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Varimax Rotation of the Principal Components Extracted from the Correlations between the Neurocranium and the Cervical Vertebrae: Toward the Solution of the Brachycephalization Problem

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Abstract In order to examine whether there is any evidence of local common factors controlling the form of both neurocranium and cervical vertebrae, the principal components from the metric data of 30 male and 20 female skeletons were transformed by KAISER's normal varimax rotation method. The rotated solutions obtained show that most of the factors which are significantly correlated with one or two of the main neurocranial measurements, *i.e.*, cranial length, breadth and height are not the local common factors which are also associated with the cervical vertebrae. This, together with the direct results of the principal component analyses, suggests no relationship of the cervical vertebrae with brachycephalization.

On the premise that common morphogenetic and/or biomechanical factors generate some associations among morphological characters, MIZOGUCHI (1992, 1994, 1995) has statistically analyzed the correlations between the neurocranium and other parts of the skeleton to clarify the causes of brachycephalization. In the present study, the principal components obtained by MIZOGUCHI (1995) from the correlations between the neurocranium and the cervical vertebrae are further rotated to examine another aspect of the same complex system of characters by using KAISER's normal varimax rotation method.

Materials and Methods

The measurements of the neurocranium and the cervical vertebrae published by MIYAMOTO (1924) and OKAMOTO (1930) were utilized. They are of the same individuals, *i.e.*, 30 male and 20 female Japanese from the Kinai district. The means and standard deviations for the neurocranial measurements used here are presented in MIZOGUCHI (1994) and those for the measurements of the cervical vertebrae are in MIZOGUCHI (1995).

First, the principal component analysis (LAWLEY and MAXWELL, 1963; OKUNO *et al.*, 1971, 1976; TAKEUCHI and YANAI, 1972) was applied to the correlation matrices on the measurements of the neurocranium and the cervical vertebrae. The number of principal components was so determined that the cumulative proportion of the variances of the principal components exceeded 80%. The principal components obtaind in such a way were then transformed by KAISER's normal varimax rotation method (ASANO, 1971; OKUNO *et al.*, 1971) into different factors, which may suggest some other associations hidden behind the measurements dealt with.

The significance of the loadings on the rotated factors was tested by the bootstrap method (EFRON, 1979a, b, 1982; DIACONIS and EFRON, 1983; MIZOGUCHI, 1993). Further, though indirectly, the reality of rotated factors was examined by finding similarities between the factors obtained from different cervical vertebrae, *i.e.*, by estimating a SPEARMAN's rank correlation coefficient (SIEGEL, 1956) between the variation patterns of the factor loadings.

The statistical calculations were executed with the mainframe, HITACHI MP5800/320 System, of the Computer Centre, the University of Tokyo. The programs used are BTPCA for the principal component analysis and KAISER's normal varimax rotation and RKCNCT for rank correlation coefficients, all of which have been written in FORTRAN by the present author.

Results

The loadings on the rotated factors for males are shown in Tables 1 to 7, and those for females are in Tables 8 to 14. Taking only significant factor loadings ($P<0.05$) into account, many of the rotated factors in these tables may be interpreted as specific factors, which are in general so called when they are each

Table 1. Loadings of the factors obtained through the normal varimax rotation of the first four principal components for the correlation matrix on the measurements of the neurocranium and the atlas of males.[1)]

Variable[2)]		Factor loadings			
		Fac I	II	III	IV
1	Cranial length	.89*	.05	.08	.17
8	Cranial breadth	.10	.04	.99*	.06
17	Basi-bregmatic height	.46	.62**	.12	.01
K1	Total sagit. diameter	.24	.88**	−.08	.07
K2	Total trans. diameter	.72	.44	.05	.14
10	Sagit. diam. of vert. foramen	−.21	.67	.19	.54
11	Trans. diam. of vert. foramen	.32	.08	.04	.89

[1)] The sample size is 30. The cumulative proportion of the variances of the four principal components is 81.95%.

[2)] Variable number according to MARTIN and SALLER (1957) except for K1 and K2, which are Nos. 1 and 2, respectively, of KIYONO's (1929) measurement system.

*$P<0.05$; **$P<0.01$; ***$P<0.001$, in the two-tailed test by the bootstrap method.

Table 2. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the axis of males.[1]

Variable[2]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.14	−.14	−.07	.07	.94*	.06
8	Cranial breadth	.12	−.83***	.18	−.14	.12	−.11
17	Basi-bregmatic height	.68	.22	.21	.04	.44	−.25
1a	Total height	.89***	−.25	.05	.23	.04	.11
1b	Height of vert. body	.70*	−.47*	−.04	−.14	.09	.21
K1	Ventral vertical diam.	.91**	−.15	.13	−.03	.06	.10
K6	Total breadth	.30	−.71	−.27	.46	−.10	−.02
K9	Max. wid. sup. art. proc.	.17	−.53	.26	.46	.30	.11
5	Inf. sag. diam. of vert. body	.13	.07	.13	−.07	.04	.93*
8	Inf. trans. diam. of vert. body	.01	−.02	−.10	−.91***	−.05	.09
10	Sagit. diam. of vert. foramen	−.01	−.09	.94*	.15	−.04	.01
11	Trans. diam. of vert. foramen	.51	−.03	.74	−.03	.02	.25

[1] The sample size is 30. The cumulative proportion of the variances of the six principal components is 85.42%.

[2] Variable number according to MARTIN and SALLER (1957) except for K1, K6 and K9, which are Nos. 1, 6 and 9, respectively, of KIYONO's (1929) measurement system.

$*P<0.05$; $**P<0.01$; $***P<0.001$, in the two-tailed test by the bootstrap method.

Table 3. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the third cervical vertebra of males.[1]

Variable[2]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.12	.05	.01	.93**	.11	−.16
8	Cranial breadth	.09	−.02	.10	.10	.88*	−.06
17	Basi-bregmatic height	−.10	.03	.22	.34	.02	−.79**
1	Vent. height of vert. body	.03	.81	.07	−.37	−.04	−.22
3	Cent. height of vert. body	−.00	.91	−.01	.05	.00	.01
2	Dors. height of vert. body	−.03	.88	.07	.24	.17	−.02
4	Sup. sag. diam. of vert. body	.81	.08	.09	.06	.11	−.25
6	Mid. sag. diam. of vert. body	.93	−.16	−.08	.01	.10	.15
5	Inf. sag. diam. of vert. body	.91*	−.02	.08	.08	.07	.08
7	Sup. trans. diam. of vert. body	−.03	−.03	.85	.10	.00	−.14
8	Inf. trans. diam. of vert. body	−.20	.24	.74	−.21	.36	−.07
10	Sagit. diam. of vert. foramen	−.37	−.00	−.76	−.05	.27	−.20
11	Trans. diam. of vert. foramen	.12	.12	−.10	−.07	.20	−.86***
K12	Max. wid. trans. proc.	.54	.27	−.10	−.06	.52*	−.12
K13	Max. wid. sup. art. proc.	.50	.10	−.13	.11	.64*	−.27

[1] The sample size is 30. The cumulative proportion of the variances of the six principal components is 81.78%.

[2] Variable number according to MARTIN and SALLER (1957) except for K12 and K13, which are Nos. 12 and 13, respectively, of KIYONO's (1929) measurement system.

$*P<0.05$; $**P<0.01$; $***P<0.001$, in the two-tailed test by the bootstrap method.

Table 4. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the fourth cervical vertebra of males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.58*	−.19	.14	.06	−.12	.58
8	Cranial breadth	.12	.12	.10	.21	.85	.10
17	Basi-bregmatic height	.11	−.22	−.17	.03	.25	.81
1	Vent. height of vert. body	.06	−.24	−.85	−.06	−.12	.00
3	Cent. height of vert. body	.02	.14	−.91	−.04	.06	.19
2	Dors. height of vert. body	.04	−.05	−.60	.09	.03	.69***
4	Sup. sag. diam. of vert. body	.18	.86	−.15	.16	.02	−.15
6	Mid. sag. diam. of vert. body	.15	.86	.07	−.05	−.01	−.24
5	Inf. sag. diam. of vert. body	−.09	.87	.13	−.19	.14	.04
7	Sup. trans. diam. of vert. body	.14	−.17	.15	.88	.08	−.07
8	Inf. trans. diam. of vert. body	.16	.06	−.18	.77	.27	.27
10	Sagit. diam. of vert. foramen	.00	−.57	−.23	−.57	.31	.07
11	Trans. diam. of vert. foramen	.57	−.21	−.07	−.10	.49	.21
K12	Max. wid. trans. proc.	.78**	.24	−.04	.28	−.05	.04
K13	Max. wid. sup. art. proc.	.74*	.21	−.12	.10	.40	.04

1) The sample size is 30. The cumulative proportion of the variances of the six principal components is 80.76%.

2) See the footnote to Table 3.

$*P<0.05$; $**P<0.01$; $***P<0.001$, in the two-tailed test by the bootstrap method.

Table 5. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the fifth cervical vertebra of males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.11	−.02	.07	.11	.03	.93***
8	Cranial breadth	.03	.01	−.11	.20	.89***	.08
17	Basi-bregmatic height	.35	−.31	.37	.24	.23	.42
1	Vent. height of vert. body	−.15	−.35	.79	−.07	−.04	.19
3	Cent. height of vert. body	.19	.21	.88	−.00	.01	−.04
2	Dors. height of vert. body	.55*	−.18	.41	.35	−.31	−.21
4	Sup. sag. diam. of vert. body	.02	.91	−.05	−.09	.16	−.02
6	Mid. sag. diam. of vert. body	.00	.93	−.19	.08	−.01	.12
5	Inf. sag. diam. of vert. body	−.06	.86	.17	.17	−.08	−.17
7	Sup. trans. diam. of vert. body	.15	.06	−.10	.81**	.30	.16
8	Inf. trans. diam. of vert. body	.21	.10	.09	.86***	.11	.06
10	Sagit. diam. of vert. foramen	.22	−.63	.09	−.55*	.19	.00
11	Trans. diam. of vert. foramen	.85*	−.13	.07	.09	.21	.06
K12	Max. wid. trans. proc.	.78**	.17	−.14	.12	−.07	.43
K13	Max. wid. sup. art. proc.	.55	−.01	.33	.15	.60*	−.08

1) The sample size is 30. The cumulative proportion of the variances of the six principal components is 82.17%.

2) See the footnote to Table 3.

$*P<0.05$; $**P<0.01$; $***P<0.001$, in the two-tailed test by the bootstrap method.

Table 6. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the sixth cervical vertebra of males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.14	.09	.11	.89	−.07	.12
8	Cranial breadth	−.20	.33	.14	.13	.17	.79
17	Basi-bregmatic height	−.21	.15	−.41	.66	.28	−.05
1	Vent. height of vert. body	−.24	.13	−.82	.09	.15	−.26
3	Cent. height of vert. body	.04	−.03	−.87	.02	−.18	.14
2	Dors. height of vert. body	.43	.15	−.77	−.11	−.12	−.10
4	Sup. sag. diam. of vert. body	.82	.02	−.03	−.12	.33	.09
6	Mid. sag. diam. of vert. body	.93*	.03	.08	−.06	.08	−.13
5	Inf. sag. diam. of vert. body	.81	.21	−.15	.23	.16	−.03
7	Sup. trans. diam. of vert. body	.32	.27	.13	.35	.64*	.22
8	Inf. trans. diam. of vert. body	.27	−.01	.06	−.09	.87*	.07
10	Sagit. diam. of vert. foramen	−.34	.41	.01	.45	−.16	−.43
11	Trans. diam. of vert. foramen	−.04	.89*	.05	.08	.20	−.12
K12	Max. wid. trans. proc.	.34	.79	−.11	.14	.07	.23
K13	Max. wid. sup. art. proc.	.10	.83	−.24	.08	−.12	.28

1) The sample size is 30. The cumulative proportion of the variances of the six principal components is 81.92%.

2) See the footnote to Table 3.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, in the two-tailed test by the bootstrap method.

Table 7. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the seventh cervical vertebra of males.[1)]

Variable[2)]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.49*	−.31	.54	−.19	−.18	.23
8	Cranial breadth	−.03	−.04	.10	.10	.15	.94*
17	Basi-bregmatic height	.16	−.01	.79	−.04	.19	.07
1	Vent. height of vert. body	.04	.77	.47	−.14	.03	−.05
3	Cent. height of vert. body	.06	.85	−.24	.00	−.21	.20
2	Dors. height of vert. body	.26	.82	−.00	.03	−.02	−.21
4	Sup. sag. diam. of vert. body	.79**	.16	−.01	.10	.41*	−.01
6	Mid. sag. diam. of vert. body	.83**	.24	.01	.02	.36*	−.07
5	Inf. sag. diam. of vert. body	.89**	.04	.08	.10	−.01	−.03
9	Mid. trans. diam. of vert. body	.18	−.20	−.01	−.02	.88***	.15
8	Inf. trans. diam. of vert. body	.24	−.01	−.06	.07	.88***	.02
10	Sagit. diam. of vert. foramen	−.07	.09	.71	.19	−.25	.01
11	Trans. diam. of vert. foramen	−.02	−.14	.28	.88*	.11	−.03
K12	Max. wid. trans. proc.	.55	.14	.27	.35	.35	.18
K13	Max. wid. sup. art. proc.	.29	.07	−.26	.80	−.07	.17

1) The sample size is 29. The cumulative proportion of the variances of the six principal components is 80.63%.

2) See the footnote to Table 3.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, in the two-tailed test by the bootstrap method.

Table 8. Loadings of the factors obtained through the normal varimax rotation of the first four principal components for the correlation matrix on the measurements of the neurocranium and the atlas of females.[1)]

Variable[2)]		Factor loadings			
		Fac I	II	III	IV
1	Cranial length	.12	−.92**	−.20	−.11
8	Cranial breadth	−.26	.76	−.20	−.44
17	Basi-bregmatic height	.07	.04	−.10	−.97***
K1	Total sagit. diameter	.01	−.08	−.91	−.13
K2	Total trans. diameter	.86	−.30	−.09	.01
10	Sagit. diam. of vert. foramen	.72	.06	−.52**	.01
11	Trans. diam. of vert. foramen	.81	−.11	.14	−.05

[1)] The sample size is 20. The cumulative proportion of the variances of the four principal components is 84.71%.

[2)] See the footnote to Table 1.

*$P<0.05$; **$P<0.01$; ***$P<0.001$, in the two-tailed test by the bootstrap method.

Table 9. Loadings of the factors obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the measurements of the neurocranium and the axis of females.[1)]

Variable[2)]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	.20	−.21	−.07	.85***	.22
8	Cranial breadth	−.10	.79	.08	−.37	−.32
17	Basi-bregmatic height	.12	.84	−.25	−.08	.14
1a	Total height	.92*	.20	−.21	.03	−.04
1b	Height of vert. body	.92	−.16	.05	−.06	.03
K1	Ventral vertical diam.	.94*	−.03	−.01	.11	.02
K6	Total breadth	.37	.06	−.80*	−.10	−.25
K9	Max. wid. sup. art. proc.	.14	−.52	−.37	−.04	.34
5	Inf. sag. diam. of vert. body	.20	−.01	.80	.08	−.26
8	Inf. trans. diam. of vert. body	.19	.24	−.13	.05	−.88***
10	Sagit. diam. of vert. foramen	.26	.09	−.43	.15	.73**
11	Trans. diam. of vert. foramen	.19	.07	−.39	−.74**	.27

[1)] The sample size is 18. The cumulative proportion of the variances of the five principal components is 82.67%.

[2)] See the footnote to Table 2.

*$P<0.05$; **$P<0.01$; ***$P<0.001$, in the two-tailed test by the bootstrap method.

correlated with only one original variable.

In the principal component or factor analyses based on small samples, it is frequently observed that the sequence of the factors extracted from the samples of similar kinds is somewhat different between the samples. For example, in the case of the male neurocranium and atlas (Table 1), the factor which can be regarded as a cranial length factor is the first factor but, in the case of females (Table 8),

Table 10. Loadings of the factors obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the measurements of the neurocranium and the third cervical vertebra of females.[1)]

Variable[2)]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	.01	.31	−.80	−.29	.01
8	Cranial breadth	−.16	.17	.89	−.07	.03
17	Basi-bregmatic height	.06	.42	.49	.05	.55
1	Vent. height of vert. body	.89	−.05	−.10	.02	−.01
3	Cent. height of vert. body	.86	.19	.09	.25	.09
2	Dors. height of vert. body	.83	.11	−.04	.08	.39
4	Sup. sag. diam. of vert. body	−.58	−.08	−.11	−.68**	.09
6	Mid. sag. diam. of vert. body	−.21	.15	.06	−.88***	.03
5	Inf. sag. diam. of vert. body	−.38	.01	−.11	−.86***	.12
7	Sup. trans. diam. of vert. body	.27	.22	.51	−.72**	−.03
8	Inf. trans. diam. of vert. body	.20	.21	−.11	−.17	.83
10	Sagit. diam. of vert. foramen	−.16	.48	.43	.58	−.23
11	Trans. diam. of vert. foramen	.27	.03	.68	−.51*	−.14
K12	Max. wid. trans. proc.	.21	.81*	−.10	−.31	.23
K13	Max. wid. sup. art. proc.	.04	.88*	.05	.05	.16

1) The sample size is 18. The cumulative proportion of the variances of the five principal components is 83.42%.

2) See the footnote to Table 3.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, in the two-tailed test by the bootstrap method.

Table 11. Loadings of the factors obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the measurements of the neurocranium and the fourth cervical vertebra of females.[1)]

Variable[2)]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	−.06	.23	−.11	−.81	.14
8	Cranial breadth	.13	.13	.03	.90	.20
17	Basi-bregmatic height	.47	−.06	−.05	.21	.60
1	Vent. height of vert. body	.33	−.23	−.70	−.44	−.10
3	Cent. height of vert. body	.18	.01	−.92	.01	.14
2	Dors. height of vert. body	.05	−.08	−.95*	−.06	.04
4	Sup. sag. diam. of vert. body	.09	.84	.34	−.06	−.11
6	Mid. sag. diam. of vert. body	−.11	.97*	.05	−.10	.05
5	Inf. sag. diam. of vert. body	−.01	.90	−.11	.03	.15
7	Sup. trans. diam. of vert. body	.74*	.35	−.41	.18	−.05
8	Inf. trans. diam. of vert. body	.70	.34	−.31	−.06	.36
10	Sagit. diam. of vert. foramen	.28	−.58	−.00	−.12	.64
11	Trans. diam. of vert. foramen	.83	−.33	.06	.25	.16
K12	Max. wid. trans. proc.	.79	−.25	−.19	−.13	.36
K13	Max. wid. sup. art. proc.	.12	.19	−.06	.01	.81

1) The sample size is 20. The cumulative proportion of the variances of the six principal components is 83.87%.

2) See the footnote to Table 3.

* $P<0.05$; ** $P<0.01$; *** $P<0.001$, in the two-tailed test by the bootstrap method.

Table 12. Loadings of the factors obtained through the normal varimax rotation of the first six principal components for the correlation matrix on the measurements of the neurocranium and the fifth cervical vertebra of females.[1]

Variable[2]		Factor loadings					
		Fac I	II	III	IV	V	VI
1	Cranial length	.03	.24	.01	.17	.01	−.91***
8	Cranial breadth	−.14	−.05	.27	.38	−.23	.76**
17	Basi-bregmatic height	.14	−.17	−.08	.80**	−.25	.06
1	Vent. height of vert. body	.91	−.13	−.06	.22	.17	−.07
3	Cent. height of vert. body	.91*	.24	−.03	.16	.09	.04
2	Dors. height of vert. body	.90	.05	.03	.05	−.08	−.09
4	Sup. sag. diam. of vert. body	−.04	.94*	−.06	−.11	−.12	−.12
6	Mid. sag. diam. of vert. body	−.01	.88	.19	.02	.21	−.18
5	Inf. sag. diam. of vert. body	.22	.84	−.07	.11	−.04	−.03
7	Sup. trans. diam. of vert. body	.21	.32	.29	.62*	.22	.22
8	Inf. trans. diam. of vert. body	.26	.21	.14	.76***	−.05	−.12
10	Sagit. diam. of vert. foramen	.25	−.40	−.53	.51	−.20	.05
11	Trans. diam. of vert. foramen	−.01	.05	−.93***	−.02	.07	−.13
K12	Max. wid. trans. proc.	.11	.01	−.03	−.02	.92	−.11
K13	Max. wid. sup. art. proc.	−.04	−.11	−.31	.73*	.34	−.02

[1] The sample size is 20. The cumulative proportion of the variances of the six principal components is 84.04%.
[2] See the footnote to Table 3.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, in the two-tailed test by the bootstrap method.

Table 13. Loadings of the factors obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the measurements of the neurocranium and the sixth cervical vertebra of females.[1]

Variable[2]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	.55	−.19	.07	−.58	−.30
8	Cranial breadth	−.06	−.08	.02	.91	−.23
17	Basi-bregmatic height	.13	.10	.08	.15	−.88*
1	Vent. height of vert. body	−.01	.83	.02	−.33	−.19
3	Cent. height of vert. body	−.03	.90	−.02	.19	−.13
2	Dors. height of vert. body	.01	.91	−.24	−.04	.02
4	Sup. sag. diam. of vert. body	.91	−.07	−.08	.06	.16
6	Mid. sag. diam. of vert. body	.92	−.03	−.12	−.12	.04
5	Inf. sag. diam. of vert. body	.87	.09	−.07	−.15	.01
7	Sup. trans. diam. of vert. body	.62*	.26	.28	.31	−.20
8	Inf. trans. diam. of vert. body	.35	.63*	.52	.29	.02
10	Sagit. diam. of vert. foramen	−.21	.19	.23	−.00	−.83**
11	Trans. diam. of vert. foramen	−.11	−.23	.86*	.22	−.12
K12	Max. wid. trans. proc.	−.03	−.10	.62	−.30	−.52
K13	Max. wid. sup. art. proc.	−.11	.09	.68	−.51	−.21

[1] The sample size is 19. The cumulative proportion of the variances of the five principal components is 82.56%.
[2] See the footnote to Table 3.
*$P<0.05$; **$P<0.01$; ***$P<0.001$, in the two-tailed test by the bootstrap method.

Table 14. Loadings of the factors obtained through the normal varimax rotation of the first five principal components for the correlation matrix on the measurements of the neurocranium and the seventh cervical vertebra of females.[1]

Variable[2]		Factor loadings				
		Fac I	II	III	IV	V
1	Cranial length	.21	−.30	.66	.24	.27
8	Cranial breadth	−.02	.06	−.87*	.30	.24
17	Basi-bregmatic height	.28	.31	−.04	−.04	.82*
1	Vent. height of vert. body	.04	.96*	−.10	.07	.16
3	Cent. height of vert. body	−.03	.96	−.04	.00	.11
2	Dors. height of vert. body	−.27	.93	−.11	.02	.06
4	Sup. sag. diam. of vert. body	.94	.01	.15	.23	−.06
6	Mid. sag. diam. of vert. body	.94	−.15	.03	.13	.09
5	Inf. sag. diam. of vert. body	.95*	−.07	.05	−.07	.04
9	Mid. trans. diam. of vert. body	.17	.05	−.24	.87	−.17
8	Inf. trans. diam. of vert. body	.04	.03	.23	.81*	.24
10	Sagit. diam. of vert. foramen	−.31	.29	.06	−.11	.80*
11	Trans. diam. of vert. foramen	.01	−.33	.09	.40	.65*
K12	Max. wid. trans. proc.	.29	.29	.31	.42	.47
K13	Max. wid. sup. art. proc.	.07	−.03	.62	.29	.47

[1] The sample size is 17. The cumulative proportion of the variances of the five principal components is 84.39%.

[2] See the footnote to Table 3.

$*P<0.05$; $**P<0.01$; $***P<0.001$, in the two-tailed test by the bootstrap method.

it is the second. To confirm the reality of the factors extracted, therefore, similarities in the factor loading variation patterns between the factors from different sets of data were also examined using the SPEARMAN's rank correlation coefficient in addition to the significance tests of individual factor loadings. Tables 15, 16 and 17 show the results of such factor comparisons. These were carried out to seek the factors which were strongly correlated with cranial length and breadth and basi-bregmatic height. The factors compared are, however, only those from the analyses for the third to the sixth cervical vertebrae of both sexes (Tables 3 to 6 and Tables 10 to 13) because the measurement items for the other vertebrae are not common to these cervical vertebrae.

Although many rank correlations between the rotated factors from different analyses were found to be statistically significant (Tables 15 to 17), such factors are not always highly correlated with one of the three main cranial measurements. The number of the factors which have significant rank correlations with one another and are regarded as a factor of the same kind is at most four for the cranial length factor (Table 15 and Tables 3–6 and 10–13), six for the cranial breadth factor (Table 16 and Tables 3–6 and 10–13) and three for the basi-bregmatic height factor (Table 17 and Tables 3–6 and 10–13) of the rotated factors from the eight analyses on the male and female cervical vertebrae. Further, it is discernible that most of these factors are specific factors or the like,

Table 15. Two rotated factors for each cervical vertebra showing similar loading variation patterns to that of the rotated factor for another cervical vertebra which is most highly correlated with cranial length.[1)]

Rotated factor most highly correlated with cranial length	Rotated factor (SPEARMAN's rank correlation)							
	Male							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3 Factor IV	—	—	III (.35)	VI (.30)	IV (.38)	V (.23)	VI (.38)	IV (.31)
Male cervical vertebra 4 Factor I	V (.47)	VI (.39)	—	—	III (.54*)	VI (.41)	VI (.44)	III (.36)
Male cervical vertebra 5 Factor VI	VI (.22)	II (.18)	I (.41)	V (.39)	—	—	IV (.55*)	III (.37)
Male cervical vertebra 6 Factor IV	II (.42)	IV (.31)	II (.45)	III (.43)	VI (.55*)	II (.42)	—	—
Female cervical vertebra 3 Factor III	I (.35)	II (.21)	V (.60*)	II (.37)	V (.63*)	I (.31)	I (.50)	II (.42)
Female cervical vertebra 4 Factor IV	III (.33)	IV (.28)	V (.75**)	III (.21)	V (.55*)	IV (.44)	V (.37)	II (.35)
Female cervical vertebra 5 Factor VI	I (.45)	III (.27)	I (.50)	V (.46)	V (.47)	II (.26)	I (.47)	IV (.34)
Female cervical vertebra 6 Factor IV	III (.52*)	I (.44)	V (.57*)	IV (.31)	V (.49)	IV (.34)	V (.52*)	III (.35)

Table 15. (Continued)

Rotated factor most highly correlated with cranial length	Rotated factor (SPEARMAN's rank correlation)							
	Female							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3								
Factor IV	II (.28)	I (.21)	I (.46)	IV (.28)	I (.28)	VI (.25)	V (.28)	I (.22)
Male cervical vertebra 4								
Factor I	IV (.35)	II (.32)	III (.28)	I (.19)	I (.62*)	VI (.50)	II (.66**)	III (.54*)
Male cervical vertebra 5								
Factor VI	II (.30)	IV (.20)	IV (.33)	I (.30)	III (.29)	II (.18)	V (.49)	II (.36)
Male cervical vertebra 6								
Factor IV	II (.48)	V (.34)	V (.37)	II (.22)	IV (.39)	II (.38)	V (.83***)	III (.34)
Female cervical vertebra 3								
Factor III	—	—	IV (.65**)	I (.43)	VI (.58*)	II (.36)	IV (.64**)	I (.49)
Female cervical vertebra 4								
Factor IV	III (.65**)	II (.10)	—	—	VI (.54*)	I (.29)	IV (.65**)	I (.15)
Female cervical vertebra 5								
Factor VI	III (.58*)	IV (.42)	IV (.54*)	I (.24)	—	—	V (.49)	IV (.41)
Female cervical vertebra 6								
Factor IV	III (.64**)	II (.14)	IV (.65**)	I (.45)	VI (.41)	V (.40)	—	—

[1] The similarity in the variation patterns of factor loadings between two rotated factors was assessed by using the SPEARMAN's rank correlation coefficient. The signs of rank correlations are removed because the signs of factor loadings are reversible. The rotated factors compared are only those from the solutions for the third to the sixth cervical vertebrae of both sexes (Tables 3 to 6 and Tables 10 to 13).

$*P<0.05$; $**P<0.01$; $***P<0.001$.

Table 16. Two rotated factors for each cervical vertebra showing similar loading variation patterns to that of the rotated factor for another cervical vertebra which is most highly correlated with cranial breadth.[1)]

Rotated factor most highly correlated with cranial breadth	Rotated factor (SPEARMAN's rank correlation)							
	Male							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3								
Factor V	—	—	V (.52*)	I (.47)	I (.48)	III (.40)	II (.50)	III (.37)
Male cervical vertebra 4								
Factor V	V (.52*)	I (.28)	—	—	V (.68**)	VI (.39)	II (.49)	I (.38)
Male cervical vertebra 5								
Factor V	VI (.53*)	II (.37)	V (.68**)	IV (.28)	—	—	I (.45)	III (.45)
Male cervical vertebra 6								
Factor VI	IV (.38)	V (.36)	IV (.73**)	I (.44)	IV (.39)	II (.38)	—	—
Female cervical vertebra 3								
Factor III	I (.35)	II (.21)	V (.60*)	II (.37)	V (.63*)	I (.31)	I (.50)	II (.42)
Female cervical vertebra 4								
Factor IV	III (.33)	IV (.28)	V (.75**)	III (.21)	V (.55*)	IV (.44)	V (.37)	II (.35)
Female cervical vertebra 5								
Factor VI	I (.45)	III (.27)	I (.50)	V (.46)	V (.47)	II (.26)	I (.47)	IV (.34)
Female cervical vertebra 6								
Factor IV	III (.52*)	I (.44)	V (.57*)	IV (.31)	V (.49)	IV (.34)	V (.52*)	III (.35)

Table 16. (Continued)

Rotated factor most highly correlated with cranial breadth	Rotated factor (SPEARMAN's rank correlation)							
	Female							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3								
Factor V	II (.38)	I (.33)	V (.61*)	III (.36)	I (.54*)	II (.29)	I (.48)	II (.44)
Male cervical vertebra 4								
Factor V	III (.60*)	IV (.21)	IV (.75**)	V (.60*)	VI (.46)	IV (.42)	IV (.57*)	I (.51*)
Male cervical vertebra 5								
Factor V	III (.63*)	II (.36)	IV (.55*)	III (.46)	I (.55*)	IV (.53*)	III (.53*)	IV (.49)
Male cervical vertebra 6								
Factor VI	II (.38)	V (.26)	IV (.29)	II (.26)	I (.41)	III (.36)	III (.27)	II (.26)
Female cervical vertebra 3								
Factor III	—	—	IV (.65**)	I (.43)	VI (.58*)	II (.36)	IV (.64**)	I (.49)
Female cervical vertebra 4								
Factor IV	III (.65**)	II (.10)	—	—	VI (.54*)	I (.29)	IV (.65**)	I (.15)
Female cervical vertebra 5								
Factor VI	III (.58*)	IV (.42)	IV (.54*)	I (.24)	—	—	V (.49)	IV (.41)
Female cervical vertebra 6								
Factor IV	III (.64**)	II (.14)	IV (.65**)	I (.45)	VI (.41)	V (.40)	—	—

[1)] See the footnote to Table 15.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

Table 17. Two rotated factors for each cervical vertebra showing similar loading variation patterns to that of the rotated factor for another cervical vertebra which is most highly correlated with basi-bregmatic height.[1)]

Rotated factor most highly correlated with basi-bregmatic height	Rotated factor (SPEARMAN's rank correlation)							
	Male							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3 Factor VI	—	—	II (.55*)	I (.39)	II (.56*)	V (.53*)	I (.51)	II (.40)
Male cervical vertebra 4 Factor VI	I (.54*)	II (.38)	—	—	I (.53*)	II (.49)	I (.38)	IV (.22)
Male cervical vertebra 5 Factor VI	VI (.22)	II (.18)	I (.41)	V (.39)	—	—	IV (.55*)	III (.37)
Male cervical vertebra 6 Factor IV	II (.42)	IV (.31)	II (.45)	III (.43)	VI (.55*)	II (.42)	—	—
Female cervical vertebra 3 Factor V	III (.33)	II (.30)	II (.42)	IV (.40)	IV (.54*)	II (.26)	I (.37)	III (.37)
Female cervical vertebra 4 Factor V	V (.61*)	III (.36)	V (.60*)	VI (.38)	I (.55*)	V (.38)	II (.52*)	I (.43)
Female cervical vertebra 5 Factor IV	I (.69**)	III (.33)	II (.46)	V (.42)	V (.53*)	IV (.46)	I (.55*)	IV (.39)
Female cervical vertebra 6 Factor V	I (.38)	VI (.37)	II (.51*)	VI (.34)	II (.58*)	VI (.49)	IV (.83***)	I (.66**)

Table 17. (Continued)

Rotated factor most highly correlated with basi-bregmatic height	Rotated factor (SPEARMAN's rank correlation)							
	Female							
	Cerv. vert. 3		Cerv. vert. 4		Cerv. vert. 5		Cerv. vert. 6	
Male cervical vertebra 3 Factor VI	IV (.20)	V (.19)	I (.47)	II (.44)	III (.63*)	II (.46)	III (.58*)	I (.39)
Male cervical vertebra 4 Factor VI	IV (.54*)	V (.32)	II (.44)	V (.38)	V (.49)	II (.40)	V (.34)	I (.32)
Male cervical vertebra 5 Factor VI	II (.30)	IV (.20)	IV (.33)	I (.30)	III (.29)	II (.18)	V (.49)	II (.36)
Male cervical vertebra 6 Factor IV	II (.48)	V (.34)	V (.37)	II (.22)	IV (.39)	II (.38)	V (.83***)	III (.34)
Female cervical vertebra 3 Factor V	—	—	III (.25)	V (.23)	IV (.12)	V (.11)	I (.25)	II (.23)
Female cervical vertebra 4 Factor V	II (.75**)	IV (.38)	—	—	II (.61*)	IV (.46)	III (.64**)	V (.61*)
Female cervical vertebra 5 Factor IV	II (.51*)	IV (.44)	V (.46)	III (.23)	—	—	V (.46)	II (.39)
Female cervical vertebra 6 Factor V	II (.73**)	IV (.46)	V (.61*)	II (.54*)	II (.73**)	VI (.49)	—	—

[1] See the footnote to Table 15.
* $P<0.05$; ** $P<0.01$; *** $P<0.001$.

as mentioned above, *i.e.*, not correlated with the measurements of the cervical vertebrae (Tables 3–6 and 10–13).

The rotated factors for the atlas, axis and seventh cervical vertebra (Tables 1, 2, 7, 8, 9 and 14) were not directly compared with those for the third to the sixth cervical vertebrae because of the differences in sort and number of the measurement items used. But the factors which had the highest correlations with each of the cranial measurements were also sought in the rotated solutions for the three vertebrae and were compared between males and females. In result, it was found that none of the cranial length, breadth and height factors was significantly correlated with any vertebral measurement simultaneously in males and females.

Discussion

To test the significance of individual factor loadings, the bootstrap method was used in the present study. A short comment on it will be given first.

Significance test of factor loadings

Although the bootstrap method was invented in 1977 and has been shown to be applicable to almost all kinds of statistics including principal components (DIACONIS and EFRON, 1983), its practical application to factor loadings has not been made at least in the field of physical anthropology.

The results of the bootstrap tests in the present study showed a complicated aspect of the significance test of factor loadings. Namely, it seems that the significance of a factor loading is not necessarily due to the large absolute value. For instance, the loading of -0.47 on the second factor listed in Table 2 is significant at the 5% level, but the loading of -0.71 on the same factor is not. Such a problem has not been noticed. From now on, it should also be taken into account in interpreting factor loadings.

Interrelations between the neurocranium and the cervical vertebrae

MIZOGUCHI (1995) suggested on the basis of the direct results of the principal component analyses of the same data as the present one that cranial length and breadth had no or little consistent associations with any of the measurements of the cervical vertebrae and that basi-bregmatic height was relatively highly correlated with the ventral and central heights of the vertebral body and with the transverse diameter of the vertebral foramen. These suggestions are based on the comparisons of factor loading variation patterns such as carried out in the present study.

The results of the present analyses suggested that many of the rotated factors were so-called specific factors or the like. In other words, it is likely that there are no or few local common factors which control the forms of both neurocranium and cervical vertebrae. Even the basi-bregmatic height factor showed no consistent relation with any measurement of the cervical vertebrae.

After all, it may be said from the direct results of the principal component analyses (MIZOGUCHI, 1995) and the varimax rotation of them that the forms of the cervical vertebrae are not associated with brachycephalization. This is, of course, true only on the assumption that the within-population variations reflect the among-population variations to some extent.

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