the weighted combinations of the Steiner variables in the two groups under consideration. Then if "d" is the distance between the two means, it is clear that the amount of overlap between the two populations decreases as "d/σ" increases. Any weighted combination of a set of measurements produces a single compound measurement from which a diagram like Figure 2 can be constructed, and to obtain the best set of weights the set for which "d/σ" is a maximum should be chosen.

In essence, then, the discriminant function is just a weighted combination of the original variables, the weights being chosen in such a way that the groups in question are maximally separated with respect to the range of values of this new variable. Then, given a new individual, his score for this compound measurement is computed and this serves to classify him into the appropriate group. This type of analysis has often been used successfully in medical and anthropological research; for some recent examples see Bulbrook, Haywood, Spicer and Thomas,[12] Rightmire[13,14] and the survey paper by Radhakrishna.[15] The analysis outlined in this paper was done using the computer program BMD7M written originally by the Health Sciences Computing Facility at U.C.L.A.[16] and revised and adapted for use on the Michigan Terminal System by the Statistical Research Laboratory at the University of Michigan.

Results

Table II and III give the descriptive statistics (mean, variance, standard deviation, minimum and maximum values) for the Steiner variables for the normal and Class II individuals, respectively. It is clear that some separation of the groups is achieved by the use of these variables, but the descriptive statistics alone are insufficient to answer the more important *diagnostic* question of how these variables can be combined to produce the maximal separation of the groups. This is done by means of the stepwise discriminant function analysis which is summarized in Tables IV and V.

The stepwise nature of the analysis means that the variables are entered into the discriminant functions one at a time and in order of importance. Thus,

Variable	Mean	Variance	Standard Deviation	Minimum	Maximum
SNA	81.70	12.71	3.565	71.77	90.15
SNB	77.29	11.30	3.361	67.00	85.83
ANB	4.411	3.923	1.981	0.306	9.777
GoGn/SN	34.89	25.96	5.094	24.51	48.22
Occl./SN	13.88	18.18	4.264	5.132	28.20
$\underline{1}/\overline{1}$	127.1	56.89	7.543	111.9	145.7
$\underline{1}$/NA°	20.09	23.48	4.846	7.998	33.44
$\underline{1}$ to NA mm.	2.801	2.889	1.700	0.075	7.470
$\overline{1}$/NB°	28.38	26.26	5.125	13.82	39.53
$\overline{1}$ to NB mm.	5.181	3.580	1.892	0.537	9.137
$\overline{1}$/GoGn	96.21	29.96	5.473	83.35	109.5
$\underline{6}$ to NA mm.	26.90	7.843	2.800	17.54	34.43
$\overline{6}$ to NB mm.	20.86	5.903	2.430	14.50	26.56

TABLE II

Descriptive statistics for the Steiner variables in the normal sample (N=96).

Variable	Mean	Variance	Standard Deviation	Minimum	Maximum
SNA	80.88	12.88	3.589	73.22	91.92
SNB	74.42	8.700	2.950	67.58	82.38
ANB	6.465	3.689	1.921	1.555	11.17
GoGn/SN	36.85	32.82	5.729	24.88	59.02
Occl./SN	13.65	24.05	4.904	1.381	24.43
$\underline{1}/\overline{1}$	122.8	77.73	8.817	97.35	140.5
$\underline{1}$/NA°	23.28	58.98	7.680	6.526	42.59
$\underline{1}$ to NA mm.	4.203	5.831	2.415	0.300	12.98
$\overline{1}$/NB°	27.44	37.85	6.152	9.032	41.84
$\overline{1}$ to NB mm.	5.315	4.449	2.109	0.149	11.55
$\overline{1}$/GoGn	96.18	50.35	7.096	75.70	114.5
$\underline{6}$ to NA mm.	27.29	8.225	2.868	20.89	32.48
$\underline{6}$ to NB mm.	20.20	4.742	2.178	15.01	25.74

TABLE III

Descriptive statistics for the Steiner variables in the Class II sample (N=63).

Step	Variable	F-value to enter	Weights	
			Normal	Class II
1	ANB	41.9149	3.4333	5.2285
2	$\underline{1}$ to NA mm.	38.4702	-1.5689	-0.7489
3	$\overline{1}$ to NB mm.	21.8088	-26.3243	-26.9371
4	SNA	8.1766	4.5923	4.3252
5	$\underline{6}$ to NA mm.	3.8183	-9.1295	-9.6301
6	$\overline{6}$ to NB mm.	4.1404	21.8635	22.3231
7	Occl./SN	3.1788	29.2577	29.4817
8	GoGn/SN	1.4313	25.3955	25.5075
9	$\underline{1}$/NA°	1.1121	0.2410	0.1691
10	$\overline{1}$/NB°	0.4319	14.8802	14.9403
			Constants	
			-3316.81	-3341.75

TABLE IV
Variables in Order of Inclusion into the Discriminant Functions and the Weights Attached to these Variables.

from Table IV the best single discriminator is the ANB angle, this being incorporated into the discriminant functions at the first step. At the second step the linear variable $\underline{1}$ to NA is entered. This means that *given that the ANB angle is to be used in the discriminant function* that most useful *additional* variable is the distance from $\underline{1}$ to NA, and so on. The "F-value to enter" is a measure of the significance of the variables being entered to the efficiency of the discriminant functions. While it appears that the first four variables selected would do an adequate job of discriminating between the groups (as judged by these F-values), ten variables are included in order to achieve the maximum discriminatory power of the Steiner battery of variables. On the other hand the variables SNB, $\underline{1}/\overline{1}$ and $\overline{1}$/GoGn are not used since, given that the other variables are included, they add essentially nothing to the discriminatory power of the procedure. This is especially easy to see in the case of the SNB angle: Since its value is *determined* by the values of the ANB and SNA angles, and since these angles have already been included in the discriminant functions, the value of the SNB angle cannot possibly add any *new* information and it is automatically deleted by the computer program performing the analysis.

The weights in Table IV show how to produce two scores for any indi-

TABLE V

The classification matrix for a discriminant analysis based on the Steiner variables.

	Normal	Class II	Total
Normal	85	11	96
Class II	12	51	63

vidual for whom the values of the Steiner variables are available, viz.,

Normal score = 3.4333 (ANB) + . . . + 14.8802 ($\bar{1}$/NB) — 3316.81

Class II score = 5.2285 (ANB) + . . . + 14.9403 ($\bar{1}$/NB) — 3341.75

and this individual is assigned to that group for which his score is highest. It should be pointed out that, due to the way we extract variables from our model,[3] the weight for the Occl./SN variable given in Table IV is appropriate for the transformed variable (180° - Occl./SN) but this causes no conceptual (or computational) difficulties. If this is done for the 96 +63 = 159 individuals who were used in the analysis, we can get a measure of the efficacy of this classification procedure; the results are given in the classification matrix of Table V.

From Table V we see that, using the discriminant functions given in Table IV, 85 of the original 96 normals were classified (correctly) as normal, while 11 normals were misclassified as Class II's. Of the original 63 Class II's, 51 were correctly classified and 12 were misclassified as being normal.

Discussion

Statistical Aspects

The discriminatory power of the Steiner cephalometric variables may be measured in terms of the proportions of misclassifications obtained when the procedure is applied to the individuals originally included in the study. The proportion of normals misclassified was 11/96 = 11.4% and of the Class II's 12/63 = 19%. These error rates can, of course, be expected to *increase* if the weights given in Table IV are applied to a *new* mixed collection of normal and Class II individuals, especially if these individuals are not restricted to be in the same age range (10-12 years of age) as that of the sample upon which the discriminant functions are based.[17] Hence if one uses the Steiner cephalometric analysis as a *diagnostic* tool, even if he uses the optimal weights associated with a discriminant function analysis, he should expect a rather large proportion of misclassifications. While this finding may not *in and of itself* be of particular practical importance, it may say something about the "informational content" of the Steiner variables. If this battery of variables cannot effectively discriminate between normals and Class II's, how good can they be for treatment planning and the prediction of treatment effectiveness? Otherwise stated, since a glance at the cephalogram is generally sufficient for an experienced clinician to correctly classify a given individual as normal or Class II, the Steiner variables must not include all of the relevant cephalometric information regarding the differences between normal and Class II individuals.

The ANB angle (c.f. Table IV) has been shown to be the single best discriminator in the Steiner battery, but it should be noted that the average ANB angle for the normal sample (4.4°) differs considerably from Steiner's "ideal value" (2°) for this measurement. This discrepancy has been previously reported,[18] but it takes on added importance in the present discussion. Although the ANB angle is a good discriminator, we must be careful to use the "correct norm." Similar remarks hold for the linear variables $\underline{1}$ to NA and $\bar{1}$ to NB which are effective discriminators, yet may have "normal" values which differ considerably from Steiner's "ideal" values for these measurements.

We should also emphasize the fact that although ten variables were used in the discriminant functions listed in Table IV, the first four of these variables, viz., ANB, $\underline{1}$ to NA, $\overline{1}$ to NB and SNA, contain most of the discriminatory information of the Steiner battery (as judged by the "F to enter" values) and, if only these four are used, the error rates are only slightly affected. This tends to imply either that the remaining variables contain essentially no information regarding differences between the groups or that the information that they *do* contain has already been incorporated into the discriminant functions in the form of the values of the first four variables. In either case they contribute little to the analysis. The clinical basis of this assertion is discussed in more detail below.

Clinical Aspects

Most orthodontists are interested in cephalometric analysis as a quantitative approach to clinical diagnosis, case assessment and treatment planning. The Steiner analysis is a composite of several previously proposed analyses (for a good discussion see Krogman and Sassouni),[4] being an attempt to select the most meaningful measurements and to synthesize them. The variables selected include both dental and skeletal measurements reflecting the orthodontist's interest in the treatment of malocclusion from both the functional and esthetic viewpoints. However, many of the variables are highly correlated and, by geometrical considerations alone, one would expect a change in one variable to be accompanied by changes in other variables. For example, as ANB increases and the subject becomes dentally and skeletally more Class II, one would expect SNB to become smaller, the angle between the mandibular plane and the cranial base to increase, the interincisal angle to increase, the $\underline{1}$/NA angle to increase, etc. One would expect then, a real *biological* dependence among the Steiner variables and this is reflected in the *statistical* fact that just four of these variables contain most of the diagnostic information of the battery. It might also be noted here that the nature of the first variables selected provides considerable insight into the most salient differences between the groups. It is seen that these variables all measure various aspects of the relationship of the mandible to the maxilla found by Harris[19] to be highly related to the molar relationships which *define* the two groups under consideration. SNA is a measure of maxillary prognathism; the tipping of the incisors relative to the NA and NB facial planes is consistent with the clinical picture associated with the Class II patient; the relationship of the occlusal plane to SN, as well as that of the mandibular plane to SN, is again consistent with the most obvious *clinical* discrepancies between normal and Class II individuals. Other variables that are generally considered clinically significant may not have appeared in the discriminant functions simply because they are highly correlated with another variable already included in the discriminant functions. Thus the SNB angle, which measures the retrognathic position of the mandible, was excluded.

The discriminant analysis comparing normal and Class II individuals on the basis of the Steiner variables illustrates quite clearly that the values of these variables are often insufficient to correctly classify a given individual as being either normal or Class II. The classification matrix of Table V shows that, even when ten variables are included in the discriminant functions, there are a total of thirty-two individuals classified incorrectly. In these individuals the molar relationships which were used to classify them initially into one of the two groups were not determined by (or were independent of) the values of the Steiner variables. To the experienced clinician this observation is undoubtedly consistent with his own clinical experience. While tipping of the incisors, large mandibular plane/cranial base angles, etc., are *frequently* associated with Class II malocclusions, other configurations or compromises[20] are possible, especially in individuals with dentitions approaching a moderate or, as popularly labeled, a "dental Class II" malocclusion. Further, the patient with a history of thumb sucking or tongue thrusting may completely modify the relationships between the molars and the other variables. Thus the observed classification errors are more-or-less expected and do not necessarily imply that the Steiner analysis does not provide a useful description of dentofacial morphology nor a clinically relevant measure of the severity of the malocclusion in many situations. However, the results of this investigation do tend to imply that the Steiner variables, chosen primarily to measure the *degree* of malocclusion, may not in themselves *classify* the malocclusion. Put in another way, given that the patient has a Class II malocclusion, the Steiner variables may be useful in characterizing the severity of the malocclusion and indicating effective treatment strategies, but these variables are less useful in the diagnostic process itself. These observations may not be particularly new to many clinicians, but the systematic examination of the performance of a given cephalometric analysis on a carefully selected test sample by the application of discriminant function analysis provides some new insight into both our classification of malocclusion and the nature of the malocclusion itself.

In summary, then, it would appear that the Steiner analysis is "too narrow" in the general biological sense to discriminate efficiently between normal and Class II individuals, and that many of the variables contain redundant classificatory information. This appears to be the result of the facts that the Class II molar relationship is often independent of the variables comprising the Steiner analysis and that many of the variables used are dependent or overlapping. If *discrimination* is the ultimate aim, it would appear that, while certain of the Steiner variables could be omitted without decreasing the discriminatory power of the battery, additional variables are needed if we are to capture the essence of the complex morphological and functional differences between normal and Class II individuals.

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