An Analysis of Errors in Craniometry

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Abstract Twenty-six measurement items taken three times on 35 crania by 10 observers independently were analysed for the influence of careless mistakes and measurement errors. The median number of careless mistakes per trial was 7.5. Nested analysis of variance showed that 8 measurement items had greater than 10% total error variance (Table 1). The influence of careless mistakes and inter-observer error on population comparison was examined by cluster analyses of several distance coefficients. The results indicated that the influence of mistakes could be minimized by eliminating the outlying measurements outside the range of $\bar{x} \pm 3S.D.$, and that the measurement items with greater total error variance should be excluded to minimize the influence of inter-observer measurement errors.

Keywords Craniometry, Measurement error, Analysis of variance

Introduction

Many studies have been published on measurement error in somatometry (DAVENPORT *et al.* 1934; SUZUKI, 1935; GAVAN, 1950; HIRATA, 1950; NAKAO *et al.*, 1972; SPIELMAN *et al.*, 1972; JAMISON and ZEGURA, 1974; KEMPER and PIETERS, 1974; IKEDA and TERADA, 1977; KOUCHI and HANIHARA, 1981), but there are few studies on measurement error in craniometry. This is probably because the consistency of cranial measurements has been taken for granted, for they are not influenced by factors such as posture, respiration, compressibility of the soft tissues etc. Recently SAKURA and MIZOGUCHI (1983) analysed the intra- and

inter-observer measurement errors in popular cranial measurement items by nested analysis of variance. Their analysis was based on only five crania and their results might be biased because of sampling problems. PAGE (1976) studied the effect of inter-observer error in craniometry on a principal component analysis, but two observers measured different sets of crania in his data.

Careless mistakes can not be completely avoided and their influence on population comparison should not be ignored. However, this aspect of error has never been analysed.

The purposes of the present study are: 1) to study the frequency and nature of

careless mistakes; 2) to study the magnitude of intra- and inter-observer measurement errors in some popular craniometric measurement items; and 3) to examine what steps should be taken to minimize the effects of careless mistakes and measurement errors in multivariate population comparison.

Materials and Methods

The materials used for the present study were 35 relatively well preserved crania of the Edo period from the Unkoin series excavated at Unkoin temple, Fukagawa, Koto-ku, Tokyo. All the crania were sexed as male by one of the authors (K.K.). In the present study ten observers independently measured each of the 35 crania three times in order to detect careless mistakes. The 26 measurement items taken are shown in Table 1. All were measured according to MARTIN und SALLER (1957), except for upper facial height, nasal height and the four radial measurements according to HOWELLS (1973). Three of the ten observers had had a lot of experience, and four had taken a course of training in craniometry in the Department of Anthropology, Faculty of Science, The University of Tokyo. The remaining three did not have any experience, but were instructed on the detailed definition of the landmarks and measuring methods before they started the research.

Another set of 30 crania from the Unkoin series were measured by K.K. (Unkoin-2), and 26 crania of the Edo period from the Higashiueno series (Higashiueno), excavated at Higashiueno, Taito-ku, Tokyo, were measured by M.K., and were used for comparison. All the crania were relatively well preserved and sexed as male by K.K. These two series of crania belong to the Department of Anthropology and

Prehistory, University Museum, The University of Tokyo. Also, the basic statistics of 65 male crania of the Edo period from Joshinji temple, Fukagawa, Koto-ku, Tokyo, reported by Commission of Anthropological Investigation of Modern Japanese Crania (1983), were used for comparison. The Joshinji series was measured by one of the present observers.

Nested analysis of variance (SOKAL and ROHLF, 1981) was used to test the significance of the differences between the intra- and inter-observer variances and between the inter-observer and among-skull variances. Whether the measurement errors have a serious influence on the data or not should be judged by another criterion than the F-test. For this purpose, the total variance was partitioned into the three components, intra- and inter-observer error variances and among-skull variance, and the proportion of each component was calculated. When the total error variance is less than 10% of total variance, the measurement items are tentatively considered to be reliable.

To minimize the effects of careless mistakes, a screening step was adopted and measurements outside the range of $\bar{x} \pm 3S.D.$ were eliminated in each subsample. To examine the influence of careless mistakes and measurement errors on multivariate analysis, mean square distances, PENROSE's size and shape distances, and MAHALANOBIS' generalized distances among the populations were calculated and analysed by cluster analysis based on the following five sets of measurement items: 1) 26 measurement items without any mistakes corrected; 2) 26 measurement items after the above-mentioned screening without any mistakes corrected; 3) 26 measurement items with mistakes corrected; 4) 18 measurement items with

less than 10% total error variance and mistakes corrected; 5) 18 measurement items after the screening without mistakes corrected. Thirty-four populations were used for this analysis: 30 subsamples (three trials by ten observers), average of the series based on the medians of 30 observations for each measurement (Unkoin-1), and the three groups used for Comparison (Unkoin-2, Higashiueno and Joshinji).

Standard deviations and the variance-covariance matrix based on 65 crania of the Unkoin series measured by K.K. were used to calculate PENROSE's distances and MAHALANOBIS' generalized distances respectively. The weighted group average method of cluster analysis was used.

The exclusion of measurement items with greater than 10% total error variance might cause a serious loss of information. Therefore, the data of 65 crania of the Unkoin series measured by K.K. were analysed by factor analysis, and the importance of the measurement items with greater error variances in terms of the uniqueness of information was examined. The data were analysed by program BMDP4M with varimax rotation. All the calculations for the factor analysis were processed by the HITAC M200H system of the Computer Centre of The University of Tokyo.

When the measurement items with greater total error variance were excluded to minimize the influence of measurement errors, the relationship among the populations might have been altered because of the loss of information. Also, the screening step may not be efficient enough to minimize the influence of careless mistakes. The consistency of the relationship among the populations can be ascertained if the measure of accordance between the two sets of distance

coefficients is high. In the present study, PENROSE's shape distance was used as a distance coefficient, and the distances between the four populations, Unkoin-1 (average based on the medians of subsamples), Unkoin-2, Higashiueno and Joshinji, were calculated based on the following three sets of measurement items: 1) 26 measurement items with mistakes corrected; 2) 18 measurement items with less than 10% total error variance with mistakes corrected; 3) 18 measurement items after the screening step without any mistakes corrected. As a measure of accordance, PEARSON's correlation coefficient was calculated between the distance coefficients based on the above three sets of measurement items.

Results

I. Careless mistakes

Since each observer measured the same cranium three times, careless mistakes could be detected. Among about 900 measurements in one trial (26 measurement items for 35 crania) the number of mistakes ranged from 0 to 51 with the median 7.5. About 70% of these mistakes were mistakes in reading the caliper by 5 mm or by 10 mm and mistakes from filling in the wrong places of the protocol. The experienced observers tended to make a smaller number of mistakes, but the inexperienced did not necessarily make many mistakes.

By the screening step of eliminating the measurements outside the range of $\bar{x} \pm 3S.D.$, the mistakes whose differences with the correct values were greater than 20 mm were eliminated, but the mistakes in reading by 5 mm or 10 mm were not.

Since these careless mistakes were caused by different factors from those responsible for the measurement errors, they were

replaced by new measurements taken by the observers concerned.

II. Nested Analysis of Variance

Nested analysis of variance was based on the data with no missing observations among the 30 trials (3 trials by 10 observers). The results are shown in Table 1. All the F-values were significant at the 0.005 level:

in all the measurement items inter-observer error variance was significantly greater than intra-observer error variance, and among-skull variance was significantly greater than inter-observer error variance. Inter-observer error variance was greater than intra-observer error variance, particularly in biauricular breadth, sagittal parietal arc, sagittal occipital arc, sagittal parietal chord and

Table 1. Results of nested analysis of variance.

MARTIN'S no.	Measurement	F1	F2	component of variance			
				Intra-obs.	Inter-obs.	Total error	Among skulls
1	Maximum cranial length	3.06	774.75	1.24%	0.85%	2.09%	97.91%
2	Cranial base length	2.11	622.83	2.22	0.82	3.04	96.96
8	Maximum cranial breadth	3.30	613.61	1.45	1.11	2.55	97.45
9	Minimum frontal breadth	2.52	1006.69	1.16	0.59	1.75	98.25
11	Biauricular breadth	21.18	16.64	5.33	35.84	41.16	58.84
17	Basion-bregma height	2.45	1185.57	1.02	0.49	1.51	98.49
26	Sagittal frontal arc	1.71	1304.09	1.32	0.31	1.64	98.36
27	Sagittal parietal arc	23.60	44.62	2.33	17.58	19.92	80.08
28	Sagittal occipital arc	21.93	51.10	2.24	15.64	17.89	82.11
29	Sagittal frontal chord	1.43	1701.74	1.22	0.17	1.39	98.61
30	Sagittal parietal chord	15.00	50.07	3.31	15.45	18.76	81.24
31	Sagittal occipital chord	17.38	64.39	2.32	12.64	14.96	85.04
40	Facial length	3.78	339.12	2.25	2.08	4.33	95.67
45	Bizygomatic breadth	2.20	2284.20	0.59	0.24	0.83	99.17
46	Middle facial breadth	5.58	136.02	3.62	5.52	9.14	90.86
*	Upper facial height	2.70	209.68	4.92	2.78	7.70	92.30
51	Orbital breadth I	2.23	51.98	19.27	7.87	17.14	72.86
51a	Orbital breadth II	3.32	45.17	15.00	11.61	26.62	73.38
52	Orbital height	2.59	132.08	7.79	4.12	11.92	88.08
54	Nasal breadth	2.15	214.30	6.00	2.30	8.30	91.70
*	Nasal height	3.36	163.38	5.00	3.94	8.94	91.06
61	Upper alveolar breadth	1.73	1381.77	1.23	0.30	1.54	98.46
*	Vertex radius	2.90	499.82	2.00	1.27	3.27	96.73
*	Nasion radius	2.37	470.03	2.60	1.18	3.79	96.21
*	Subspinal radius	3.51	348.65	2.35	1.97	4.32	95.68
*	Prosthion radius	3.51	444.66	1.86	1.56	3.42	96.58

*: HOWELLS (1973)

F1: Inter-observer variance/Intra-observer variance

F2: Among skull variance/Inter-observer variance

All the F values were significant at the 0.005 level

sagittal occipital chord. When the original measurements were inspected, the measurements taken by the same observers were very close to each other, but those taken by different observers tended to differ considerably in these measurement items. In biauricular breadth, most of the crania showed considerable between-observer discrepancy, so that the determination of the landmark, auriculare, seemed to differ according to the observer. In the other four measurement items, considerable inter-observer discrepancies were observed only in those crania in which the landmark, lambda, must be estimated because of suture closure or presence of a sutural bone.

Among-skull variances were rather small for the inter-observer error variance in the above-mentioned five items, orbital breadth I and orbital breadth II.

The total variance was partitioned into three components: intra- and inter-observer error variances and among-skull variance. The percentages of these three components, as well as that of total error variance, are also shown in Table 1. If the proportion of total error variance is small enough, then the item can be judged as reliable. The criterion for this judgement is arbitrary. When total error variance less than 5% is taken as the criterion, all the facial measurements such as upper facial height, nasal breadth, nasal height, middle facial breadth, orbital breadth I, orbital breadth II and orbital height should be excluded. Though the smaller the total error variance the better, it is not desirable to lose too much information by setting an overly strict criterion. When the criterion of total error variance smaller than 10% is adopted, the measurement items which should be excluded are the following eight: biauricular breadth,

orbital breadth I, orbital breadth II, sagittal parietal arc, sagittal occipital chord, sagittal occipital arc, sagittal parietal chord and orbital height. Apart from orbital height, the other seven of these measurement items show particularly great inter-observer error variances, and thus the measurement error in them may have considerable influence on population comparison.

An observer often records a measurement value with "?" when he is not confident of the value because of slight damage to the cranium or suture closure etc. In the above nested analysis of variance, the measurements with "?" were also used, and this might have inflated the total error variance. Therefore, nested analysis of variance was applied to the data with no missing observations among the 30 after the measurements with "?" were eliminated. The results are shown in Table 2.

There is little difference for the results of measurement items with less than 10% total error variance in the first analysis. In the six items with greater than 10% total error variance in the first analysis (sagittal parietal arc, sagittal occipital arc, sagittal parietal chord, sagittal occipital chord, orbital breadth I and orbital breadth II), the percentage of total error variance did decrease, but was still greater than 10%. Greater intra-observer error variances of orbital breadth I and orbital breadth II indicate that their reproducibilities are not good even when the same observer takes the measurement twice. For the other four items, different observers seem to use different lambda with confidence.

III. Cluster Analysis

The influence of careless mistakes and measurement errors on the distance coefficient

Table 2. Results of nested analysis of variance. Unreliable measurement values are excluded from the data.

MARTIN'S no.	Measurement	F1	F2	component of variance			
				Intra-obs.	Inter-obs.	Total error	Among skulls
27	Sagittal parietal arc	46.08	60.29	0.93%	14.03%	14.96%	85.04%
28	Sagittal occipital arc	31.94	70.14	1.18	12.14	13.32	86.68
30	Sagittal parietal chord	27.55	68.07	1.40	12.39	13.79	86.21
31	Sagittal occipital chord	36.72	68.73	1.04	12.43	13.47	86.53
40	Facial length	3.76	307.43	2.48	2.28	4.76	95.24
46	Middle facial breadth	5.58	148.25	3.01	5.23	8.24	91.76
*	Upper facial height	2.89	177.60	5.36	3.38	8.74	91.26
51	Orbital breadth I	2.27	50.33	19.42	8.20	27.62	72.38
51a	Orbital breadth II	3.77	52.75	11.88	10.95	22.83	77.17
*	Nasal height	3.13	176.76	4.99	3.54	8.53	91.47
61	Upper alveolar breadth	1.71	1498.73	1.16	0.27	1.43	98.57
*	Vertex radius	2.87	507.33	2.00	1.25	3.24	96.76
*	Subspinal radius	3.64	340.45	2.32	2.04	4.36	95.64
*	Prosthion radius	3.72	416.43	1.87	1.70	3.57	96.43

*: HOWELLS (1973)

F1: Inter-observer variance/Intra-observer variance

F2: Among skull variance/Inter-observer variance

All the F values were significant at the 0.005 level

ents was analysed by cluster analysis. The results of cluster analysis based on PENROSE's size distances were not informative because they did not show any clear pattern. The results based on mean square distances and MAHALANOBIS' generalized distances were generally consistent with the results based on PENROSE's shape distances. Therefore, only the results based on shape distances will be shown here.

1. Analysis based on 26 measurement items without any mistakes corrected:

The dendrogram (Fig. 1) shows the 30 subsamples by 10 observers divided into three main clusters. The three different populations (Unkoin-2, Higashiueno and Joshinji) were not separated from the 31 populations based on the same series of

crania. Also, there is one subsample diverged widely from the other subsamples. 2. Analysis based on 26 measurement items after screening without any mistakes corrected:

Fig. 2 shows that the overall distance decreased drastically and that the one subsample which diverged widely from all the other subsamples in Analysis 1 joined the two subsamples by the same observer. Generally, the three subsamples by the same observer tend to make a single small cluster. The 31 populations based on the same crania were not separated from the other cranial populations.

3. Analysis based on 26 measurement items with mistakes corrected:

Fig. 3 shows that the results of this

analysis is very similar to that of Analysis 2 (Fig. 2). This indicates the efficacy of the screening step in minimizing the influence of careless mistakes. However, the 30 subsamples are still divided into three main clusters. It is clear that this was not caused by careless mistakes but by inter-observer measurement errors. In fact, observers F, H and J tend to measure biauricular breadth systematically smaller than other observers. Observer G tends to measure orbital breadth I systematically larger than and orbital breadth II systematically smaller than the other observers.

To minimize the influence of inter-observer measurement errors, 8 measurement items with greater than 10% total error variance (biauricular breadth, orbital breadth I, orbital breadth II, sagittal parietal arc, sagittal parietal chord, sagittal occipital arc, sagittal occipital chord and orbital height) were excluded from further analysis.

4. Analysis based on 18 measurement items with mistakes corrected:

The values of shape distance decreased after the 8 measurement items were excluded. The dendrogram (Fig. 4) shows that the 30 subsamples and Unkoin-1 based on the same series of crania made one cluster and they were clearly separated from the other populations based on the different cranial series. There is no tendency for the subsamples by experienced observers to form one cluster, and this suggests that experience does not play an important role in determining landmarks.

The distance from the origin to nod 1 in Fig. 4 can be considered to be due to measurement error, and the distance from the origin to nod 3 to be due to sampling error. PENROSE's shape distances based on the 18 measurement items among the 30

subsamples ranged from 0.001 to 0.059, and those among the 30 subsample and Unkoin-2 ranged from 0.042 to 0.093. The corresponding MAHALANOBIS' generalized distances ranged from 0.038 to 7.963, and from 3.988 to 12.672, respectively. Fig. 4 also suggests that the sampling error can not be ignored.

5. Analysis based on 18 measurement items after screening without any mistakes corrected:

The shape distance is generally a little greater than in Analysis 4, where there were no mistakes. Shape distances between the 30 subsamples ranged from 0.001 to 0.067, and those between Unkoin-2 and the 30 subsamples ranged from 0.037 to 0.088. The corresponding MAHALANOBIS' generalized distances ranged from 0.093 to 7.774 and from 4.144 to 15.423, respectively. Fig. 5 shows that the relationship among the populations is also a little different from that in Fig. 4: the 30 subsamples were clearly separated from Unkoin-2 and Higashi-ueno but not from Joshinji.

IV. Factor Analysis

Eight factors with eigenvalues greater than 1 before varimax rotation explained about 83% of the total variance. Table 3 shows the results after varimax rotation. Among 8 measurement items with greater than 10% total error variance, orbital height did not have a high correlation with any of the eight factors. Therefore, the loss of information caused by exclusion of orbital height may not be serious even if it carries unique information.

Sagittal occipital arc and sagittal occipital chord are highly correlated with the 2nd factor, sagittal parietal chord and sagittal parietal arc with the 4th factor, orbital

Fig. 1. Cluster analysis of the male Japanese cranial series from the Edo period using PENROSE's shape distance based on 26 measurement items without any mistakes corrected (Analysis 1).
Note: A to J denote the ten observers, and 1 to 3 the three observation tests on the same 35 crania from the Unkoin series. Unkoin-1: average based on the median of the 30 observations by observer A to J.; Unkoin-2: The 30 crania also from the Unkoin series.; Higashiueno: The 26 crania from the Higashiueno series.; Joshinji: The 65 crania from the Joshinji series (Commission of Anthropological Investigation of Modern Japanese Crania, 1983).

Fig. 2. Cluster analysis of the male Japanese cranial series from the Edo period using PENROSE's shape distance based on 26 measurement items after screening and without any mistakes corrected (Analysis 2). See note of Fig. 1.

Fig. 3. Cluster analysis of the male Japanese cranial series from the Edo period using PENROSE's shape distance based on 26 measurement items with mistakes corrected (Analysis 3). See note of Fig. 1.

Fig. 4. Cluster analysis of the male Japanese cranial series from the Edo period using PENROSE's shape distance based on 18 measurement items with mistakes corrected (Analysis 4). See note of Fig. 1.

Fig. 5. Cluster analysis of the male Japanese cranial series from the Edo period using PENROSE's shape distance based on 18 measurement items after screening without any mistakes corrected (Analysis 5). See note of Fig. 1.

Table 3. Results of factor analysis. Factor loadings after varimax rotation. Factor loadings greater than 0.316 are shown.

Measurement	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8
Subspinal radius	.864							
Prosthion radius	.767		.319					
Cranial base length	.738	.321						.349
Nasion radius	.728							
Facial length	.711			.398				
Sag. occipital arc		.915						
Sag. occipital chord		.834						
Cranial length	.500	.651						
Sag. frontal chord			.841					
Sag. frontal arc			.817					
Cranial breadth			.638					
Nasal breadth	.362		.554				.347	
Sag. parietal chord				.957				
Sag. parietal arc				.913				
Orbital breadth I					.906			
Orbital breadth II					.849			
Min. frontal breadth				.412	.605			
Nasal height						.769		
Upper facial height			.335			.728		
Upper alveolar breadth						.728		
Middle facial breadth							.789	
Biauricular breadth	.390						.711	
Bizygomatic breadth	.501						.660	
Basion-bregma height								.941
Vertex radius								.782
Orbital height		-.485				.428		
Variance explained by the factor	3.96	2.85	2.75	2.66	2.48	2.29	2.28	2.18

breadth I and orbital breadth II with the 5th factor, and biauricular breadth with the 7th factor. As the 7th factor is highly correlated not only with biauricular breadth but also with bizygomatic breadth and middle facial breadth, the loss of information caused by excluding biauricular breadth may not be serious either. The 2nd and the 5th factors have rather high correlations with maximum cranial length and minimum frontal breadth,

respectively. However, the information on the parietal bone would be almost completely lost if sagittal parietal chord and sagittal parietal arc were excluded. As for orbital breadth I and orbital breadth II, a considerable part of their variances reflects not morphological variation but the difficulty of determining the measuring points judging from their great intra-observer error variances.

Table 4. Correlation coefficients between the PENROSE's shape distances among the four populations (Unkoin-1, Unkoin-2, Higashiueno and Joshinji) based on the 3 sets of measurements.

Shape distance	1	2	3
1 26 measurement items with mistakes corrected	1.		
2 18 measurement items with mistakes corrected	.868*	1.	1.
3 18 measurement items after screening without mistakes corrected	.868*	1.**	1.

* significant at the 0.05 level

** significant at the 0.01 level

It seems that the loss of information caused by the exclusion of the measurement items with greater than 10% total error variance is not negligible.

V. Correlations between the Shape Distances

PEARSON's correlation coefficient between the shape distances is shown in Table 4. When there are no mistakes, the correlation coefficient between shape distances based on 26 and 18 measurement items was 0.868 and significant at the 0.05 level. This suggests that the relationships among the populations did not change greatly in spite of the loss of information caused by the exclusion of the 8 measurement items. A correlation coefficient as high as 1.0 between the shape distances based on 18 measurement items with the mistakes corrected and those without any mistakes corrected but having undergone screening indicates the efficacy of this step, that is, of screening, in minimizing the influence of careless mistakes.

Discussion

SAKURA and MIZOGUCHI (1983) analysed measurement errors in craniometry using nested analysis of variance, and their results were compared with the present results. In the present results, all the F-values were highly significant partly because of very large degrees of freedom. Therefore, the

percentages of total error variance instead of the significance of the F-values were compared (Table 5).

Nineteen measurement items were analysed in common in SAKURA and MIZOGUCHI and the present study. A rather large discrepancy in the percentage of total error variance was observed in the following four measurement items: minimum frontal breadth, biauricular breadth, sagittal parietal arc and sagittal occipital arc. In biauricular breadth, the discrepancy was caused by the fact that the landmark, auriculare, was determined in two different ways by the present observers.

In the other three measurement items, however, the crania, not the observers, may have caused the discrepancy. The measuring point lambda had to be estimated in 12 out of 35 crania used in the present study. If lambda could have been determined without difficulty in these crania, the percentage of total error variance in the present study may have been much smaller and closer to the values reported by SAKURA and MIZOGUCHI. Minimum frontal breadth was one of the very reliable measurement items in the present study, but it showed large inter-observer error in SAKURA and MIZOGUCHI. If the right and left temporal lines ran in such a way that the landmarks, fronto-temporale, could not be easily determined even in a single cranium out of the five

Table 5. Comparison of proportion of total error variance.

MARTIN's no. Measurement	SAKURA & MIZOGUCHI (1983)	Present study
1 Maximum cranial length	0.87%	2.09%
5 Cranial base length	1.38	3.04
8 Maximum cranial breadth	2.70	2.55
9 Minimum frontolobreadth	15.44	1.75
11 Biauricular breadth	5.07	41.17
17 Basion-bregma height*	2.17	1.51
26 Sagittal frontal arc	1.10	1.64
29 Sagittal frontal chord	1.12	1.39
30 Sagittal parietal chord	5.23	18.77
31 Sagittal occipital chord	1.55	14.96
40 Facial length	3.16	4.33
45 Bizygomatic breadth	0.85	0.83
46 Middle facial breadth	5.36	9.14
** Upper facial height	4.83	7.70
51 Orbital breadth	57.49	27.14
52 Orbital height	10.09	11.92
54 Nasal breadth	2.64	8.30
** Nasal height	2.71	8.94
61 Upper alveolar breadth	1.85	1.54

* Measurements by SAKURA and MIZOGUCHI were taken according to HOWELLS (1973).

** HOWELLS (1973).

they used, the error variance might have been inflated. It may be safer not to estimate the landmark when it is difficult to determine it.

The present results coincide with those of SAKURA and MIZOGUCHI in the inconsistency of orbital measurements.

The influence of measurement errors on the population comparison have been discussed (SPIELMAN *et al.*, 1972; PAGE, 1976), but the influence of careless mistakes has failed to arouse the interest of anthropologists. It is very difficult to avoid careless mistakes completely, however careful one might be (only one trial among the 30 was free from careless mistakes in the present study), and the comparison of the results of cluster analyses 1 and 3 (Figs. 1 and 3) shows that this could have a serious effect on the inter-

population comparison. However, this effect can be minimized by a screening step to eliminate measurements outside the range of $\bar{x} \pm 3S.D.$ when original data are available. Mistakes in reading the caliper by 5 mm or by 10 mm can not be eliminated by this screening method, but their effects are not systematic but random, and their influence on population comparison may not be serious.

In the analysis of population relationship, one of two strategies must be chosen to take into account the effects of inter-observer measurement errors. They are: 1. to use as many variables as possible and to interpret the results after careful consideration of measurement errors; and 2. to select reliable variables only, though this leads to the loss of some information.

There is no practical and reasonable way to interpret the results giving careful consideration to measurement errors, because it is impossible to know the nature of inter-observer measurement errors, especially when data from published papers are used. The only practical way to minimize the effects of inter-observer measurement errors is not to use unreliable measurement items.

However, whether a measurement item should be used or not depends on the populations to be compared. When comparison is made between the main racial stocks and morphological differences are rather great, the influence of measurement errors may not be very serious. However, when the morphological differences between the populations are small, for example, when geographic variations in the modern Japanese are to be studied, the influence of inter-observer measurement errors can be very serious. The three populations used for comparison in the present study are from the same area and period as the Unkoin series, and one of them is a different sample from the Unkoin series, so that the morphological differences between the skeletal populations used in this study are considered to be very small. Since the 30 subsamples made a single cluster in the cluster analysis 4 based on 18 measurement items (Fig. 4), these 18 measurement items are considered very reliable.

The results of the factor analysis indicated that the exclusion of the measurement items with greater than 10% total error variance naturally caused a loss of information. In fact, the relation between the populations altered to some extent when a different set of measurement items was used. However, the results of cluster analyses strongly suggest that it would be safe to choose the

second strategy, especially when the morphological difference among the populations are small. If the measurement items which have been shown to have greater inter-observer errors are to be used for population comparison, the best method is for all the measurements to be taken by the same observer. When this is impossible, the landmarks should not be estimated when they can not be determined without difficulty.

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抄 録

頭骨計測値の誤差

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本研究の目的は、実際のデータ分析において計測ミスと計測誤差の影響をできるだけ小さくして合理的な分析結果を得るためにはどのような前処理が必要か、またどのような計測項目を使用すべきかを検討することである。

この目的のため、深川雲光院出土の江戸時代人男性頭骨35個について、26項目の計測値を10人が3回計測した延べ30人分のデータを使用して、不注意によるミスの頻度と種類を調べると同時に、計測者内・計測者間の誤差の分析を行った。以下、本文の各章について要約する。

1) 約900個の計測値のうちおよそ0.8%が不注意によるミスで、このうち約7割は5mmあるいは10mm単位の読み違いか記入場所の誤りであった。これらのうち、実際の値との差が20mmをこえるものは、平均値 ± 3 S.D.以上離れた計測値を取り除くスクリーニングで取り除くことができる。

2) Nested analysis of variance 法により分析した結果、すべての項目において計測者間分散は計測者内分散よりも有意に大きい。このうち、両耳幅、眼窩幅Ⅰ、眼窩幅Ⅱ、矢状頭頂弧長、矢状頭頂弦長、矢状後頭弧長、矢状後頭弦長、眼窩高の8項目で全誤差分散が全分散の10%をこえた(Table 1)。この結果は、計測者があまり確信を持たずに括弧付きで計測した値を取り除いても変わらない(Table 2)。

3) 同時代・同地域の他集団(浄心寺、東上野、雲光院2)の計測値、および延べ30人分のデータの中央値(雲光院1)を加えた34集団間のPenroseのShape distanceをクラスター

分析をした結果、上記8項目を除いた18項目のセットは計測誤差の面からみて信頼がおけることが確認された(Figures 1-5)。

4) 雲光院頭骨65個について因子分析をした結果、上記8項目のうち、眼窩高はどの因子とも相関が低い。また、両耳幅、眼窩幅Ⅰと眼窩幅Ⅱ、矢状後頭弧長と矢状後頭弦長は3つの因子への寄与が高いが、これらの因子には他にも相関が高い項目がある。したがって、これらを使用しなくても情報の損失はあまりない。しかし、矢状頭頂弧長、矢状頭頂弦長を取り除いた場合には頭頂部に関する情報が失われる(Table 3)。

5) 26項目を用いた場合と、18項目を用いた場合のShape distanceの相関は高く、8項目を取り除いても集団間の関係はあまり変わらない。18項目に基づいた距離で、計測ミスがない場合と計測ミスはあるが平均値 ± 3 S.D.以上離れた計測値を取り除くスクリーニングをしたものの相関は1.0である(Table 4)。

実際に計測する際には、いくら注意深く計測しても不注意によるミスは避けられないものである。本研究のように極めて類似性の高い集団を分析する際には、このような計測ミスが分析結果に与える影響は大きい。この影響を小さくするためにこのスクリーニングは極めて有効である。同様に、形態的差異の小さい集団を分析する際には計測誤差の影響も無視できない。計測者間誤差の大きい項目を使用して分析すると、集団間の差ではなく、計測者間の差を比較してしまうことになりかねない。日本人の地域性を

分析するような類縁性の高い集団を比較する際 択して分析する方が望ましい。
には、誤差の少なく信頼性の高い項目だけを選

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