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INTERCORRELATIONS OF HEAD AND FACE DIMENSIONS

Measurements of the head and skull, obtained either directly from living subjects and from bone collections, or indirectly from cephalometric roentgenograms, are commonly used in anthropological investigations of growth and development, in studies of differences among ancient populations and among recent populations and/or various ethnic groups. They are also used in medical practice (mostly cephalometric roentgenograms), i.e. in plastic surgery, genetics, orthodontics, etc.

In most instances, numerical analysis of data resulting from these studies has been limited to the estimation of group parameters such as means and variances or the establishment of the significance of differences in mean values between groups. Multivariate approach, mainly discriminant and factor analyses, has appeared in anthropological studies of crania more frequently now when computational difficulties have been overcome. Unlike more routine statistical treatments, these methods allow simultaneous analysis of large numbers of interdependent measurements.

In this study, factor analysis was used for determination of the most important measurements on the head and face for the preparation of face prosthesis, i.e. artifical face restoration.

MATERIALS AND METHODS

This study was carried out on one hundred 19—26-year old university students from Bohemia, 50 males and 50 females being analyzed separately.

These basic measurements of a total of 54 taken on the head and face were included in the detailed analysis:

1. the maximum length of the head (g — op, M 1)
2. the maximum breadth of the head (eu — eu, M 3)
3. the breadth of the cranial base (t — t, M 5)
4. the bizygomatic breadth of the face (zy — zy, M 6)
5. the bigonial breadth of the mandible (go — go, M 8)
6. the intercanthal distance (en — en, M 9)
7. the breadth of the nose (al — al, M 13)
8. the length of the nose (n — prn, M 23)
9. the physiognomic height of the face (tr — gn, M 17)
10. the morphologic height of the face (n — gn, M 18)
11. the breadth of the oral orifice (ch — ch, M 14)
12. the bipupillar distance (M 12).

The measurements were carried out according to Martin and Saller (M a r t i n — S a l l e r, 1957).

The statistical analysis of the recorded data included the calculations of means ($\bar{x}$), standard deviations (s), standard errors of means ($s_{\bar{x}}$), coefficients of variations (V), and coefficients of correlations (r). Canonical factor analysis (R a o, 1955) and Kaiser-varimax method of factor rotation (K a i s e r, 1958) were performed for both male and female correlation coefficient matrices. The linear regression equations were calculated for (1) estimation of the breadth of the oral orifice from the breadth of the cranial base, and (2) estimation of the length of the nose from the morphological height of the face.

RESULTS

The results of basic univariate statistics of each measurement are listed in *table I.* Mean values of all measurements studied are greater in the male series than in the female series. Variances are greater in males than in females in the following six

TABLE I

Basic univariate statistics

Measurements	MALE					FEMALE				
	$\bar{x}$	$s_{\bar{x}}$	s	V	min.—max.	$\bar{x}$	$s_{\bar{x}}$	s	V	min.—max.
g — op	190.58	0.90	6.39	3.35	173—205	179.72	0.74	5.26	2.92	171—193
eu — eu	161.92	0.61	4.30	2.65	151—169	155.78	0.73	5.19	3.33	143—165
t — t	142.58	0.70	4.39	3.45	131—153	135.74	0.62	4.38	3.22	126—144
zy — zy	134.52	1.07	7.54	5.60	123—152	131.72	1.15	8.13	6.17	116—149
go — go	112.16	0.88	6.24	5.56	102—131	105.76	0.59	4.21	3.97	97—118
en — en	32.48	0.37	2.65	8.16	27—38	31.66	0.38	2.71	8.57	26—39
al — al	35.12	0.35	2.45	6.99	28—39	31.94	0.27	1.94	6.08	29—36
n — prn	68.64	0.56	3.95	5.75	60—75	64.82	0.66	4.65	7.16	54—75
tr — gn	187.78	1.29	9.18	4.89	168—215	175.58	1.20	8.51	4.84	154—194
n — gn	117.38	0.88	6.25	5.32	104—129	108.12	0.79	5.59	5.17	95—119
ch — ch	52.36	0.38	2.72	5.18	47—57	49.22	0.41	2.87	5.83	41—55
bipupillar distance	62.24	0.41	2.93	4.71	57—69	59.64	0.45	3.17	5.32	53—66

TABLE II

Correlation matrix — MALE

Measurements											
g — op											
eu — eu	—.008										
t — t	.221	.430									
zy — zy	.288	.123	.412								
go — go	.180	.380	.242	.072							
en — en	.223	.039	—.138	—.296	.005						
al — al	.264	.028	—.213	—.219	.005	.221					
n — prn	.084	—.253	.048	.129	.095	—.086	—.217				
tr — gn	.376	.013	.055	.302	—.027	—.058	.006	.408			
n — gn	.386	—.080	.279	.452	—.061	.051	—.179	.429	.511		
ch — ch	—.051	.148	.226	.203	.015	—.111	—.117	—.132	.045	.114	
bipupillar distance	.302	.201	.356	.077	.153	.356	.155	.008	.044	.153	.117

features: the maximum head length, the cranial base breadth, the bigonial mandibular breadth, the nose breadth, the morphologic and physiognomic height of the face. Variances of the rest of the measurements are greater in the female series than in the male series. *(Table I)*

The coefficients of correlation between all pairs of the twelve head and face measurements are shown in matrix form in *table II* for the male series, in the *table III* for the female series. The significance of each correlation coefficient was not tested statistically but their significance has been determined arbitrarily according to *H r u b ý* (1951) who recommended to consider the value $r = \pm 0{,}5$ as a limit for significance of any biological correlation.

In the male series the values of correlation coefficients range from —.296 to +.511. Correlation coefficient greater than | 0.5 | occurs only between the psysiognomic and morphologic heights of the face. In the female series the values of correlation coefficients range from —.227 to +.693. Correlation coefficients greater than | 0.5 | were found in five cases: between the maximum head breadth and the cranial base breadth; between the cranial base breadth and the bizygomatic face breadth; between the nose length and the morghologic and physiognomic face heights: and between morphologic and physiognomic face height. Besides these also coefficients greather than | 0.4 | are underlined in *tables II* and *III*.

From the correlation analysis performed implementing coefficients of correlation in both series, it is possible to conclude that the mutual relationships of the features under study on the head and face are only of slight to moderate significance. The interdependence of morphologically closely related features (e.g. linear dimensions measured in the median sagittal plane of the face, and breadth dimensions of the head and the face) is on the lower limit of biological significance.

FACTOR ANALYSIS

Factor analysis is one of several multivariate methods of analyzing the mutual dependence of variables studied. The main aim of factor analysis is to find out hypothetical variables, called factors,

TABLE III

Correlation matrix — FEMALE

Measurements											
g — op											
eu — eu	.060										
t — t	.201	.693									
zy — zy	.162	.427	.598								
go — go	.160	.255	.373	.273							
en — en	.177	.032	.059	.028	.202						
al — al	—.012	.066	.137	.356	.086	.281					
n' — prn	.347	.290	.431	.357	.131	.155	.055				
tr — gn	.254	.290	.404	.229	—.024	.208	—.108	.565			
n — gn	.360	.028	.209	.183	.111	.255	—.227	.605	.658		
ch — ch	.031	.243	.405	.282	.099	.229	.196	.285	.138	.031	
bipupillar distance	.294	.104	.300	.103	.269	.455	.112	.152	.222	.167	.392

TABLE IV

Factor analysis — MALE

Measurements	Canonical factor loadings					Varimax factor loadings				
	I	II	III	IV	V	I	II	III	IV	V
g — op	.536	—.154	.479	—.148	—.238	.592	...	...	...	—.415
eu — eu	.182	—.590	—.246	.100	—.099	...	—.549	...	—.350	...
t — t	.582	—.401	—.341	.033	.136	...	—.424	...	—.614	...
zy — zy	.636	.053	—.288	—.254	—.103	.484	...	....	—.524	...
go — go	.208	—.384	—.084	.416	—.278	...	—.667	...	...	...
en — en	—.063	—.279	.589	.091	.304	...	...	.680	...	...
al — al	—.171	—.250	.476	—.155	—.279	...	...	...	...	—.572
n — prn	.419	.511	.103	.479	.020	.571	...	...	...	.500
tr — gn	.542	.281	.196	—.037	—.174	.663	...	...	...	...
n — gn	.736	.293	.148	—.092	.181	.743	...	...	...	...
ch — ch	.180	—.137	—.247	—.187	.134	...	...	...	—.403	...
bipupillar distance	.329	—.454	.279	.052	.271	...	...	.592	...	...
% of total variance	19.1	12.3	10.6	4.9	4.1					

which reproduce as simple as possible the inner relationships of observed variables. Moreover in canonical factor analysis, the correlation of factors and experimental variables is maximalized.

Factor analysis solutions were derived from correlation matrices of both series. One factor was verified by statistical test in the male series which exhausted about 30 % of the total variance. In the female series there were two factors statistically evaluated which exhausted more than 40 % of the total variance. As the amount of exhausted variance is very small in both instances, a total of five factors was chosen for each series in both the canonical factor solution and the varimax rotation of factors. The results obtained by these two methods of factor analysis solution are shown in *table IV* for males and in *table V* for females. For ease of reading only significant values of loadings are given in the varimax solution.

In the male series, factor I is highly correlated first of all with basic face dimensions, i.e. with the morphologic face height and bizygomatic breadth. Lower loadings are for maximum head length (+.536), for cranial base breadth (+.582), and for physiognomic face heigth (+.542). Two loadings are negative in this factor: loadings for intercanthal distance (—.063) and for nose breadth (—.171).

Factor II is bipolar; negative loadings are for maximum head length and for all breadth dimensions except for bizygomatic face breadth, the loading of this being of slight value. Positive loadings occur in face height and nose length measurements. The highest negative loading is for maximum head breadth (—.590), the highest positive loading is for nose length (+.511).

Factor III has the highest values of its loadings for the intercanthal and nose breadths, and for maximum head length. Factor IV is highly positively correlated with nose length and mandibular bigonial breadth, and negatively correlated with bizygomatic and oral orifice breadths. Factor V appeared to be associated mainly with eye distances as

TABLE V

Measurements	Canonical factor loadings					Varimax factor loadings				
	I	II	III	IV	V	I	II	III	IV	V
g — op	.380	.213	.138	—.043	.184	. . .	.393	. . .	. . .	. . .
eu — eu	.550	—.333	—.345	—.167	—.101	.744	. . .	. . .	. . .	. . .
t — t	.797	—.339	—.278	—.173	—.051	.857	. . .	. . .	. . .	. . .
zy — zy	.594	—.340	—.203	.260	.178	.545	. . .	. . .	.461	. . .
go — go	.366	—.235	.122	—.284	.419	. . .	. . .	. . .	. . .	.610
en — en	.340	.039	.596	.041	—.011	. . .	. . .	.599	. . .	. . .
al — al	.166	—.484	.292	.487	.057	. . .	. . .	. . .	.725	. . .
n — prn	.686	.275	—.106	.203	—.004	. . .	.691	. . .	. . .	. . .
tr — gn	.638	.449	—.117	.073	—.212	. . .	.729	. . .	. . .	. . .
n — gn	.572	.681	.001	.069	.157	. . .	.887	. . .	. . .	. . .
ch — ch	.433	—.255	.185	.004	—.311	.386	. . .	.438	. . .	. . .
bipupillar distance	.458	—.059	.547	—.275	—.123	. . .	. . .	.731	. . .	. . .
% of total variance	27.6	12.4	8.9	4.8	3.7					

both intercanthal and bipupillar breadths have higher loadings on it.

In this study, the varimax rotation of factors provides a better basis for their interpretation. Here, factor I concentrates length dimensions: maximum head and nose lengths and both face heights. High loading appears also for bizygomatic breadth. Factor II represents mainly breadth dimensons of the head and mandible, factor III is related to the eye distances only; factor IV correlates with breadth dimensions (three of which have already appeared in preceding factors); and factor V is associated with the head length and both nose dimensions.

In the female series, the following results of canonical factor analysis were obtained:

Factor I is highly correlated with both head and face breadth as well as nose length and face height dimensions. In the group of breadth dimensions the highest loading is for cranial base breadth; in the group of height dimensions the highest loading is for nose length.

As in the male series, the second factor is also bipolar, the positive loadings being for heigth and length dimensions and the negative loadings being for all breadth dimensions except for intercanthal distance, the loading of which is of only slight value. Factor III is highly positively correlated with eye distances. Factor IV and factor V have high positive loadings each for one measurement — factor IV for nose breadth, factor V for mandibular breadth.

In varimax solution, the following interpretation of factors suggests itselfs:

Factor I represents mainly head and upper-face dimensions, factor II is associated with head and nose length and with face height dimensions, factor III correlates with eye distances and oral orifice breadth. Factor IV correlates not only with nose breadth, but also with bizygomatic breadth. Factor V expresses the variability of mandibular bigonial breadth.

The results obtained in factor analysis of mutual interdependence of twelve selected face and head measurements coincide quite well both in the male and in the female series. In both sexes factor I correlated with most of the measurements studied, factor II diferentiates between length and height measurements on the one hand and the breadth dimensions on the other, the former having positive loadings and the latter having negative loadings. These first two factors exhausted 31.4 % of total variance in the male series and 40 % of total variance in the female series; and their differentation corresponds to the general scheme of factor analysis resulting from anthropometric studies suggested by Tanner (1964). Factor III is clearly correlated with eye distances in females. In males the relation of eye distances to the third factor is more evident in varimax solution than in canonical analysis, where also factor V is saturated by both intercanthal and bipupillar breadths. Nevertheless, the eye distances appears to be a relatively independent feature in both sexes.

The explicit interpretation of the two remaining factors is more difficult probably because of their arbitrary determination. These two factors each exhausted about 4—5 % of total variance in both sexes. Factor IV correlates with nose and may be also with bizygomatic breadth in females; in males this factor is negatively related to the main head and upper-face breadth dimensions in varimax solution. Factor V is closely associated with mandibular breadth in females while in males this correlation appears only in the canonical solution of factor IV. Varimax loadings of factor V correlate mainly with nose dimensions in the male series.

The sum of total variance of the original twelve measurements under study exhausted by all five extracted factors amounts to only 51 % in the male series and 57.4 % in the female series, so that a considerable amount of biological information is lost. This findings indicate that to omit any measure from the initial battery of twelve selected features on the head and face causes an essential diminution of biological variance and thus of the biological information contained in the twelve features studied.

REGRESSION ESTIMATES

In spite of not very satisfying results concerning mutual dependence of the main head and face dimensions obtained in both correlation and factor analyses, two linear regression equations were calculated for each series separately.

Firstly, the equation for estimation of the oral orifice breadth (y) from the cranial base breadth (x) was calculated:
for males: (1.1) $y = 0.381\,765\ x - 0.208\,320$; and
for females: (1.2) $y = 0.367\,733\ x - 0.071\,021$.

Secondly, the equation for the estimation of the nose length (y) from the morphologic face height (x) was calculated:
for males: (2.1) $y = 0.463\,136\ x - 0.320\,708$; and
for females: (2.2) $y = 0.447\,356\ x - 0.015\,422$.

To verify how accurate results are to be expected by using these regression equations, the calculated size of estimated measurements was compared with the actual size of each pertinent measurement. The calculated size of the estimated oral orifice breadth agrees with the actual size in 26 % of cases in the male series and in 36 % in the female series; when calculating the nose length agreement is found to be 26 % in males and 40 % in females.

DISCUSSION

The results obtained show that the intercorrelations of twelve head and face measurements studied are of only slight to moderate biological significance. Nearly the same low values of correlation coefficients were found by Blažek (1975) in the detailed study of facial morphology carried out on 22 measurements taken on students of similar age and provenance as in this study. The relatively low validity of regresion estimates of the maximum head and face breadth were also obtained by Šmahel and Figalová (1976) in an anthropometric evaluation of craniostenosis in children. The correlations of these two measurements just mentioned range from about 0.5 to 0.7 in normal children of six months to six years of age. Higher correlation coefficients (about 0.8) occur only in the youngest age group of three-month-old babies.

Results of factor analysis are commonly considered to be incomparable because of considerable dependence of each factor analysis solution on the initial selection of variables (measurements) entering into analysis. However, the general scheme of factor analysis solutions concerning anthropometric data as suggested by Tanner (1964) usually emerges spontaneously from most interpretations of extracted factors. According to this scheme, the first factor is a general one, representing the size of the individuals studied. The second factor differentiates between linear and non-linear measurements (i.e. volume measurements). On the head and face, the second factor separates head height and face length from the head and face breadth dimensions, both for various sectors of the face. The only more detailed factor analyses, obtained mainly from a large number of measurements on cephalometric roentgenograms (e.g. Solow, 1966; Nakata et all., 1975) or on bone collections (e.g. Howells, 1957, 1973), provide the possibility of extracting a larger number of interpretable factors than can be obtained in studies like the present one.

SUMMARY

An analysis of mutual dependence of twelve selected main head and face measures was carried out. Data were taken on 100 university students from Bohemia of both sexes, age group 19—26 years.

Coefficients of correlation obtained in correlation analysis are of only slight to moderate significance, ranging in males from —.296 to +.511, in females from —.227 to +.693.

In canonical factor analysis solution five factors were extracted which exhausted about half of the variance in both sexes. The interpretation of these factors coincides with the general scheme of factor analytis suggested by Tanner. In both sexes the first three factors represent: (1) general size, (2) length and height dimensions, and breadth dimensions of various sectors of the head and face, (3) eye distances which appear to be a feature relatively independent of the other dimensions.

The agreement of regression estimates of the oral orifice breadth from the cranial base breadth with actual size is not greater than 26 % in males and 36 % in females; the agreement of nose-length regression estimates from the morphologic face height with actual size is 26 % in males and 40 % in females.

As the intercorrelations of individual features on the head and face is also small, it is not probable that any regression estimates of the size of the features studied could be more adequate. This might be feasible only in analyses within each individual face type.

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