Factors of Human Skeletal Craniofacial Morphology

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The introduction of standardized cephalometric radiography by Broadbent[1] made possible the study of the craniofacial skeleton in the living subject. Subsequent cephalometric studies have provided valuable standards and diagnostic criteria for the orthodontist but have provided little insight into the basic dimensions or determining factors of craniofacial skeletal morphology.

Analysis of measurements from a classical cephalometric study employing univariate techniques tends to fragment individual subject information into bulky and unwieldy data. Furthermore, there is considerable overlap of underlying common dimensions among standard cephalometric measurements. By removing this overlap from many cephalometric measurements it is possible to isolate or reconstitute considerably fewer basic dimensions or factors of craniofacial size. These factors can be isolated through a multivariate technique, factor analysis, which makes it possible to group certain measurements reflecting a common dimension or factor.[2] In essence, a factor analysis provides the simplest description of the observed data.

Factor analyses of head measurements derived from skeletal material have been performed in earlier studies[3,4,5] but the first such analysis of measurements derived from cephalometric X-rays was performed by Brown et al.[6] Eleven cephalometric measurements were analyzed from two sample populations, Swedish adult males and a pooled sample of Australian aborigines. In both samples five factors were extracted and interpreted as: mandibular length, anterior nasal height, posterior nasal height, a factor for mandibular ramus height (Swedish sample only), and a cranial base factor which affects maxillary length. No measurements of craniofacial width were included in the study and consequently this represented only a two-dimensional study.

Solow[7] included bilateral measurements in a factor analysis of 17 trunk and limb measurements and 61 cephalometric measurements but systematically dropped overlapping measurements from subsequent analyses. In casting out variables after exploratory analyses, however, a great deal of information concerning each factor was lost and in some cases entire factors were lost. In both of these previous studies no criterion measurement of the anteroposterior relationship of mandible to maxilla was included.

The purpose of the present study is to factor analyse a large number of radiographic measurements representing craniofacial depth, height, and width and degree of mandibular prognathism or retrognathism in an effort to locate specific areas of variability within the skeletal craniofacial complex.

The subjects used in the investigation were a part of the male sample of the Burlington Orthodontic Research Centre. They represent a Canadian, middle-class population of European extraction. Serial anthropometric and orthodontic data were available for

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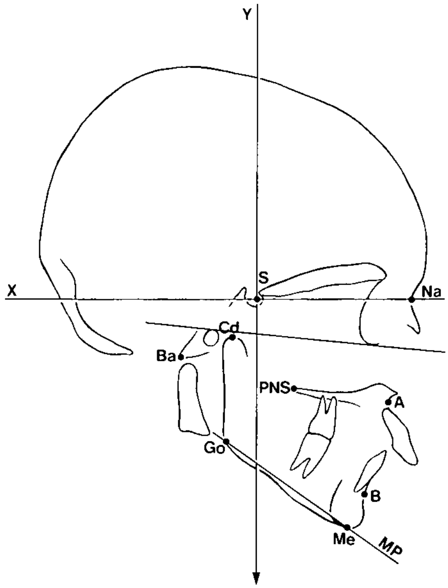

Fig. 1 A tracing of a lateral cephalometric radiograph to indicate the axes and landmarks used in the derivation of the anteroposterior and vertical measurements.

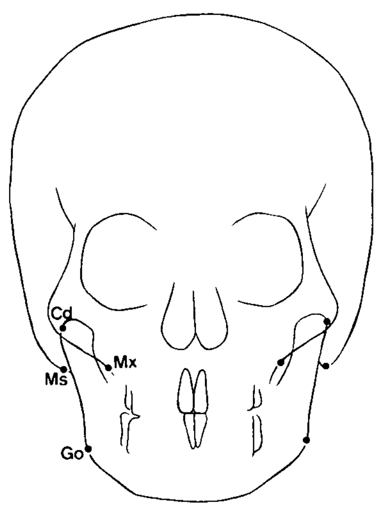

Fig. 2 A tracing of an anteroposterior radiograph to indicate the landmarks used in the derivation of the measurements of width.

each of the subjects from the age of 3 to 14 years and 16 to 18 years. Sixty-six male children were chosen for the present study on the basis of availability of complete serial records plus supplementary records of both parents from a total of 300 male children in the Burlington sample. This paper will consider only the age-range midpoint, 8 years, as a preliminary to an ultimate serial and genetic study.

METHOD

Cephalometric Measurements

Tracings were made of each of the 66 sets of lateral and anteroposterior radiographs. The reference points and lines chosen for this study are illustrated in Figures 1 and 2. Twenty-eight linear measurements and one angular measurement were selected to represent craniofacial depth, height and width (Table I). In addition, the anteroposterior relationships of maxilla and mandible were assessed by measuring the distance between the projections of points A and B on the sella-nasion plane. Duplicate measurements were made on every second set of radiographs to determine the intraobserver error.

Statistical Procedure

The computer program used for the subsequent analyses was from the library of the University of California (BMDX 72) and supported by the 360-65 IBM computer facility at the University of Toronto. The program provided univariate, bivariate and multivariate descriptions of the data. For each of the thirty measurements, the means, standard deviations, and coefficients of variation were calculated to compare the relative variation of each measurement. For each of the possible 435 pairings, product-moment correlations were calculated to provide the correlation matrix necessary for the initial step of the factor analysis. The multivar-

TABLE I

DEFINITIONS OF AXES, PLANES AND CEPHALOMETRIC MEASUREMENTS

Axes and Planes	
1. Sella-nasion (SN)	X axis
2. Perpendicular to SN	Y axis
3. Mandibular plane	MP
Measurements	
A. *Horizontal*	
1. A and B projected to X axis	A-B horizontal
2-7. Each landmark projected to the Y axis	Landmark-Y
B. *Vertical*	
8. Projections of A and B on the Y axis	A-B vertical
9-14. Each landmark projected on the X axis	Landmark-X
C. *Facial Width*	
15. Bimaxillary width	Mx-Mx
16. Bicondylar width	Cd-Cd
17. Bigonial width	Go-Go
D. *Oblique*	
18. Sella — A	S-A
19. Sella — B	S-B
E. *Jaw Size*	
20. Maxillary length	PNS-A
21. Mandibular length	Cd-B
22. Mandibular corporal length	Go-Me
23. Mandibular ramus height	Cd-Go
F. *Cranial Base*	
24. Clivus length	S-Ba
25. Anterior cranial base	S-N
26. Bimastoidal width	Ms-Ms
G. *Cranial Vault*	
27. Maximum vault length	V.L.
28. Maximum vault width	V.W.
29. Vault height (sella to intersection of Y axis and vault)	V.H.
H. *Vertical Relationship of Mandible to Anterior Cranial Base*	
30. Mand. plane—SN angle	MP-SN

iate portion of the program based on a factor model described by Harman[2] provided either a principal factor or a principal component initial solution. The difference between the two solutions lies in the values of the diagonal of the correlation matrix to be analysed. The principal component solution method retains the ones in the diagonal. The principal factor solution replaces the ones with communality estimates, that is, the portion of the variance of each variable accounted for by all the common factors. The principal component method was chosen after preliminary analyses revealed communalities which were close to one. No attempt was made to interpret the principal component solution but it was instead rotated to a multiple factor orthogonal pattern (Varimax).[9] Preliminary rotations to an oblique (direct quartimin) solution revealed that the degree of intercorrelation among the newly found factors was very small and therefore the factors were interpreted directly from the orthogonal Varimax solution. Since the factor loadings in an orthogonal solution represent the correlations between the original measurements and the newly found factors, those coefficients which were 0.32 or higher were considered significantly different from 0 at the 1% level.[10]

Results

At the 95 percent level of confidence, the systematic error accumulated through each step of tracing the radiographs on acetate sheets, location of the chosen landmarks, and the actual measurement of each variable from the tracing averaged plus or minus 0.51 mm for the linear cephalometric measurements and plus or minus 0.85 degrees for the one angular measurement.

The means, standard deviations, and coefficients of variation for all 30 measurements are presented in Table II. Anteroposterior facial measurements in relation to the Y axis (meas. 1-6) exhibit higher coefficients of variation as a group than vertical and width facial measurements. The meas-

TABLE II

MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF 30 CEPHALOMETRIC MEASUREMENTS FOR 66 BOYS AT AGE 8 YEARS

Measurement (cm.)	Mean ($\bar{x}$)	S.D. (s)	Coef. of Var. (s/x%)
1. A-B horiz.	1.23	0.28	22.7
2. A-Y	6.20	0.39	6.3
3. B-Y	4.97	0.56	11.3
4. Me-Y	4.07	0.63	15.5
5. PNS-Y	1.57	0.25	15.9
6. Cd-Y	1.40	0.30	21.4
7. Go-Y	1.22	0.38	31.1
8. A-X	5.05	0.25	4.9
9. B-X	8.50	0.35	4.1
10. Me-X	10.38	0.46	4.4
11. PNS-X	4.01	0.26	6.4
12. Cd-X	1.74	0.30	17.2
13. Go-X	6.77	0.39	5.7
14. Mx-Mx	6.30	0.42	6.6
15. Cd-Cd	10.56	0.47	4.4
16. Go-Go	8.82	0.41	4.6
17. S-A	8.02	0.34	4.2
18. S-B	9.89	0.41	4.1
19. PNS-A	4.75	0.24	5.0
20. Cd-B	9.32	0.40	4.2
21. Go-Me	6.42	0.39	6.0
22. Cd-Go	5.04	0.32	6.3
23. S-Ba	4.30	0.38	6.5
24. S-N	7.02	0.31	4.4
25. Ms-Ms	10.82	0.42	3.8
26. V.L.	19.47	0.42	3.4
27. V.W.	15.16	0.62	4.0
28. V.H.	11.33	0.43	3.7
29. A-B vert.	3.46	0.28	8.0
30. M.P-SN (°)	34.36	3.62	10.6

urement A-B (horizontal) also shows a high coefficient of variation.

The matrix of product-moment correlations among the 30 measurements is presented in Table III. The eigen values and the cumulative variance are shown in Table IV. Thirty components were originally extracted and a problem arose as to how to extract the least number of components yet still account for a maximum of the total variance. Since components with eigen values less than 1 can be considered insignificant,[11] twelve components which exhibited eigen values of 1 after they were completely rounded off were retained for subsequent orthogonal rotation. The twelve components account for 91 percent of the total variance.

The rotated orthogonal Varimax solution is shown in Table V and the factors (columns) are in order of the respective variance which each contributes to the total variance. The selection of factor names was influenced by the nature of the measurements displaying the largest loadings or correlations with each column under consideration. In each column, loadings of single measurements or groups of measurements stand out from the others. The interpretation and subsequent naming of the factors then centres around this particular measurement or group of measurements provided that the interpretation was consistent with the remaining measurements loading on this factor.

Factor I

The first column was identified as a "retrognathic facial type" factor from high loadings which relate the facial complex in general and the mandible in particular to the vertical Y axis (meas. A-Y, B-Y, Me-Y, PNS-Y, Cd-Y and Go-Y). In addition, this is the only factor which contains a significant loading contributed by the criterion measurement of anteroposterior maxillomandibular relationship (A-B horizontal).

Factor II

This was identified as a factor representing "dentoalveolar height" from the high loading of measurement A-B vertical. Total face height (meas. B-X and Me-X loads almost equally on this factor but anterior maxillary height (A-X) does not, thus leaving dentoalveolar height as the primary source of variation in this factor. The oblique distance of B point from sella is strong-

TABLE III

MATRIX OF CORRELATIONS AMONG 30 CEPHALOMETRIC MEASUREMENTS

MEASUREMENT	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
	30	.51	.17	-.02	.08	-.22	.03	.02	-.20	-.09	-.07	-.18	-.10	-.25	.19
		29	-.03	-.09	.23	-.04	.12	.28	.14	.19	.27	.11	.58	.07	.06
1. A-B hor.	1		28	.27	.25	.00	.35	-.05	-.02	-.06	-.07	.01	-.13	-.06	.07
2. A-Y	-.37	2		27	-.08	.31	-.01	-.07	.12	-.02	-.12	-.08	-.17	-.13	.14
3. B-Y	-.75	.89	3		26	-.12	.42	.32	.01	.12	.23	.19	.29	.30	-.04
4. Me-Y	-.76	.80	.94	4		25	.03	.15	.36	.25	.26	.18	.10	.09	.35
5. PNS-Y	-.49	.75	.78	.70	5		24	.09	.12	.43	.40	.56	.24	.62	.17
6. Cd-Y	.14	-.31	-.29	-.22	-.50	6		23	.19	.03	.22	-.01	.38	.18	.15
7. Go-Y	.62	-.52	-.68	-.67	-.67	.55	7		22	.08	.38	.18	.26	.22	.31
8. A-X	.23	-.06	-.15	-.20	-.12	.14	.34	8		21	.71	.50	.49	.58	.33
9. B-X	.22	.08	-.06	-.13	-.14	.10	.26	.60	9		20	.61	.65	.63	.38
10. Me-X	.13	.23	.10	.05	.02	.07	.21	.54	.89	10		19	.43	.72	.29
11. PNS-X	-.19	.36	.35	.35	.26	-.17	-.16	.32	.49	.53	11		18	.68	.25
12. Cd-X	-.19	.35	.35	.34	.30	.00	-.13	.01	.35	.43	.39	12		17	.28
13. Go-X	-.13	.33	.30	.38	.12	.01	-.09	.27	.55	.64	.65	.59	13		16
14. Mx-Mx	-.10	.10	.12	.13	.01	.39	.18	.07	.00	.17	-.16	.13	.04	14	
15. Cd-Cd	-.07	-.05	.00	.08	-.08	.39	.11	.19	-.01	.07	.00	.00	.17	.50	15
16. Go-Go	-.26	.13	.23	.29	-.06	.27	-.03	.32	.17	.26	.19	.13	.37	.25	.31
17. S-A	-.23	.86	.73	.61	.61	-.23	-.31	.43	.36	.45	.48	.32	.42	.09	.04
18. S-B	-.31	.56	.55	.46	.37	-.15	-.28	.35	.72	.69	.54	.47	.59	.00	-.02
19. PNS-A	-.04	.69	.51	.42	.10	.06	-.07	.19	.23	.27	.13	.11	.24	.16	.03
20. Cd-B	-.39	.55	.58	.52	.23	.32	-.12	.30	.43	.46	.33	.02	.32	.25	.21
21. Go-Me	-.33	.54	.54	.53	.26	.24	.12	.23	.32	.52	.30	.24	.24	.41	.18
22. Cd-Go	.00	.09	.07	.17	-.08	.05	-.01	.32	.32	.37	.44	-.16	.68	-.11	.21
23. S-Ba	-.09	.08	.10	.10	.11	-.03	-.15	.23	.38	.28	.27	.22	.32	-.11	.08
24. S-N	.02	.56	.39	.36	.37	-.11	-.16	.23	.08	.21	.09	-.06	.06	.10	-.08
25. Ms-Ms	-.05	.02	.03	.12	-.11	.33	.21	.20	.08	.18	.06	-.02	.31	.36	.63
26. V.L.	.12	.25	.13	.04	.20	-.09	-.07	.09	.27	.22	.14	.06	.06	-.10	-.14
27. V.W.	.24	-.20	-.26	-.16	-.24	.27	.30	.12	.00	.00	-.08	.04	.13	.26	.48
28. V.H.	.25	.00	-.12	-.13	.00	-.07	.07	-.08	-.07	-.04	-.23	-.19	-.13	.07	-.03
29. A-B vert.	.08	.14	.06	.02	-.08	-.02	.03	-.11	.72	.65	.34	.43	.47	-.06	-.16
30. MP-SN	.51	-.43	-.56	-.67	-.39	.14	.44	.30	.33	.23	-.25	-.34	.38	-.02	-.16

TABLE IV

EIGEN VALUES OF FIRST 12 COMPONENTS AND THE PERCENTAGE VARIANCE WHICH EACH COMPONENT CONTRIBUTES TO THE TOTAL VARIANCE (30)

Component	Eigen Value	% of Total Variance
I	8.28	27.6
II	4.80	16.0
III	3.22	10.7
IV	2.53	8.5
V	1.71	5.7
VI	1.49	4.9
VII	1.19	4.0
VIII	1.14	3.8
IX	0.85	2.8
X	0.76	2.6
XI	0.68	2.2
XII	0.56	1.9
	27.21	90.7

ly related to this factor as well. There is, in addition, a moderately low association with posterior facial height (meas. PNS-X, Cd-X) and a low association with mandibular length measurements (meas. Cd-B, Go-Me).

Factor III

This was identified as a factor of "maxillary body length" from the singularly high loading of measurement PNS-A. Loading moderately on this factor and therefore relating to maxillary length are the position of A point anterior to the Y axis (meas. A-Y), the oblique distance of A point from sella (meas. S-A) and the anterior cranial base length (meas. S-N). This factor is associated to a lesser extent with mandibular length (meas. Cd-B, Go-Me, and B-Y).

Factor IV

This was identified as a factor of "cranial base width and facial width" from the high loadings of measurements Ms-Ms, Cd-Cd, and Mx-Mx. Related slightly to this factor is condylar position posterior to the Y axis (meas. Cd-Y).

Factor V

This was identified as a factor of "mandibular ramus height" from the high loading of measurement Cd-Go and the moderate loading of measurement Cd-X. Associated with mandibular ramus height is posterior facial height (meas. PNS-X) and the mandibular plane angle (meas. MP-SN). A small negative loading is present as well for bimaxillary width (meas. Mx-Mx).

Factor VI

This was identified as a factor of "anterior maxillary body height" from the one high loading of measurement A-X. This factor contributes moderately to the vertical component of the oblique sella to A point distance (meas. S-A) and bears as well a small but negative relationship to dentoalveolar height (meas. A-B vert.).

Factor VII

This was identified as a factor of "mandibular length" from the relatively high loadings of measurements Cd-Y and Go-Me and the moderate loadings of mandibular measurements B-X and Cd-B. It is interesting to note that chin position measurements anterior to the Y axis (meas. B-Y and Me-Y) do not load on this factor and for this reason factor VII may reflect the effect of bone growth at the condyle and gonial angle as a posteriorly oriented compensatory mechanism.

Factor VIII

This was identified as a factor of "cranial vault height" from the loading of measurement V.H. A moderate loading is present for anterior cranial base length (meas. S-N) and a small loading for vault length (meas. V.L.).

Factor IX

This was identified as a factor which determines the "vertical position of the condyle" from the high loading of

TABLE V

ORTHOGONAL (VARIMAX) FACTOR PATTERN FOR 30 CEPHALOMETRIC MEASUREMENTS (UNDERLINED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM 0 AT THE 1% LEVEL)

	Factor											
Measurement	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1. A-B hor.	.85	.04	.17	-.04	.00	.11	-.19	.20	.07	.03	-.26	-.04
2. A-Y	-.68	.16	.65	.00	.05	.03	.02	.10	.17	.03	-.12	-.05
3. B-Y	-.90	.09	.38	.02	.04	-.04	.10	-.03	.09	.01	.04	-.07
4. Me-Y	-.88	.01	.28	.09	.18	-.11	.13	-.01	.14	-.01	.12	-.04
5. PNS-Y	-.83	-.03	.12	-.03	-.06	.21	-.11	.14	.17	.10	-.26	-.08
6. Cd-Y	.41	-.02	.01	.31	-.04	-.14	.66	-.18	-.03	-.06	.27	.17
7. Go-Y	.82	.06	-.03	.16	.00	.15	.40	.02	.08	-.12	-.07	.01
8. A-X	.25	.25	.17	.11	.15	.83	.03	-.09	-.07	.10	.20	.07
9. B-X	.21	.88	.12	-.02	.14	.23	.06	-.05	.02	.17	.06	.02
10. Me-X	.06	.84	.14	.11	.19	.33	.15	.10	.15	.03	.05	-.08
11. PNS-X	-.31	.41	-.01	-.14	.57	.32	.12	-.15	.25	.09	.08	.02
12. Cd-X	-.25	.43	.02	-.01	-.09	-.03	.02	-.14	.81	.06	.08	.10
13. Go-X	-.16	.52	.10	.17	.62	.03	-.05	-.04	.40	.05	.20	.09
14. Mx-Mx	-.07	.07	.05	.64	-.33	.06	.36	.19	.14	-.21	.11	.07
15. Cd-Cd	-.04	-.04	-.05	.78	.05	.10	.10	-.11	-.07	.03	.07	.44
16. Go-Go	-.13	.06	.14	.20	.17	.17	.15	.01	.07	.01	.85	.06
17. S-A	-.49	.25	.68	.02	.12	.42	.02	.02	.12	.10	.00	.00
18. S-B	-.41	.75	.29	.00	.10	.17	.00	-.10	.02	.18	.08	-.01
19. PNS-A	-.12	.16	.94	.07	.04	-.03	.09	-.02	-.03	-.03	.15	-.02
20. Cd-B	-.37	.40	.45	.18	.15	.07	.48	-.07	-.36	.14	.17	.00
21. Go-Me	-.33	.32	.36	.22	-.02	.21	.65	.08	.06	-.10	.04	-.10
22. Cd-Go	.00	.20	.09	.18	.87	.08	-.04	.05	-.22	.01	.15	.04
23. S-Ba	-.10	.30	-.11	.18	.06	.10	-.18	-.08	.03	.77	.18	-.11
24. S-N	-.21	-.06	.60	-.05	.03	.30	.12	.52	-.05	.21	.03	-.06
25. Ms-Ms	.06	.01	.10	.85	.30	-.01	.05	-.01	.00	.05	.10	-.01
26. V.L.	-.03	.13	.24	-.22	.01	.02	.18	.30	.03	.73	-.18	.04
27. V.W.	.21	-.05	-.06	.28	.07	.04	.03	.21	.11	-.07	-.06	.84
28. V.H.	.10	-.03	.02	.01	-.04	-.11	-.06	.89	-.09	.06	.00	.15
29. A-B vert.	.04	.89	-.01	-.09	.06	-.36	.03	.01	.10	.11	-.10	-.04
30. MP-SN	.55	.29	-.13	-.14	-.41	.30	.02	.18	-.43	.02	-.06	-.08
V*	5.67	4.17	3.02	2.29	2.06	1.73	1.63	1.48	1.45	1.40	1.25	1.05

* Contribution of each factor to total variance.

measurement Cd-X. This factor displays as well a moderate negative relationship with the mandibular plane angle (meas. MP-SN) and a small negative relationship to total mandibular length (meas. Cd-B).

Factor X

This was identified as a factor of cranial vault length and clivus length from high loadings of measurements V.L. and S-Ba.

Factor XI

This was interpreted as a factor of bigonial width from the high loading of measurement Go-Go.

Factor XII

This was identified as a factor of cranial vault width from the high loading of measurement V.W. This factor also contains a small loading of bicondylar width (meas. Cd-Cd).

Discussion

The objective of a factor analysis is to provide the simplest description of the observed data. The analysis of 30 cephalometric measurements resulted in 12 factors of craniofacial skeletal size which account for virtually all the essential information contained in the original 30 measurements.

Of the 12 factors extracted, factor I "retrognathic facial type" is perhaps the most interesting from a clinical point of view for it is the only factor which contains a significant loading of the retrognathic-criterion variable A-B horizontal.

Several other variables load significantly on this factor. Chin position anterior to the Y axis (measurements B-Y and Me-Y) displays a strong negative relationship to factor I while gonial angle position posterior to the Y axis (measurement Go-Y) displays a strong positive relationship to factor I. This would indicate that mandibular position in a posterior direction is a marked feature of mandibular retrognathism. A moderate positive loading of the mandibular plane angle (measurement MP-SN) and a small loading of condylar position posterior to the Y axis (measurement Cd-Y) indicate that retrognathism is characterized to a certain extent by a mandible whose chin is tipped backwards and downwards about the condyles. In addition, small negative loadings of mandibular total length (Cd-B) and corporal length (Go-Me) show that, as these measurements decrease, the degree of retrognathism increases.

Maxillary position relative to the Y axis (measurements A-Y and PNS-Y) contributes negatively to factor I but maxillary body length (PNS-A) has a negligible loading on this factor. Thus protruded maxillary position contributes as well to factor I but to a lesser degree than retruded mandibular position.

It should be understood, however, that these results are derived from grouped data, and individual analyses would likely reveal one or more combinations of these characteristics contributing to a retrognathic profile. The most frequently occurring characteristic is likely posterior mandibular position.

The name "retrognathic facial type" is purely arbitrary. because of the bipolarity of factor I and, indeed, if the signs of the loadings were reversed, the factor becomes a "prognathic facial type" factor.

The remaining 11 factors do not contain significant loadings of the criterion measurement A-B horizontal. They are uncorrelated among each other and with factor I because of the orthogonal criterion of the Varimax method. Rotation to an oblique method such as Promax[12] does not create correlations among factors but rather determines whether any correlation is present. A preliminary oblique rotation did not change the factor pattern appreciably and the correlations among the factors were extremely small. The factors isolated in this study cannot be compared with those isolated in previous studies[6-7] because of differences in the measurements chosen to be analysed and methods of analysis.

Subsequent studies of skeletal craniofacial growth should include some measure of these twelve basic factors. These measurements can be in the form of factor scores[2] or should at least include these variables with considerably high loadings on each of the factors.

A logical sequel to the present study would be to factor analyse the same variables taken from the same individuals at different age levels. A serial factor analysis study would reveal whether criterion variable A-B horizontal remains factorially simple, i.e., loads on factor I only throughout the selected age range, if indeed the same factors extracted in this study can be identified throughout the age range.

Summary

Thirty cephalometric measurements representing craniofacial depth, height, and width were obtained from lateral and posterior radiographs of 66 boys, 8 years of age. A multivariate factor analysis was performed on these measurements in an effort to locate specific areas of variability within the craniofacial complex. Twelve uncorrelated factors were extracted which account for 91% of the total variance and these were identified as: 1) retrognathic facial type, 2) anterior dentoalveolar height, 3) maxillary body length, 4) cranial base and facial width, 5) mandibular ramus height, 6) anterior maxillary body height, 7) mandibular length, 8) cranial vault height, 9) vertical position of the condyles, 10) cranial vault and clivus length, 11) bigonial width, and 12) cranial vault width.

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References

1. Broadbent, B. H.: A new x-ray technique and its application to orthodontia. *Angle Orthodont.*, 1:45-66, 1931.
2. Harman, H. H.: *Modern Factor Analysis*, ed. 2, Toronto, 1967, University of Toronto Press.
3. Howells, W. W.: The cranial vault; factors of size and shape. *Amer. J. Phys. Anthrop.*, n.s., 15: 19-48, 1957.
4. Schwidetzky, I.: Factoren des Schädelbaus bei der vorspanichen Bevölkerung den Kanarischen Inseln. *Homo.* 10:237-246, 1959.
5. Landauer, C. A.: A factor analysis of the facial skeleton. *Human Biol.*, 34:239-255, 1962.
6. Brown, T., M. J. Barret, and J. N. Darroch. Craniofacial factors in two ethnic groups. *Growth*, 29:109-123, 1965.
7. Solow, B.: The pattern of craniofacial associations. *Acta. Odont. Scand.*, 24:Suppl. 46, Copenhagen, 1966.
8. Harvold, E. P. and M. E. Hatton. The Burlington Orthodontic Research Centre: A measure of its role in dental public health. *J. Canad. Dent. Assoc.* 28:6-17, 1962.
9. Kaiser, H. F.: Computer program for Varimax rotation in factor analysis. *Ed. Psych. Measurement*, 19: 413-420, 1959.
10. Arkin, H. and R. R. Coulton. *Tables for Statisticians*, ed. 2, New York, Barnes and Noble, 1963.
11. Guttmann, L. Some necessary conditions for factor analysis. *Psych.* 19:149-161, 1954.
12. Hendrickson, A. E. and D. O. White. Promax: A quick method for rotation to oblique simple structure. *Brit. J. Stat. Psych.* 17:65-70, 1964.