A morphological analysis of Japanese crania by means of the vestibular coordinate system

Gen SUWA
Department of Anthropology
Faculty of Science
The University of Tokyo

Abstract A total of 63 macerated Japanese crania of known sex were analyzed in terms of three dimensional coordinates of 36 landmarks in the vestibular coordinate system. The horizontal plane is defined by the plane of the lateral semicircular canals. The same data were analyzed in both cartesian coordinates (X, Y, Z) and in polar coordinates (R, T, Z). In order to summarize the intra-population variation, principal component analysis was performed on the correlation matrix of the coordinates. The first principal component accounting for over 30% of the total variance was interpreted as mainly expressing variance of facial orientation in relation to the vestibular horizontal. Comparison between the Japanese and European whites showed that while the occipital region was almost identical, orientation of the facial skeleton differed markedly in the two populations; the Japanese possessing a more antero-superiorly orientated facial skeleton in relation to the vestibular horizontal. The stability of the occipital region was a feature again confirmed when comparing 10 reference lines in various populations.

INTRODUCTION

Morphological analyses of the human cranium utilizing a reference plane which has direct relationships with head posture would be of great value to disciplines concerned with human evolution. The Frankfort horizontal is the most widely used in this respect. However, it is the opinion of the present author that the Frankfort horizontal has received undue attention. Criticisms have been made from both theoretical and technical viewpoints (SUWA, 1980; SUWA, 1981). An alternative, the vestibular orientation, was

applied in the present study. This orientation is determined by the plane of the lateral semicircular canals of the internal ear and has been recommended mainly for its physiological significance (FENART, 1966). Although direct associations of the vestibular orientation with head posture remains to be established, a morphological analysis utilizing this orientation should prove to be interesting. In the present study, a three dimensional space, i.e. the vestibular coordinate system, was defined by the plane of the lateral semicircular canals and the median sagittal plane. The aim of the present study is to describe the Japanese cranium by means

of this coordinate system in both intra- and inter-population levels. This study is a continuation of a previous study which discussed the fundamental characteristics of the vestibular coordinate system (SUWA, 1981); and morphological analyses are based on the data obtained in the previous study.

MATERIALS AND METHODS

A total of 63 macerated modern Japanese crania were selected of which 40 were male and 23 were female. All male crania and most female crania are of known age between the range from 20 to 44 years. Crania with marked alveolar resorption or any apparent pathological or traumas conditions were not included.

Craniometric data were analyzed in terms of three dimensional coordinates of 36 landmarks chosen to cover all regions of the cranium. Definitions of the landmarks and a detailed explanation of the procedure taken to obtain the coordinate data is presented in the previous study (see SUWA, 1981). The vestibular coordinate system is defined as follows. The X-axis, the anteroposterior axis, is determined by the plane of the lateral semicircular canals and lies in the median sagittal plane. The Z-axis, the vertical axis, also lies in the median sagittal plane and is perpendicular to the X-axis. The Z-axis is perpendicular to the former two, thus being the transverse axis. The point *vestibion* (defined as the middle of the lateral semicircular canals projected onto the sagittal plane) is the origin. X and Y coordinates were transformed into polar

coordinates (R and T) which were also analyzed. The polar coordinates were defined as R, the distance from the origin and T, the amplitude.

The advantage of coordinate data is that, as BENFER (1975) and MCHENRY and CORRUCINI (1978) state, three dimensional coordinates contain all the information available from the landmarks, thus by far exceeding the amount of information available from a limited set of measurements between the landmarks. LAITMAN *et al* (1978) also discuss the advantages of coordinates. In the present study, no standardization was performed on the coordinate data, although MCHENRY and CORRUCINI (1978) and LAITMAN *et al* (1978) recommend various standardization techniques. The main purpose of standardization is to mute size differences among the samples, which in the present study is not of importance.

PRINCIPAL COMPONENT ANALYSIS

To summarize the intra-population variation, principal component analysis was performed on the correlation matrix of the larger male sample. Both cartesian and polar coordinates were analyzed, enabling a more reliable interpretation than could be possible solely from either one. The two sets of coordinates tended to compensate for each other during interpretation. Not all 108 (36×3) variables were analyzed. Since asymmetry was not of concern, the Z coordinate of the median landmarks were omitted. Thus a total of 90 variables were analyzed.

15 components with eigenvalues greater

Table 1. Correlation coefficients between principal components obtained from analysis on cartesian and polar coordinates.

	CARTESIAN		P C 3	P C 4	P C 5	P C 6	P C 7	P C 8
	P C 1	P C 2						
P C 1	-0.993	0.109						
P C 2	-0.104	-0.973						
P C 3			0.964	-0.237				
P C 4			0.233	0.899	0.285		0.165	
P C 5				-0.301	0.764	0.515	0.101	0.128
P C 6					0.530	-0.823		
P C 7				-0.133	-0.122	-0.170	0.890	0.331
P C 8							0.360	-0.876
P C 9								
P C 10								0.103
P C 11								-0.183
P C 12								
P C 13								
P C 14								
P C 15								-0.142
P C 16								

	CARTESIAN		P C 11	P C 12	P C 13	P C 14	P C 15
	P C 9	P C 10					
P C 1							
P C 2							
P C 3							
P C 4							
P C 5							
P C 6							
P C 7				-0.101			
P C 8			0.162	0.173			
P C 9	0.916	-0.211	-0.130	0.182	0.135		
P C 10	0.226	0.852	0.302	-0.126	0.180	0.163	
P C 11	0.149		-0.181	-0.745	-0.352	0.234	0.207
P C 12	0.217		0.547	-0.113	-0.526	-0.459	-0.237
P C 13		0.341	-0.476	0.386	-0.549	-0.179	
P C 14			-0.235	-0.297	0.407	-0.787	0.103
P C 15		0.194	-0.404	-0.191			-0.657
P C 16		0.123	-0.139	0.113			0.533

Only coefficients with absolute values greater than 0.1 are given.

than 1.0 were identified in the analysis on cartesian coordinates (X, Y, Z) and 16 components with eigenvalues greater than 1.0 were identified for the polar coordinates (R, T, Z). They accounted for 90.6% and 90.4% of the total variance in the analysis on cartesian and polar coordinates respectively. Before describing the

components, the relative stability of the components was tested. Since the cartesian and polar coordinates essentially contain the same information, the extracted components are theoretically expected to coincide. From the factor scores of the individual crania, correlation coefficients between the components obtained from the cartesian and polar coordinates were calculated (Table 1). For the first 10 components, the corresponding components from the two analyses correlated well, whereas from the 11th to 16th component the situation was complicated and corresponding components could not be found on a one to one basis. Thus, it can be concluded that only the first 10 components were stable. Therefore, descriptions were made only on these first 10 components. They accounted for 83.3% and 81.3% of the total variance in ana-

lysis on cartesian and polar coordinates respectively.

The popular varimax rotation was not performed. Rotation is usually carried out to facilitate interpretation of factors whereas principal component analysis is a method of data transformation (KOUCHI, 1977). Furthermore, results of varimax rotation were found to differ depending on the number of principal components rotated. As it can be seen in Table 2, from factor 6 onwards, the varimax rotated factors of the first 10 principal components (found to be stable) and that of the first 15 principal components (eigenvalues greater than 1.0) cannot be paired on a one to one basis. This makes interpretations somewhat subtle and less significant.

Subsequent results are of the principal component analysis without varimax ro-

Table 2. Correlation coefficients between varimax rotated factors of 10 and 15 principal components of analysis on cartesian coordinates.

	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8	FC9	FC10
FC 1	0.990									
FC 2		0.986								
FC 3			0.878				0.105	-0.180		
FC 4				0.910		0.120	0.136		-0.122	
FC 5					0.854		-0.119		0.284	
FC 6				-0.288	0.280	0.657	0.159	-0.324	-0.337	
FC 7					0.186		0.533	0.603		
FC 8					-0.102	0.132	-0.168	0.586		
FC 9					0.182	-0.191		-0.102	-0.324	0.728
FC10					0.167		-0.122		0.506	
FC11			0.226		0.154		0.306		-0.351	
FC12			-0.294		-0.115		0.663	-0.238	0.421	
FC13				0.168		0.672	-0.173	0.216	0.198	
FC14			0.241	-0.180	-0.131	0.153	0.156	0.168	0.228	0.632
FC15			0.102		0.168				-0.135	-0.188

Only coefficients with absolute values greater than 0.1 are given.

tation. The factor matrix of both cartesian and polar coordinates are given in the Appendix. Descriptions are based on the analysis on cartesian coordinates unless indicated otherwise.

PC 1 Facial orientation 38.2% (XYZ), 30.5% (RTZ)

All landmarks seem to be rotated in the same direction and substantial loadings were not found in the Z coordinates. As was pointed out by the present author (SUWA, 1981), the vestibular coordinate system seemed to possess a relatively great rotatory variance which was expressed by the high variability of the coordinate T. PC 1 could be considered as an expression of this rotatory variance. However, scrutiny of the loadings shows that more than mere rotatory variance is summarized in this component. This is evident from the fact that the loadings of the T coordinates are not of the same magnitude in all landmarks and from the high loadings on the R coordinates of the anterior facial landmarks. This component could be considered to represent an association of upper facial protrusion with an antero-superiorly orientated facial skeleton relative to the posterior cranium and to the vestibular horizontal.

PC 2 Upper facial protrusion 11.2% (XYZ), 14.4% (RTZ)

This component indicates an association of a relatively small face, especially a retracted upper facial region, with a high positioned lower temporal region as represented by PO and CDL.

PC 3 Postero-inferior skull protrusion 9.0% (XYZ), 8.7% (RTZ)

A general postero-inferior dislocation of the occipital bone is associated with a broad face.

PC 4 Cranial breadth 6.5% (XYZ), 6.8% (RTZ)

A broad cranial vault is associated with a high positioned posterior basicranium. High loadings were also found on the R coordinates of LB, BR, IN and AST indicating some associations with general vault size.

PC 5 Nasal breadth 4.7% (XYZ), 5.7% (RTZ)

Highest loadings were found on the Z coordinates of NAR, EK, EM and LG. Associated with a broad face were a high positioned posterior cranial base and a high vault in relation to the anterior cranial base. Analysis on the polar coordinates produced somewhat different results. Loadings of the R and T coordinates of the landmarks on the vault were exaggerated while concerning the Z coordinates of landmarks on the facial skeleton only NAR had a relatively high loading.

PC 6 Posterior facial breadth 4.0% (XYZ), 4.5% (RTZ)

No substantial loading was found in the X and Y or R and T coordinates. High negative loadings were found in the Z coordinates of LG, CDL, PO and EM and to a lesser extent on AST, ZG, NAR and GO. In the analysis on polar coordinates, loadings were highest on LG, EM, NAR, CDL and PO. This implies that nasopharyngeal breadth might be the major cause of this component.

PC 7 Interorbital breadth 3.0% (XYZ),

3.4% (RTZ)

Highest loadings were found in the Z coordinates of MF and CP, implying associations of small interorbital breadth with relatively posteriorly diverging occipital condyles.

PC 8 Parallelness of occipital condyles 2.5% (XYZ), 2.7% (RTZ)

A high negative loading was found in the Z coordinate of CP. Associations with an anteriorly situated foramen magnum and posteriorly placed IN and AST were indicated.

PC 9 Euryon and asterion position 2.2% (XYZ), 2.0% (RTZ)

A low positioned EU and a high positioned AST were associated with an antero-superiorly situated HO and SE and laterally placed occipital condyles.

PC 10 Gonion position 1.9%(XYZ), 2.0% (RTZ)

A high, medially positioned GO was found to be associated with relatively parallel occipital condyles. High loadings on PO found in the cartesian coordinates were not found in the polar coordinates.

Discussions

Theoretically, the vestibular coordinates contain all morphological and positional information which could be expressed by the landmarks. Information on morphology which could be expressed by simple indices or angles popular in anthropology (cranial, facial, orbital indices, facial angle etc.) are included in the coordinate data. In addition to these regional morphological information, the vestibular coordinates are expected to

contain positional information of the different skull regions. Therefore, associations between regional morphology and positional relationships were hoped to be revealed. Although this was realized to some extent, the results were not totally satisfactory. The morphological information being expressed by coordinates was sometimes difficult to detect. For example, PC 9 has high loadings on the X and Y coordinates of HO with no substantial loading on PNS and PHT. It can be assumed that this is an expression of pharyngeal shape. However, the present author would feel far assured to have investigated the angle PNS-HO-PHT itself. Similar conditions were found in almost all components.

Another problem is that many aspects of morphology were not identified. No component expressing orbital shape, prognathism, etc. were obtained. This might have occurred in part by difficulty in detecting them as discussed above. However, there are possibilities that information concerning variables commonly used in anthropology were engulfed in the total information. A thorough comparison of coordinate data with ordinary linear and angular variables is desired. After results of such comparisons are obtained, a more detailed interpretation on regional morphology from coordinate data should be possible.

SEXUAL DIFFERENCES

Sexual difference in the mean

Mean and standard deviation values of males and females have already been

Fig. 1. Mean male and female diagrams.

Table 3. T-test of vestibular coordinates between males and females.

X			Y			R			T			Z		
t	df		t	df		t	df		t	df		t	df	
NA	-6.104**	48.84	0.649	56.32	6.391**	48.51	-0.589	54.40						
BA	0.795	48.78	-2.628*	48.74	2.736**	48.91	0.570	44.29						
IN	4.440**	55.48	0.368	40.62	4.593**	53.82	-0.280	40.12						
BR	0.001	55.38	3.512**	50.65	4.529**	49.07	-1.015	53.18			0.531		52.72	
LB	1.481	51.16	1.139	46.86	3.064**	47.07	-0.386	47.89			1.269		39.63	
SG	-5.305**	47.97	1.546	56.62	6.278**	49.10	-1.051	54.37						
GL	-6.453**	46.88	0.215	58.34	6.690**	49.63	0.086	56.18						
FT	-4.930**	53.87	1.158	57.06	6.048**	54.49	-0.484	54.94			2.639*		57.02	
OS	-6.222**	47.72	0.709	54.45	6.690**	49.26	-0.445	52.16			0.731		55.66	
MF	-5.739**	52.29	0.819	56.97	6.242**	52.07	-0.860	55.19			-0.421		45.44	
OR	-3.955**	55.29	0.296	56.24	5.237**	54.26	-0.880	54.83			2.137*		48.42	
EK	-5.839**	58.83	-0.007	54.28	6.699**	59.44	-0.321	52.29			3.755**		43.76	
RH	-6.616**	54.65	0.985	57.77	7.673**	50.74	-1.751	56.14			-1.095		40.13	
NAR	-3.458**	53.97	-0.136	53.72	5.196**	48.25	-0.855	53.21			0.444		51.99	
ANS	-3.790**	59.25	-1.302	53.75	6.627**	54.00	-0.281	54.75			-1.600		49.27	
PR	-2.759**	55.63	-1.068	58.35	5.653**	43.24	-0.782	57.52			-0.332		48.42	
ID	-2.485*	56.31	-1.324	55.24	5.175**	48.26	-0.870	55.71			-0.930		48.35	
GN	-1.854	57.27	-3.831**	53.77	6.902**	48.35	-0.438	55.65			-0.882		50.72	
ZM	-1.896	56.91	-1.315	53.08	3.449**	46.80	0.268	56.22			3.853**		51.02	
EM	-2.812**	59.79	-2.678**	58.87	5.768**	50.87	-0.248	59.86			3.026**		49.99	
PNS	-2.344*	58.31	-1.436	56.67	4.748**	55.25	-0.459	56.24			0.434		52.60	
LG	-3.540**	59.11	-1.234	56.37	4.987**	54.32	-1.056	56.98			2.662*		41.61	
HO	-1.643	58.37	-0.410	53.47	2.112*	55.78	-0.403	54.89			0.984		55.68	
PHT	-1.305	50.36	-2.025	48.96	2.745**	46.45	-0.270	47.92			1.070		60.58	
CA	0.025	53.53	-2.969**	48.37	3.065**	49.02	-0.295	49.60			2.498*		43.42	
CP	1.617	48.42	-2.647*	47.01	3.364**	48.14	-0.813	44.46			3.630**		51.12	
OP	2.609*	55.73	-0.838	52.24	2.820**	53.38	-0.114	51.30			-0.580		38.86	
COR	-2.562*	47.20	0.582	55.72	3.219**	58.05	0.677	50.60			3.548**		59.14	
AST	4.614*	37.01	0.620	51.71	5.434**	37.11	-1.102	45.22			3.419**		47.57	
EU	-1.488	45.98	-1.324	38.56	-1.231	38.00	1.657	50.43			3.410**		46.40	
ZG	-1.112	43.72	-0.930	57.64	1.572	40.27	0.450	56.35			6.304**		43.76	
CDL	-1.414	59.06	-2.441*	53.25	3.278**	55.32	1.540	50.88			6.695**		46.00	
GO	0.120	60.88	-5.159**	55.07	5.420**	53.32	0.390	60.29			4.290**		51.35	
PO	0.644	42.85	-1.494	53.13	0.555	51.26	1.086	49.47			5.576**		54.82	
SE	-3.160**	56.07	1.734	52.10	3.491**	55.82	-1.350	48.53						
CRA	-2.871**	46.15	0.899	54.90	3.070**	45.92	-0.024	53.78						

*,** Significant at the 5% and 1% levels respectively.

published (SUWA, 1981). Sexual differences were analyzed statistically by t-tests. The value t was calculated from the formula $t = (\bar{m} - \bar{f}) / \sqrt{s_m^2/n_m + s_f^2/n_f}$, where $\bar{m}$, $\bar{f}$ are the means, s_m , s_f the standard deviations and n_m , n_f the sample sizes of males and females respectively. The degree of freedom is obtained from the formula $(\frac{s_m^2}{n_m} + \frac{s_f^2}{n_f}) / df = \frac{s_m^4/n_m^2}{n_m - 1} + \frac{s_f^4/n_f^2}{n_f - 1}$. Table 3 shows the results of t-tests of X, Y, R, T and Z coordinates. The Z coordinates of all landmarks except for MF and NAR showed significant differences. Most landmarks differed significantly in either X or Y coordinate. The total effect can be demonstrated by superimposing male and female sagittal diagrams (Fig. 1). It can be seen that sexual differences are mainly of size.

Polar coordinates were useful in expressing this situation. The R coordinates of all landmarks except for EU, ZG and PO have highly significant positive t values. On the other hand, no significant t value was found whatsoever for the T coordinates (Table 3). This can be interpreted as sexual difference occurring mainly in size and not in the mutual positioning of the landmarks. Of course minor positional differences do exist. For example the R coordinate of EU has a negative value. Considered together with the X and Y coordinates, it can be seen that EU is positioned higher and more posteriorly in females.

Inclination of the Frankfort horizontal

The Frankfort horizontal is inclined antero-inferiorly by 15.54° in males and

by 17.42° in females. Thus, the Frankfort horizontal has a more antero-inferior inclination in females by approximately 1.9°. This sexual difference can be interpreted as a result of the general size difference between males and females, which concerning the upper facial region acts mainly in a horizontal direction.

POPULATIONAL COMPARISONS

PELLERIN (1979) published cartesian coordinates in the vestibular coordinate system of 38 landmarks obtained from 54 Japanese crania from Kobe of Hyogo prefecture. Of the 38 landmarks, 20 are in common with the landmarks selected for the present study. However, PELLERIN's sample are of unknown sex making strict comparisons impossible. It can only be pointed out that his data roughly falls in between the male and female data of the present study, thus reinforcing the present study.

Difference between Japanese and European white crania

Coordinate data of three European white populations from northern France have been published. However, the population studied by CANAL (1978) is a Gallo-Romanian population of a different historical age from the others and the population studied by FENART (1967) consisted of elder individuals. FENART *et al* (1975) discussed the influence of aging which was summarized as a sinking of the pre-vestibular region. Furthermore, in these two populations sex was not distinguished, thus discouraging statistical compari-

a

Fig. 2. Comparison of Japanese and European white; a, male; b, female.

b

sons. The final French population of FENART and SALMON (1973) consists of French living subjects of known age and sex. Therefore, comparisons with the Japanese of the present study were made with the population studied by FENART and SALMON (1973).^{*} The total effect of European white-Japanese differences in the vestibular coordinate system is illustrated in Fig. 2. The position and orientation of the face differs greatly while the occipital region is almost identical. In the Japanese, the whole facial skeleton and cranial base is orientated antero-superiorly in relation to the occipital region and the vestibular horizontal.

This was confirmed statistically by performing t-tests between the Japanese data of the present study and the data published by FENART and SALMON (1973). The results are given in Table 4. Essentially identical results were obtained for males and females. X and Y coordinates of all landmarks on the occipital (BA, OP, IN and LB) did not differ significantly excepting the X coordinate of LB in males. On the other hand, landmarks of the anterior cranial base (SE and CRA), most landmarks of the facial skeleton and BR differed significantly in both X and Y coordinates. The X coordinate of ANS and PNS did not differ significantly in both males and females, indicating a relatively strict supero-inferior dislocation of the

palate between the Japanese and the European whites.

Table 4. T-test between Japanese and European whites.

		Male		Female	
		t	df	t	df
B A	X	-0.200	59.42	-1.914	35.19
	Y	-0.266	61.19	0.280	33.08
O P	X	-0.139	66.96	-2.019	38.00
	Y	-1.012	70.32	-1.091	38.92
I N	X	1.386	67.69	-0.483	33.47
	Y	0.229	66.88	-1.513	39.97
L B	X	3.703**	67.27	1.528	39.04
	Y	0.303	69.74	0.333	38.25
B R	X	5.640**	69.67	4.638**	38.56
	Y	4.257**	65.89	3.320**	37.99
N A	X	3.813**	64.17	2.618*	33.62
	Y	6.092**	70.25	5.014**	39.31
O R	X	-5.855**	70.97	-4.558**	33.76
	Y	5.117**	70.35	4.310**	39.19
R H	X	5.610**	65.28	4.458**	31.25
	Y	5.910**	69.84	4.592**	35.50
A N S	X	-0.231	70.58	-0.422	31.52
	Y	5.700**	69.36	4.259**	35.65
P R	X	-4.465**	68.97	-3.928**	39.17
	Y	5.916**	69.31	5.028**	38.37
I D	X	-3.898**	66.88	-3.599**	35.11
	Y	5.031**	70.06	3.440**	39.87
G N	X	-2.142*	62.10	-1.753	32.82
	Y	3.588**	70.71	3.099**	39.97
P N S	X	-1.566	69.01	-1.439	33.49
	Y	5.992**	70.81	5.704**	39.00
G O	X	-2.691**	61.91	-2.651*	28.26
	Y	2.232*	67.62	2.546*	39.37
P O	X	-0.197	70.91	-1.374	32.21
	Y	4.597**	52.24	5.175**	28.53
S E	X	2.856**	57.36	2.063*	30.51
	Y	3.346**	66.32	2.839**	37.05
C R A	X	6.051**	58.54	4.180**	35.83
	Y	4.670**	70.99	4.059**	36.89

*, ** Significant at the 5% and 1% levels respectively.

* The data published by FENART and SALMON (1973) were not corrected for enlargement. Therefore, in order to make direct comparisons, all coordinates were multiplied by 0.971 following FENART's instruction.

Correlation with natural head position

The present author (SUWA, 1980) reported that the angle the Frankfort horizontal makes with the true vertical when the head is orientated in the natural head position differed significantly between Japanese and European or American whites. Compared with European or American whites, the Japanese were found to possess a more antero-superiorly orientated Frankfort horizontal in the magnitude of 5° to 10° . Interestingly, similar conclusions were reached from the vestibular orientation. The angle the Frankfort horizontal makes with the vestibular horizontal was, in the Japanese crania of the present study, 15.54° and 17.42° for males and females respectively. The corresponding values for European whites were 20.62° and 22.10° for males and females respectively in the French whites studied by FENART and SALMON (1973), 20.59° in the Gallo-Romanian population of CANAL (1978) and 23.86° in the French population of FENART (1967). This indicates that the Frankfort horizontal is inclined more antero-superiorly in Japanese by approximately 5° to 8° .

Thus, correlation between natural head position and the vestibular orientation was observed in the populational level. This does not necessarily indicate a strict relationship between the two. However, possibility of the two being controlled by common factors cannot be dismissed.

MCCULLOUGH (1970) examined the visual field of various human populations. He found that the visual field of Mongoloids differed significantly from that of Euro-

pean or American whites. The visual field of Mongoloids was found to be larger medialwards but more confined superiorly and infero-laterally in relation to the Frankfort horizontal. Here, one is reminded of the case of condylar hypoplasia and palpebral ptosis reported by BJÖRK and KURODA (1968). This patient had a restricted upper visual field and because of this held his head in an extraordinary antero-superiorly directed attitude. The restricted upper visual field in relation to the Frankfort horizontal in Mongoloids could be a possible explanation for the relatively antero-superiorly inclined cranial reference lines in both natural head position and vestibular orientation.

Stability of the occipital region among various human populations

Comparisons of the Japanese crania with European white crania showed that the occipital region was almost identical in the two populations. In order to confirm the relative stability of the occipital region among various human populations, 10 angles were calculated between the vestibular horizontal and various craniofacial reference lines. For definition of the angles see Fig. 3. From the populational means, cross populational variances were calculated (Table 5). It can be seen that the foramen magnum is the most stable. The *glabella-inion* line, the Frankfort horizontal and the orientation of the palate as expressed by ANS-PNS were also relatively invariable among the populations. On the other hand, the most variable was the orientation of the

Table 5. Cross populational variances of 10 craniofacial reference lines in relation to the vestibular horizontal.

study	population	sex	n	FOR/ VEST	FH/ VEST	NA-SE /VEST	NA-BA /VEST	GL-IN /VEST	ANS- PNS/ VEST	GN-GO /VEST	GO- CDL/ VEST	NA-PR /VEST	OS-OR /VEST
present study	Japanese	M+F	63	12.75	16.23	5.05	13.18	2.82	15.10	42.18	76.57	81.18	68.60
PELLERIN 1979	Japanese	?	54	10.81	13.55	5.07	13.74	2.91	12.58	44.18	79.72	80.62	70.48
FENART and SALMON 1973	French white	M+F	52	14.25	21.12	11.37	7.33		19.24	44.37	78.91	71.86	
FENART 1967	French white	?	51	14.70	23.86	13.63	5.09	8.54				67.76	
CANAL 1978	Gallo-Romanian	?	56	14.42	20.59	7.98	9.12	5.94	16.73	38.67	77.75	75.08	64.10
PRUDON 1975	Peruvian	?	35	17.09	22.23	13.00	5.49	10.51	21.40	42.84	68.43	73.40	61.07
PELLERIN 1970	Melanesian	?	55	18.02	19.49	8.99	7.49	8.83		34.10	79.22	84.28	60.49
Cross populational variance				5.97	12.72	14.93	13.03	10.47	11.90	15.85	17.97	34.78	19.89

facial profile as represented by NA-PR. Orientation of the other facial reference lines, mandibular base (GN-GO), mandibular ramus (GO-CDL) and orbit (OS-OR) were all highly variable compared to the orientation of the foramen magnum. Reference lines on the cranial base (NA-SE, NA-BA) were intermediate in variability. From the above considerations, it is concluded that the occipital region is relatively stable among populations. Similar conclusions were reached by PRUDON (1975), CANAL (1978) and PELLERIN (1979).

A characteristic of the vestibular orientation in relation to head posture is that the vestibular orientation tends to orientate the head so as to express cranial-cervical spatial relationships. FENART (1966) and TERK and FENART (1976) published invaluable experimental data which demonstrate this relationship. They experimentally altered body and head postures of rats by amputating their forelegs. In this way a "super-quadrupedal" condition was enforced. This produced a new postural relationship between the cranium and the axial skeleton. The main consequence on cranial morphology was a postero-superior rotation of the occipital region so that the foramen magnum with the whole cerebellar region rotated postero-superiorly in relation to the vestibular horizontal. This was considered as a direct reaction to the experimentally enforced cranial-cervical spatial relationship. Analogously, the relative stability of the occipital region found in the populational comparisons of the present study

Fig. 3. Explanation of angular measurements,
 1 FOR/VEST, 2 FH/VEST, 3 NA-SE/VEST, 4 NA-BA/VEST,
 5 GL-IN/VEST, 6 ANS-PNS/VEST, 7 GN-GO/VEST,
 8 GN-CDL/VEST, 9 NA-PR/VEST, 10 OS-OR/VEST,
 (Angles are defined from all landmarks projected onto sagittal plane.)

can be interpreted as expressing a relatively stable cranial-cervical relationship among the populations.

SUMMARY

The vestibular method was applied to 40 male and 23 female modern Japanese

crania. The craniometric data were analyzed in terms of three dimensional coordinates of 36 landmarks. Both cartesian coordinates and polar coordinates were analyzed. The two seemed to compensate for each other during interpretation of the results. In some instances cartesian coordinates were the more useful, and in other instances polar coordinates were the more useful. Results obtained are summarized as follows.

1) Principal component analysis was performed to reveal associations between morphological and positional informations. The 1st principal component accounting for over 30% of the total variance was interpreted as mainly expressing variance of facial orientation in relation to the vestibular horizontal.

2) Sexual differences were described as being essentially of size difference with little difference in the mutual positioning of the landmarks.

3) Compared with European whites, the Japanese were found to possess a more antero-superiorly orientated facial skeleton in relation to the vestibular horizontal. This result correlates well with differences in facial orientation of the two populations in relation to natural head position in the living.

4) The occipital region of European whites and Japanese was found to be almost identical in the vestibular orientation. This stability of the occipital region was again confirmed in a comparison of various human populations.

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半規管座標系による日本人頭蓋の形態解析

諏 訪 元

東京大学理学部人類学教室

人類頭蓋を頭位 (head posture) に関連のある基準面を用いて解析することは 人類進化を考えるうえで興味深いことである。従来、このような目的の研究では耳眼水平面が最も頻繁に使用されてきた。しかしながら、一方では理論面実践面の双方から批判が提起されている (SUWA, 1980; SUWA, 1981)。本研究では基準面として三半規管の外側半規管のなす面 (半規管面) を用いた。この半規管面は主としてその生理学的意義から使用が推奨されているものである (FENART, 1966)。本研究の目的はこの半規管面を水平面とする半規管座標系を用いて日本人頭蓋を集団内集団間の両レベルにおいて解析することである。なお、この研究は筆者による前研究「人類頭蓋学における半規管座標系の基本的性質」の継続研究であり、同一原データを解析したものである。

使用標本は現代日本人頭蓋骨63個 (男40, 女23) であり、年齢は20~44才に限定した。半規管座標系は原点を *vestibion* (外側半規管の中心を矢状面に投影した点) とし、半規管面と正中矢状面とで定義される。この半規管座標系に36個の計測点を組み込み、直交座標系 (X, Y, Z) における座標値を原データとした。また、直交座標 (X, Y) を矢状面上で極座標 (R, T) に変換し、極座標系 (R, T, Z) を得た。計測方法および計測点の定義はすでに詳しく述べてある (SUWA, 1981)。

〔主成分分析〕

集団内変異を総括する目的で主成分分析を行った。各計測点の座標値は頭蓋各部位の形態に関する情報と各部位の位置関係に関する情報とを持ち合わせている。従って、主成分分析によって形態と位置関係の関連性を見出すことができる。なお、主成分分析は直交座標系 (X, Y, Z) と極座標系 (R, T, Z) との双方で分析を行った。両座標系のデータには同一の情報が含まれているため、両分析からは同一の結果を得ることが期待された。実際に双方の分析を比較すると、それぞれの分析の第1～第10主成分は一對一に良く対応する。しかしながら、第11主成分以後は複雑な様相を呈した (Table 1)。また、しばしば行われる varimax 回転は本研究では最終的には行わなかった。Varimax 回転によって得られる因子は回転する主成分の数によって微妙に変化し (Table 2)、即ち因子の解釈は人為的なものとなる。以上の理由から主成分分析の解釈は回転前の主成分の内、第1～第10主成分に限定した。結果は以下の通りである。第1主成分、顔面の方位；第2主成分、上顔部の突出；第3主成分、後頭部の後下方への突出；第4主成分、脳頭蓋幅；第5主成分、鼻幅；第6主成分、顔面後部の幅；第7主成分、眼窩間幅；第8主成分、後頭顆の平行性；第9主成分、*eurion, asterion* の位置；第10主成分、*gonion* の位置。

〔性差〕

直交座標系、極座標系の双方で検定を行った (Table 3)。性差は主として大きさの違いと解釈できる (Fig. 1 参照)。この状況を極座標系の分析が良く表している。R座標 (原点からの距離) ではほとんどすべての計測点において1%レベルで有意差が存在したが、T座標 (偏角) では5%レベルで有意差のある計測点は存在しなかった。

〔他集団との比較〕

1) 日本人頭蓋とヨーロッパ白人頭蓋との比較 双方の平均図を重ね合わせることによっておおよその比較ができる (Fig. 2)。顔面部の位置および方位は著しく異なるが後頭部はほとんど一致する。日本人頭蓋では顔面頭蓋全体が後頭部および半規管面に対してより前上方を向いているためである。この結論は統計学上でも確認された (Table 4)。なお、日本人と欧米白人とは自然頭位 (natural head position) に対する顔面部の方位が異なることが筆者によってすでに指摘されている (Suwa, 1980)。この報告は本研究で得た結果と良く一致する。これは半規管面と自然頭位との間に集団レベルで関連性が存在することを示唆している。

2) 後頭部の安定性 前述のごとく日本人頭蓋とヨーロッパ白人頭蓋の後頭部はほとんど一致した。この集団間における後頭部の安定性をより広範囲にわたる比較で調べた。方法としては、顔面頭蓋、脳頭蓋に合計10本の基準線を設け (Fig. 3)、各集団のこれらの基準線と半規管面のなす角度の平均値から集団間分散を計算した (Table 5)。その結果、大後頭孔の傾きが半規管面に対して最も安定していることが確認された。FENART (1966) および TERK and FENART (1976) はラットを使用した実験で半規管面に対する後頭部の方位は頭蓋と脊柱および頸部との位置関係を直接反映していることを示した。同様の論法をもって本研究の結果を解釈すると、頭蓋と脊柱および頸部との位置関係に関する集団間における変異は相対的に小さいと結論できる。

APPENDIX Factor matrix of first 10 principal components (continued)
analysis of cartesian coordinates

	PC 1			PC 2			PC 3			PC 4			PC 5		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
NA	-494	960		746	060		129	092		105	152		-218	006	
BA	-734	-069		008	265		260	-656		183	456		255	267	
IN	210	-384		-215	024		679	-375		149	069		-168	337	
BR	755	696		229	-014		332	091		168	248		-171	369	
LB	517	-477		048	-040		677	-464		004	335		-207	296	
SG	083	938		813	105		258	069		093	194		-227	026	
GL	-278	951		830	072		194	061		087	156		-207	-058	
FT	274	826	058	555	243	-346	327	203	106	179	008	573	-240	137	089
OS	-163	950	037	834	127	-403	233	123	179	211	114	542	-243	005	-107
MF	-555	955	-023	651	110	-190	204	036	497	060	149	254	-206	030	313
OR	-764	956	144	490	192	-096	063	079	578	144	036	055	-072	068	354
EK	-575	926	-092	660	220	-244	104	139	640	156	026	161	-021	117	426
RH	-691	959		523	046		135	028		042	158		-019	025	
NAR	-826	955	077	422	146	104	084	029	324	099	134	-454	122	011	542
ANS	-830	942		421	180		052	019		053	157		023	008	
PR	-894	928		262	235		051	-081		-051	012		058	-013	
ID	-910	863		207	299		031	-105		080	029		071	-019	
GN	-911	749		075	405		006	-220		067	-012		087	-005	
ZM	-816	899	-188	337	335	-065	050	041	648	093	-119	-071	096	120	337
EM	-838	841	008	339	412	-186	086	-038	479	125	-108	-212	035	071	463
PNS	-885	820		233	346		032	-155		110	131		032	027	
LG	-872	760	-037	260	401	-000	045	-183	346	152	165	-272	021	145	406
HO	-668	691		358	281		167	-347		206	337		072	145	
PHT	-681	304		099	259		276	-638		081	478		179	242	
CA	-754	152	-144	007	274	037	187	-637	-065	216	199	062	068	326	039
CP	-661	-416	135	-001	297	112	368	-554	251	217	187	-085	145	316	-064
OP	-462	-476		-174	023		455	-618		048	187		078	355	
COR	642	495	-031	280	131	-481	359	123	-036	247	431	715	-223	245	-133
AST	403	-426	115	-201	-128	-140	524	-180	147	291	-222	553	-133	408	124
EU	391	-228	-073	224	177	-232	054	-025	-292	408	091	722	-069	365	-077
ZG	-526	779	001	-035	274	-395	159	172	395	444	-204	435	057	293	293
CDL	-575	439	082	046	580	-371	278	091	092	258	-380	197	092	417	270
GO	-873	155	230	088	511	-115	068	-362	471	202	-283	-106	089	346	229
PO	-284	327	101	031	432	-372	044	107	072	163	-360	484	-068	560	172
SE	066	783		655	100		410	-216		110	255		189	140	
CRA	-445	927		650	072		110	017		179	177		-136	071	

	PC 6			PC 7			PC 8			PC 9			PC10		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
NA	-198	107		039	049		042	051		025	075		061	-000	
BA	188	-084		130	-140		-212	-124		-176	-056		144	-151	
IN	318	330		088	218		303	163		-015	274		-149	-250	
BR	063	228		-068	135		150	184		-008	-132		092	082	
LB	141	110		035	233		102	133		-127	-041		112	-002	
SG	-212	050		-024	017		014	061		220	066		011	049	
GL	-221	123		002	025		035	072		144	053		038	081	
FT	048	106	237	-377	167	-343	-091	080	-128	110	106	029	-168	-038	-342
OS	-130	081	234	-061	015	-059	-023	080	031	142	064	102	-037	061	-118
MF	-213	064	131	029	043	-470	049	046	-201	072	029	084	-040	001	304
OR	-065	060	186	052	-010	-279	-024	018	-207	027	016	166	-083	-022	-060
EK	018	100	142	-103	-046	-293	-156	020	-059	089	042	226	-055	001	092
RH	-253	050		-040	030		025	-038		-029	024		001	-012	
NAR	-054	-017	-312	093	-062	-374	091	-000	037	046	067	-041	002	-035	128
ANS	-050	-023		-031	-054		132	-097		073	-022		013	-029	
PR	035	-029		-021	021		156	-213		127	-025		020	-025	
ID	101	-016		-029	-057		093	-268		126	-054		069	-021	
GN	104	-021		-063	-026		132	-358		072	-013		081	037	
ZM	-008	050	-255	-157	040	-340	077	-059	170	067	023	-062	102	036	-113
EM	-076	-086	-443	-036	-000	-084	201	-160	208	108	-038	-039	070	037	011
PNS	027	-074		107	046		150	-195		-069	128		-036	088	
LG	-012	-090	-522	126	013	242	009	035	-020	-115	028	006	-097	183	-013
HO	198	000		172	026		-005	016		-348	264		-007	-027	
PHT	368	-077		154	027		-349	049		-002	076		121	-056	
CA	369	-115	364	099	-282	-004	-259	071	319	015	-228	377	182	-137	562
CP	178	065	123	317	-217	452	-094	020	-477	-032	-143	238	018	-199	-012
OP	156	225		353	-008		-421	-151		062	110		007	-102	
COR	139	066	-123	-007	342	-140	079	313	-065	-145	-158	-154	-140	078	137
AST	223	285	-375	-086	277	288	335	197	-065	-123	404	-285	-154	-084	089
EU	129	115	-259	171	-094	-023	243	-083	082	-288	-459	-033	-040	205	299
ZG	-135	018	-331	055	159	012	-132	018	-113	-013	-087	174	131	035	-139
CDL	062	140	-580	-313	054	256	-146	-031	-064	-041	-084	248	051	008	-096
GO	084	115	-293	-075	-187	238	200	044	186	107	-076	-004	-058	264	-265
PO	165	192	-617	-209	063	178	-089	045	-094	132	-095	148	-476	-242	024
SE	174	-047		191	017		-095	119		-198	287		-161	097	
CRA	-114	071		110	-000		009	121		-026	141		-012	012	

analysis of polar coordinates

	P C 1			P C 2			P C 3			P C 4			P C 5		
	R	T	Z	R	T	Z	R	T	Z	R	T	Z	R	T	Z
NA	-579	949		628	177		-146	-062		023	-163		330	000	
BA	017	761		285	002		763	020		-235	290		036	227	
IN	-082	408		156	-057		432	-482		388	044		213	444	
BR	-186	773		113	268		-303	-238		359	-219		643	039	
LB	156	537		-104	079		-151	-642		574	085		274	160	
SG	-544	902		601	271		-253	-055		137	-182		334	058	
GL	-568	932		642	202		-210	-039		061	-141		311	054	
FT	-259	782	-078	367	388	276	-171	-235	-051	002	-109	562	390	-134	-013
OS	-509	922	-066	687	253	358	-192	-113	028	-049	-126	565	346	008	-176
MF	-557	939	016	594	218	173	-245	-010	415	017	-143	398	306	003	132
OR	-432	954	-145	725	199	074	-130	-074	543	-154	-032	260	130	-054	256
EK	-445	916	074	734	269	253	-150	-140	569	-114	-049	397	041	-088	287
RH	-443	960		631	100		-169	020		-081	-144		241	004	
NAR	-381	963	-089	742	113	-099	-135	006	446	-305	-054	-274	-010	084	324
ANS	-331	965		749	096		-074	021		-172	-071		128	064	
PR	-332	947		738	121		-005	053		141	003		-026	097	
ID	-051	939		724	132		149	029		-051	064		021	113	
GN	121	910		639	163		336	010		087	083		-003	123	
ZM	-367	945	188	674	185	091	-108	-039	662	-021	080	131	-188	-038	125
EM	-092	932	-026	840	124	159	-053	016	518	003	132	037	026	-003	199
PNS	-158	919		734	169		207	065		-246	032		084	098	
LG	-410	916	038	648	214	-046	157	103	427	-271	003	-039	006	009	147
HO	-313	814		563	115		174	313		-413	-053		-148	057	
PHT	-041	671		390	116		660	421		-440	013		-151	221	
CA	182	773	133	292	056	028	662	029	-083	-044	231	074	-091	181	189
CP	169	743	-122	211	-151	-126	650	-256	276	204	282	005	-027	267	021
OP	217	590		162	013		647	-508		121	193		-046	355	
COR	-069	570	-002	017	279	421	-239	-121	-218	443	-507	604	368	-054	-404
AST	-055	437	-118	264	120	093	258	-210	016	343	-118	614	462	538	-213
EU	280	322	055	-141	281	181	-045	016	-446	138	-383	557	310	-073	-382
ZG	-209	796	-020	129	338	312	-150	-196	297	-456	156	551	-015	-302	-128
CDL	-104	556	-112	507	502	277	-272	-063	069	063	284	305	-489	-390	-144
GO	070	884	-235	476	035	050	302	004	489	302	195	131	-421	108	069
PO	046	272	-127	311	446	279	-086	-174	-007	171	098	501	-475	-641	-336
SE	-206	774		557	327		-440	174		-165	-236		-176	-030	
CRA	-521	914		566	198		-114	007		-074	-177		234	-025	

	PC 6			PC 7			PC 8			PC 9			PC10		
	R	T	Z	R	T	Z	R	T	Z	R	T	Z	R	T	Z
NA	-006	117		-148	-008		110	017		093	-057		-075	-019	
BA	-215	-032		197	-086		-029	299		-037	-176		244	004	
IN	-482	-041		146	097		-261	-016		167	321		-135	-021	
BR	140	167		144	025		046	091		-108	080		040	-114	
LB	-279	174		330	057		-128	006		-209	101		007	-147	
SG	-017	064		-061	012		069	024		-071	-047		-000	-070	
GL	-077	156		-098	-005		092	041		-033	-005		-052	-102	
FT	182	090	-145	545	-104	-477	099	-011	-056	-094	-044	067	186	-010	-282
OS	034	100	-285	008	006	-121	064	044	-138	-044	-012	121	-015	-094	-138
MF	-025	066	045	-167	003	-574	115	007	039	009	-014	-021	-004	001	230
OR	040	026	002	-064	042	-406	055	006	041	-072	020	093	117	007	-098
EK	076	042	084	204	068	-386	-009	009	-019	-094	008	135	010	-017	120
RH	-189	066		-063	018		067	-057		053	-014		-016	023	
NAR	-104	016	583	-099	087	-285	183	007	-104	-148	-036	-067	040	023	043
ANS	-051	014		031	071		188	-088		-068	044		026	048	
PR	014	002		-015	031		-025	-152		-245	062		068	084	
ID	104	-029		253	032		-238	-116		-118	-080		-061	100	
GN	016	-021		229	-019		-378	-134		-029	029		-201	117	
ZM	-096	028	377	167	-068	-228	112	-108	-278	-110	-016	-095	-207	056	-132
EM	-167	-000	637	019	018	018	022	-174	-136	-139	072	-045	-121	089	078
PNS	-017	-036		-121	094		-161	-136		-131	-086		-003	-070	
LG	-092	-093	628	-148	032	289	-042	050	144	114	-035	047	003	-162	016
HO	186	-110		-069	045		-123	076		190	-338		148	-035	
PHT	-029	-287		013	-071		-192	343		-116	-049		108	033	
CA	-295	-316	-309	213	-119	-017	173	297	-266	157	-022	284	319	083	497
OP	-230	-010	-215	301	-038	226	233	045	629	069	-060	216	216	-149	042
CP	-183	-016		210	-077		434	223		-015	181		-076	-066	
COR	262	099	048	420	-256	-218	-165	166	042	-118	218	-149	272	-059	075
AST	-369	022	296	147	227	235	-404	010	165	270	382	-310	-099	035	-026
EU	142	219	168	-179	-119	-049	000	165	-058	-507	318	-095	119	-043	308
ZG	-175	-063	397	069	-129	-102	-278	-013	110	-101	027	210	-201	051	-105
CDL	-107	-048	584	315	-171	212	-169	-055	154	133	015	355	-136	072	-066
PO	-157	-032	291	175	-057	250	080	-183	-077	119	073	177	-337	040	-376
GO	004	-132	565	230	-091	109	-030	011	168	-117	132	180	130	227	068
SE	180	-037		-055	-022		-119	083		225	-227		318	-090	
CRA	050	051		-127	028		057	092		049	-141		044	-041	