Occlusion and Arch Size in Families

A Principal Components Analysis

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A statistical analysis of the heritability of seventeen attributes of arch size, arch shape and occlusal relations indicates a dominance of environmental over genetic factors. Some combinations of traits show noticeable genetic influence, while individual occlusal traits appear to be almost entirely related to environmental effects.

Recent studies of family data[13] and of twins[9] suggest that occlusal similarities within families may be more related to common environmental effects than to heredity. When the genetic contributions to variation are assessed by comparing parents and offspring, the confounding effects of intra-generational environmental influences are avoided. In such comparisons, features such as overjet, overbite, molar relationship and anterior crowding fail to exhibit heritability (h^2) estimates significantly different from zero.[13]

Individual occlusal variables are not functionally or anatomically independent. Their interdependence means that sets of occlusal features could have different patterns of inheritance or response to environmental influences than individual attributes. A variety of multivariate statistical techniques, falling into the general category of factor analysis, can be used to reduce a large number of characteristics to smaller sets of composite variables. These techniques depend on the statistical analysis of associations (correlation or covariance) among individual variables.

Correlation does not prove causation, so the composite variables generated from such an analysis are not necessarily "real."[1] On the other hand, many studies of craniofacial measurements have demonstrated that factor analytic techniques can produce composite variables that appear biologically meaningful and useful.[5,7,15,18,19,28]

In this study, we have analyzed 17 parameters of occlusion and arch size to identify a smaller number of independent factors, and then evaluated the heritability of those composite variables to estimate relative genetic and environmental contributions to the variation.

Materials and Methods

The source of data, measurement techniques, evaluation of measurement error, and adjustment for age-related variation have been described in previous reports.[13,25] A total of 761 individuals from 112 families are included in the analysis.

Since the subjects in this study are Melanesian, the results might differ from a similar analysis of a Western population because of unknown differences in the nature and amount of genetic and environmental variation within the population.

Seventeen attributes were measured or calculated for each individual. These included ten features of arch size and shape, and seven variables related to occlusion, as shown in table 1.

The derivation of principal components is based on the total sample with sexes pooled, since inspection showed none of the 136 correlations to be significantly different between sexes. (Table 2).

TABLE 1
Measurement Definitions for the Occlusal and Arch Size Variables*

Variable	*Definition*
Overjet	Horizontal distance between labial surfaces of the upper and lower central incisors.
Overbite	Vertical distance between incisal edges of the upper and lower central incisors.
Molar Relationship	Sagittal distance between upper and lower first molar mesial contact points.
Crowding & Spacing**	A seven-grade ordinal scale between severe crowding (−3) and severe spacing (+3) scored on the anterior segment.
Rotations & Displacements**	Sum of major and minor positional variants scored on teeth of the buccal segment.
Inter-Canine Width**	Maximum linear distance between buccal surfaces of the cuspids.
Inter-Molar Width**	Maximum linear distance between buccal surfaces of the first molars.
Arch Length**	Linear distance between labial edge of the central incisor and disto-buccal aspect of the first molar.
Arch Shape**	Arch length divided by molar arch width.
Arch Width Ratio**	Cuspid arch width divided by molar arch width.

* More detailed descriptions have been published by Smith and Bailit[25] and Harris and Smith.[13]

** Measured separately for the maxillary and mandibular arches.

TABLE 2

Product-Moment Correlations Among the 17 Occlusal and Arch Size Variables, Sexes Pooled*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Overjet	—															
2	Overbite	.575															
3	Molar Rel.	—.309	—.362														
4	U Crowding	—.103	—.008	.049													
5	L Crowding	.120	—.070	—.115	.518												
6	U Rotations	.254	.067	—.046	—.314	—.158											
7	L Rotations	—.030	.025	.039	—.185	—.373	.301										
8	U 3-3 Width	.070	—.034	.156	.285	.189	—.126	—.057									
9	L 3-3 Width	—.040	—.183	.118	.207	.039	—.166	—.198	.715								
10	U 6-6 Width	—.011	—.127	.203	.088	.079	—.124	—.107	.655	.584							
11	L 6-6 Width	.027	—.067	.094	.092	.117	—.098	—.134	.581	.602	.893						
12	U Arch Length	.216	—.138	.232	.072	.016	—.030	.127	.657	.560	.613	.531					
13	L Arch Length	.066	—.224	.013	.058	.118	—.012	.078	.593	.572	.546	.555	.853				
14	Upper Shape	.234	.017	—.012	—.018	—.072	.096	—.253	—.075	—.102	—.549	—.511	.312	.252			
15	Lower Shape	.031	—.147	—.095	—.041	—.012	.097	.229	—.045	—.089	—.439	—.542	.268	.395	.824		
16	U Width Ratio	.136	.063	—.023	.201	.122	—.092	.005	.502	.238	—.234	—.228	.172	.157	.473	.401	
17	L Width Ratio	—.032	—.152	.040	.118	.280	—.182	—.153	.330	.610	—.060	—.148	.213	.200	.303	.354	.626

* Sample sizes range from 603 to 761; correlations of at least 0.07 are significant at $P<0.05$.

Principal components were extracted from the correlation matrix using the algorithm of Nie et al.[22] The five components with eigenvalues exceeding one were rotated to an orthogonal varimax solution.[16]

A composite score for each of the five components for each individual was calculated from the 17 original measurements.[11] Each measurement was first transformed to a z-score, which was weighted by the correlation (loading) of the variable with that component and added together to produce the score on the principal component.[8]

Heritability is the proportion of phenotypic variation attributable to additive genetic effects. It is calculated between sibs as twice the intraclass correlation, which is computed to incorporate unequal sibship sizes[27] with the standard error as in Becker.[2]

Between generations, h^2 is defined as twice the regression coefficient of offspring on parent,[10,17,24] with the parent's score repeated for each offspring's record. This is preferable to alternative approaches,[4,20] even though it results in a minor overestimation of the informational content of the parents' contribution.

Results

Univariate Correlations

As indicated in Table 2, correlations among the seven occlusal variables are generally low, with some positive and some negative. The highest is between overjet and overbite ($r = .57$, $r^2 = .33$). Likewise, the correlations between the seven occlusal traits and the ten arch size variables are all near zero. The largest of these is between maxillary crowding-spacing and upper intercuspid width, and here the value is only .29, indicating that variation in upper cuspid width explains just 8% of the variation in upper anterior crowding.

On the other hand, the six arch width and length dimensions show relatively high positive correlations, although they are not strongly related to arch shape or to the arch width ratio.

Principal Components

Five principal components were extracted from the correlation matrix, accounting for 76% of the total variation. Table 3 shows that the drop in percentage variance attributable to each component is rapid, with component V contributing just 6%. Components with eigenvalues less than one are excluded because they account for trivial portions of the overall variation.[14]

Component I is a composite measure of individual arch size. The six dimensions of arch width and length are positively correlated with this component, which seems to represent an overall size effect.

Component II is primarily a measure of arch shape as represented by the ratio between arch length and molar arch width. The four arch dimensions used to calculate the shape indices are moderately correlated with this component, with lengths positively correlated and molar arch widths negatively correlated with arch shape.

Component III is most highly correlated with incisor crowding, especially of the lower arch. Crowding is polarized on this component with respect to displacements from arch form. Since the crowding-spacing variable is scored with crowding being negative and spacing positive, this component shows a moderate tendency for individuals with spacing of the incisors to be relatively free of buccal segment rotations.

There is also a low but possibly important positive association between crowding and lower cuspid width, indicating that incisor crowding coincides with a narrower arch measured at the cuspids. Since the permanent cuspids erupt later than the incisors, it may be that intercuspid arch width is lower because there is space for them to erupt more medially. It also may be that jaw size predisposes the same individual to both anterior crowding and smaller intercuspid width.

Component IV is composed of high correlations on the upper and lower width ratios (cuspid arch width divided by molar arch width). Cuspid arch widths are moderately weighted on this component as well, and the signs of the four variables are all positive.

Component V accounts for only 6% of the total variation. Overjet and overbite are highly correlated with this component, and molar relationship has a moderate negative correlation. It differentiates individuals with Class II malocclusions with overjet and overbite from those with Class III malocclusions with little or negative overjet and overbite.

Communality (the proportion of total variation in a trait explained by the five components) is low for five of the occlusal variables—molar relationship, upper and lower crowding-spacing, and upper and lower malalignment. This means that the five components do not contribute a significant portion of the variation for these features; they are not statistically related to other variables or to each

TABLE 3

Orthogonally Rotated Principal Components Matrix and the Measurements' Communalities

Measurement	*Commu-nality*	*Loadings of first five principal components*				
		Component I	*Component II*	*Component III*	*Component IV*	*Component V*
Tooth Position Variables						
Overjet	.702	.155	.084	—.182	.063	.796
Overbite	.602	—.125	—.140	—.083	.059	.746
Molar Relationship	.242	.130	—.083	—.110	.088	—.446
Upper Crowding	.286	.082	—.003	.514	.125	—.003
Lower Crowding	.729	.095	.083	.839	—.001	.092
Upper Rotations	.170	—.024	.103	—.339	—.125	.167
Lower Rotations	.280	.036	.205	—.484	—.032	.036
Arch Size and Shape						
Upper 3-3 Width	.836	.726	—.151	.149	.513	—.002
Lower 3-3 Width	.749	.663	—.109	.369	.379	—.134
Upper 6-6 Width	.951	.824	—.493	.063	—.101	—.121
Lower 6-6 Width	.932	.796	—.508	.115	—.162	—.011
Upper Arch Length	.894	.892	.264	—.109	.129	—.025
Lower Arch Length	.914	.877	.372	.039	—.009	—.067
Upper Shape	.836	—.033	.849	—.175	.262	.119
Lower Shape	.913	.008	.937	—.087	.158	—.053
Upper Width Ratio	.799	.033	.305	.104	.826	.110
Lower Width Ratio	.611	.116	.268	.310	.644	—.122
Eigenvalue		4.521	3.252	2.221	1.835	1.053
% Variance Accounted For		26.6	19.1	13.1	10.8	6.2

other. The number of components would have to be increased before most of the variation could be accounted for.

Trial runs of the principal component analysis were made in an attempt to increase the communality of these variables, but this proved unsuccessful. The effect is for the first group of additional components (numbers 6 through 8) to consist of rearrangements of variables that are highly loaded on the first five components.

Familial Analysis

Results of the intraclass correlations among full sibs and of regression of offspring on parents are listed in Table 4. These different methods of estimating heritability include various biases. For example, siblings are phenotypically alike not only because they share an average of half of their genes in common, but also because they experience very similar pre-, peri- and postnatal environments.

Sibling correlations include the effects of shared environment, so this estimate of h^2 is almost invariably inflated.[10,17,21] Offspring regression on the mother eliminates those within-generation artifacts, providing a refined estimate of the true additive genetic component of the variation. However, since sibs share a similar intrauterine environment, variations in maternal influences such as age, health, and parity impose phenotypic effects that cannot be partitioned out of the mother-offspring estimate in humans.

Offspring regression on fathers circumvents the influence of these maternal effects. The presentation of all three estimates (Table 4) gives an approximate assessment of the nongenetic causes of phenotypic similarity.

It is noteworthy that, with only one exception, the h^2 of each principal component decreases in the expected sequence from sib-sib, through mother-offspring, to father-offspring, but the amount of decrease varies among components. Component I, the index of overall arch size, is least affected by the elimination of shared environmental influences. This is in good agreement with our earlier, univariate findings[13] that arch size is under stronger genetic control than occlusal variables.

Table 4 also discloses that arch shape expressed as a length-width ra-

TABLE 4

Heritability Estimates (h^2) and Their Standard Errors (s.e.) Calculated From Full Sib Intraclass Correlations and From Regression of Offspring on Parents

Component	*Sib—Sib* h^2	*s.e.*	*Mother-Offspring* h^2	*s.e.*	*Father-Offspring* h^2	*s.e.*
I	.76*	.16	.56*	.08	.56*	.11
II	.35*	.17	.24	.09	.13	.10
III	.51*	.17	.32*	.06	.39*	.17
IV	.67*	.17	.64*	.06	.33*	.12
V	.70*	.16	.46*	.07	.42*	.11

Sample sizes for each component are: sib-sib pairs = 205 (87 sibships); mother-offspring pairs = 133; father-offspring pairs = 70.

* $P<0.05$.

tio has a high environmental component. It has the lowest h^2 value from the sib-sib analysis, at 35%, and two-thirds of this similarity is attributable to common intrafamilial experiences since the father-offspring value is only 13%. Consequently, while overall arch size is largely attributable to hereditary factors, size proportionality (arch shape) is much more susceptible to non-genetic factors that may also influence growth.

From this perspective one might expect component IV (width ratios) to also show a low parent-offspring heritability, but unlike component II, component IV has a moderately high h^2 value assessed from among siblings (67%). Even though over half is due to non-genetic developmental convergence, this still leaves a statistically significant hereditary component (32%) as measured by regression of offspring on father.

Components III (crowding-spacing and malalignment) and V (overjet, overbite and molar relationship) are of particular interest since they encompass the composite information concerning occlusal variations. The situation for both components is that the two parent-offspring estimates are fairly similar, suggesting that unique maternal influences are not particularly important.

In contrast, the sib-sib values are apparent overestimates, larger than the respective father-offspring values by one third (component III) to two thirds (component V).

Discussion

Univariate Correlations

The low correlations among individual occlusal features suggests that many factors contribute to occlusal variation. We may tend to expect overjet to be closely related to overbite, for example, but their correlation of 0.57 in the present sample indicates that only one third of the variability in one can be explained by the other. Solow[28] also observed a correlation of about 0.5 for these two features. Other occlusal variables are even less well correlated, indicating that they vary relatively independently of one another.

Principal Components

It is particularly interesting that the first principal component does not include significant loadings for any of the several occlusal variables. It is a common feature of principal components analysis to extract an overall size effect as the first component.[3,23] The fact that occlusion is not found in this component indicates that, within this population, occlusion does not vary with body size or with arch size.

Our results point to two main components of dental occlusion. One is related to molar relationship, overjet and overbite, the other with malalignment in upper and lower arches. These results are at odds with Chung et al.,[6] who found these features to vary together on one principal component, but are in agreement with the studies of Solow[28] and Grainger.[12] The weight of available evidence suggests that crowding, spacing and malalignment occur independently of overjet, overbite, and molar relationship.

Familial Analysis

The heritability estimates for principal components III and V demonstrate, as we have emphasized previously,[13] that phenotypic resemblances between brother and sister should not be confused with hereditary control. Sibling correlations merely estimate the upper limit of the additive genetic component of variation. Nevertheless, the estimates of the additive genetic contributions of composite variables III and V are still 39% and 42% even after the major sources of non-genetic similarity are removed. This suggests that there are genetic predispositions for constellations of occlusal variables that may not be apparent when the variables are examined individually.[13]

In sum, these results point away from easy answers or simple solutions. When examined individually, occlusal traits seem almost solely related to environmental effects. In multivariate combination they show some significant genetic influences. The question is not whether occlusal variation is environmental *or* hereditary in origin. The question instead concerns the relative contributions of these two influences.

In these situations it is important to distinguish clinical (biological) from statistical significance. From the biological perspective, the factors most responsible for similarities between brothers and sisters, or parents and children, appear to be related to shared attributes of their environment rather than to heredity.

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