ON THE ACCURACY OF PROFILE MEASUREMENTS WITH A PHOTOGRAPHIC PROFILOSCOPE

By P. C. MAHALANOBIS.

Introduction.

In the Galton Laboratory of the University College, London, Professor Karl Pearson had introduced several years ago the drawing of profiles by hand from a shadow thrown on a screen with a powerful lantern placed at a considerable distance from the subject. The usefulness of such profile drawings for anthropometric studies* has been discussed in a number of papers by Professor Pearson and Dr. G. M. Morant and others (1928, 1933, 1934). For some time past I have been experimenting with a photographic method of recording profiles in the hope that such a method would enable the measurements being made with considerable degree of objective reliability. These experiments have now reached a state in which a preliminary note can be published.†

A Photographic Profiloscope.

It is clear that a parallel beam of light will be best for recording profiles. The initial difficulty was to find a source from which the beam of light was sufficiently parallel for this purpose. Ordinary flood-lights and search-lights deviated too much from parallelness to be of any use in this connexion. I then tried to work with a kind of composite fish-eye beam made up of a large number of point sources with small lenses. This had to be given up as the simultaneous focussing of from 30 to 40 lenses was almost impossible. I finally used a long focus lens of a very large diameter with a small electric dental lamp placed at the focus. The actual lens now being used has a focal length of about five feet and a diameter of about 16 inches. It was made at my request by Messrs. Carl Zeiss and Co., and is working satisfactorily in every way. As only a shadow photograph is required, questions of chromatic and spherical aberration are not important. This has made it possible to reduce the cost of the lens, which in fact is quite moderate, and is of the order of about £5.

The actual apparatus was made under the supervision of Mr. Narendra Nath Sen of the Presidency College, Calcutta, and consists essentially of a head piece for fixing the position of the head of the subject and a skeleton camera for holding the dark slides. The photograph is taken directly on a slow bromide paper ; the actual cost of paper is about three annas (four pence) for each subject which is not prohibitive. Another advantage of using slow bromide paper is that the work can be done in semi-darkness. Sketches of the apparatus are given in figures 1 and 2.

The head piece consists of two ear plugs (E_1 and E_2) and a standard length indicator (L. I.) which lies in the plane of the shadow. The camera (C) is simply a frame for holding the dark slides. The head piece is connected with the camera by a cross support S_1. The subject sits in front of the camera, and the ear plug (E_1), which is carried on a flexible brass strip (*b*) connected to the camera is inserted in his left ear-hole. The length indicator (L. I) and the right ear plug (E_2) are carried on a swinging arm (A) which can be lifted clear above the head of the subject and normally rests in this upper position. When the

* The original idea of using silhouettes for anthropometric purposes is, I believe, due to Francis Galton who mentioned it to Karl Pearson in a letter dated September 8, 1907. (Karl Pearson : *Life, Letters and Labours of Francis Galton*, Vol. IIIA, 1930, p. 325).

† This paper was communicated to the Indian Science Congress in 1935.

subject has taken his seat and the left ear plug has been placed in position, the swinging arm is brought down and the right ear plug is inserted into the right ear-hole of the subject, and is snapped into a locked position. The subject can now rotate his head only in a vertical plane. The distance between the two ear plugs can be adjusted by a handle which is screwed in sufficiently to exert a mild pressure on the ears. The length indicator (L. I.) is carried on a support which is geared in a 2 : 1 ratio so that it always lies in the plane bisecting the line joining the two ear plugs, and will thus coincide approximately with the plane passing through the medial section of the nose in which the shadow is photographed. Actual photographs of the apparatus before and after the head piece has been placed on the head of the subject are given below, and will show the working of the instrument.

PHOTOGRAPHIC PROFILOSCOPE.

Fig. 1A. Before Adjustment.

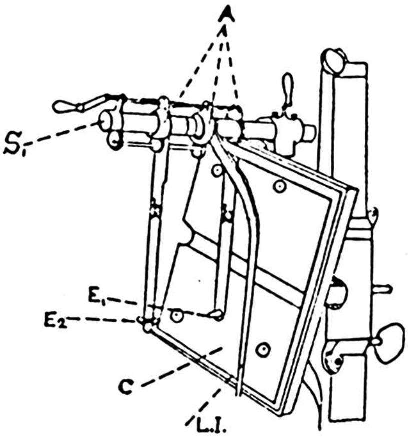

Fig. 2. Sketch of the Apparatus.

Fig. 1B. After Adjustment.

In the standard laboratory model, the source of light, the camera and the head piece are all fixed, but the chair on which the subject is seated can be raised or lowered by a simple hydraulic jack made in the laboratory. This hydraulic lift is connected with the laboratory water tap and works very smoothly.

The whole apparatus is housed in a semi-darkened room, and although the description sounds rather complicated, in actual working, everything is simple and straightforward. In fact it does not usually take more than a couple of minutes to make the subject take his seat, adjust the ear plug and get everything ready for the exposure.

The bromide paper is put into a dark slide, which is simply a shallow tin case closed by a flat shutter fixed to the tray by a single pin. The shutter is drawn out at the time of giving the exposure and is pushed back when the exposure is over. The whole thing costs only about Rs. 2 (3 shillings) to make, and it is convenient in practice to load 10 or 12 of them at a time.

As soon as the head piece and the ear plugs are adjusted and the dark-slide is in position, the ordinary light in the dark room is switched off, and at the same time the small 20 c. p. electric lamp which is worked from eight-volts secondary cells is switched on. The ear plug (E_1), which lies next to the camera has a small hole towards the camera, is also fitted with a small two-volt pea lamp. This pea lamp is switched on at the same time with the source of light for the shadow, and marks in the form of a very small point the exact positon of the ear-hole on the photographic paper. We usually give an exposure of about 2 seconds, but a good deal of variation either way does not appreciably affect the quality of the photograph. Immediately the exposure is over the room light is switched on; the ear plug (E_2) is released from the snap lock plug ; the whole head piece is rotated upon the swinging arm, and the subject gets down from the seat. We have found by experience that it is possible to take from 20 to 25 photographs per hour without any difficulty.

The exposed dark-slides are kept in a light-proof covered tin box, and the exposed papers are usually developed in a batch. There is a small red-light in the dark-room which makes it possible to load the dark slides when necessary even with the subject seated on the chair.

The photographs come out with a very sharp outline and with the position of the ear-hole marked very clearly by a small point. The length indicator has two notches cut exactly at a distance of 4.8 cm. and as these two notches are photographed in the same plane as that of the profile shadow, any change in magnification can be easily detected and corrected for. The photographs are thus practically auto-calibrating. In actual practice however no correction has been found so far necessary.

Control Photographs.

I shall now give the results of the experiments which were carried out to study the degree of reliability with which measurements can be taken on the profile photographs. Three subjects[1] belonging to three different provinces and having widely different types of profiles were selected for this purpose. Each subject was photographed by three observers[2] on three different dates. The reproductions of actual profile photographs given here will show the differences in the types.

The point, O, corresponding to the centre of the ear-hole (which was optically recorded on the photograph), was adopted as the origin. A base line, OP, was then drawn from O to P, the point on the nasal bridge nearest to O, as shown in the reproductions. A second radius was OP_2 where P_2 is the point on the tip of the nose lying furthest from O. P_3 is the point corresponding to the junction of the base of the nose and the upper lip ; P_4, the point corresponding to the junction of the two lips ; P_5 ,the point below the lower lip lying nearest to O and P_6, the point on the chin furthest away from O. We may consider the six radii (1) OP_1, (2) OP_2, (3) OP_3, (4) OP_4, (5) OP_5, and (6) OP_6 as six different characters. For each subject there were nine photographs, and six measurements of the length of the six radii OP_1, OP_2, OP_3, OP_4, OP_5 and OP_6 were taken on each photograph. For each subject, this gave 54 measurements, and for 3 subjects, 162 measurements in all which are given in Table 1. One observer constructed the base line OP_1 (joining ear-hole point to the nearest point on the nasal bridge) independently on all the photographs, and measured the length of the base as well as the length of the other five radii.

The mean value, the range (difference between the largest and the lowest reading), the standard devation, and the coefficient of variation of the measurements for each character based on 9 different readings are given in Table 2.

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[1] The three subjects were all males : (1) J. M. S.—Bengali Hindu, Vaidya caste, born in Dacca, age 30. (2) B. R.—Hindusthani, Rangwa caste; born in Azamgarh, U. P.; age 41. (3) N. R.—Andhra, Brahmin; born in Ganjam, Madras; age 38

[2] The three observers were D. G. (M.Sc. in Physics), S. S. B. (M.Sc. in Physics), and S. S. (M.Sc. in Chemistry) all about 30-31 years of age.

TABLE 1. ACTUAL MEASUREMENTS OF PROFILE DISTANCES.

Subject.	Observer.	Character (Radius Number) 1	2	3	4	5	6
J.M.S.	S. S. B.	9·88	11·94	10·70	10·80	11·20	13·05
		9·84	11·94	10·68	10·80	11·20	13·00
		9·95	12·00	10·70	10·75	11·18	13·04
	S. S.	10·08	12·10	10·82	10·90	11·30	13·02
		9·98	11·98	10·80	10·78	11·10	12·90
		10·02	12·05	10·75	10·85	11·20	13·00
	D. G.	10·08	12·08	10·80	10·92	11·14	12·92
		9·80	11·86	10·54	10·56	11·04	12·80
		9·88	11·90	10·60	10·72	11·08	12·90
N. R.	S. S. B.	9·22	11·42	10·20	10·40	10·78	12·10
		9·26	11·50	10·30	10·58	10·96	12·30
		9·30	11·60	10·38	10·50	11·02	12·40
	S. S.	9·10	11·30	10·06	10·38	10·70	12·02
		9·24	11·52	10·38	10·66	11·00	12·38
		9·28	11·58	10·42	10·75	11·05	12·45
	D. G.	9·20	11·48	10·20	10·60	10·92	12·21
		9·20	11·46	10·30	10·60	10·90	12·30
		9·16	11·46	10·24	10·60	10·92	12·28
B. R.	S. S. B.	9·60	11·30	10·14	10·48	10·30	11·04
		9·66	11·36	10·22	10·54	10·46	11·12
		9·40	10·98	9·85	10·15	10·00	10·75
	S. S.	9·82	11·50	10·32	10·60	10·42	11·02
		9·82	11·40	10·22	10·54	10·22	10·90
		9·54	11·12	10·00	10·20	10·00	10·78
	D. G.	9·50	11·06	9·90	10·02	9·94	10·66
		9·38	10·98	9·80	10·20	10·10	10·82
		9·32	11·00	9·86	10·20	10·10	10·82

TABLE 2. MEAN. VALUES AND VARIABILITIES ($n=9$).

Subject	Statistics	Character (Radius Number) 1	2	3	4	5	6
J. M. S.	Mean	9·95	11·98	10·71	10·79	11·16	12·97
	Range	0·28	0·24	0·28	0·36	0·26	0·19
	S. D.	0·10	0·08	0·09	0·10	0·07	0·07
	C. V.	0·97	0·64	0·84	0·94	0·67	0·51
N. R.	Mean	9·22	11·48	10·26	10·56	10·91	12·28
	Range	0·20	0·30	0·36	0·37	0·35	0·43
	S. D.	0·06	0·08	0·11	0·11	0·11	0·13
	C. V.	0·63	0·73	1·04	1·06	0·98	1·06
B. R.	Mean	9·56	11·19	10·08	10·33	10·71	10·88
	Range	0·50	0·52	0·52	0·58	0·52	0·46
	S. D.	0·17	0·29	0·18	0·20	0·18	0·14
	C. V.	1·81	1·37	1·82	1·94	1·67	1·32

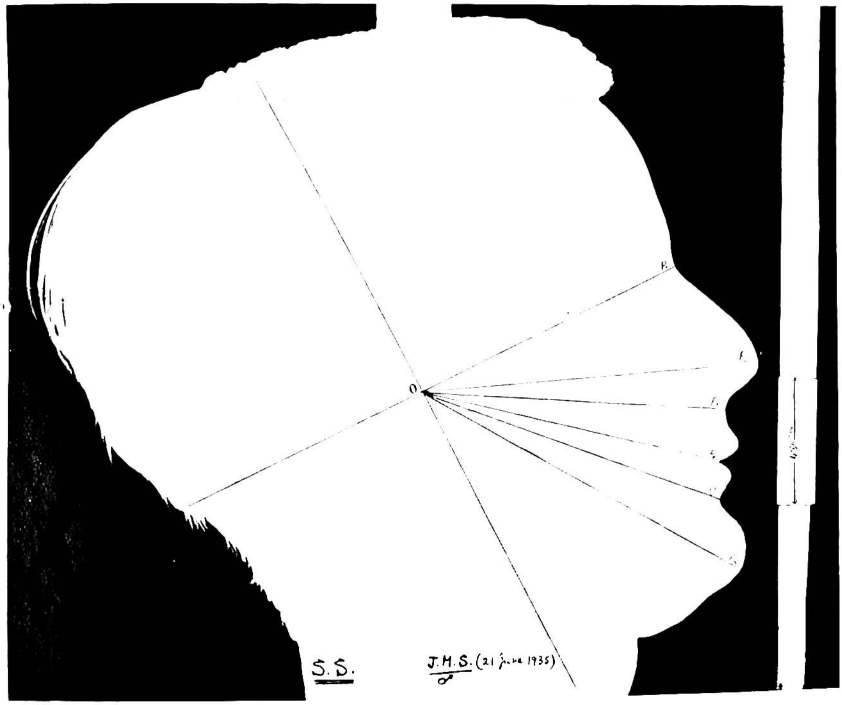

PLATE 1.

Subject : J. M. S.
Observer : S. S.
Reduction : ×0·432

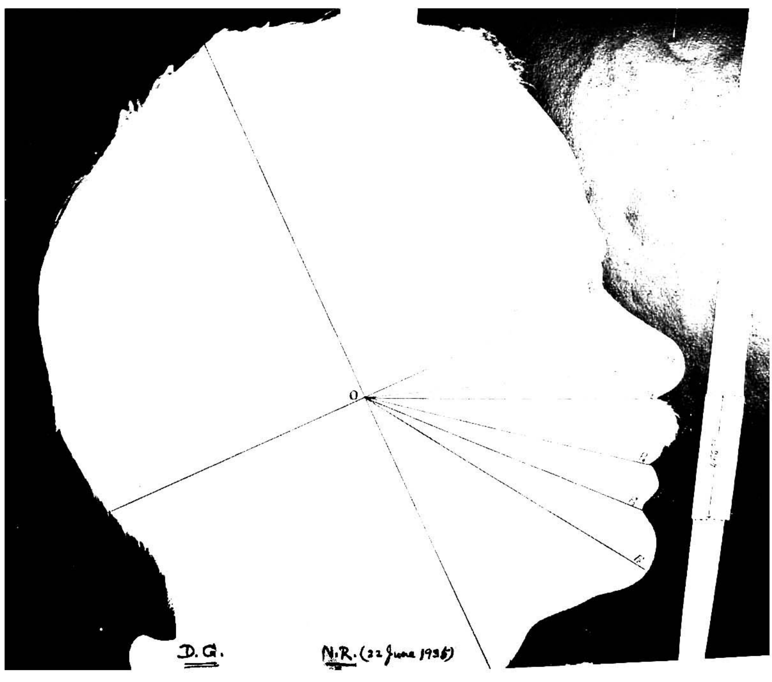

PLATE 2.

Subject : N. R.
Observer : D. G.
Reduction : ×0·444

Statistical Laboratory, Calcutta.

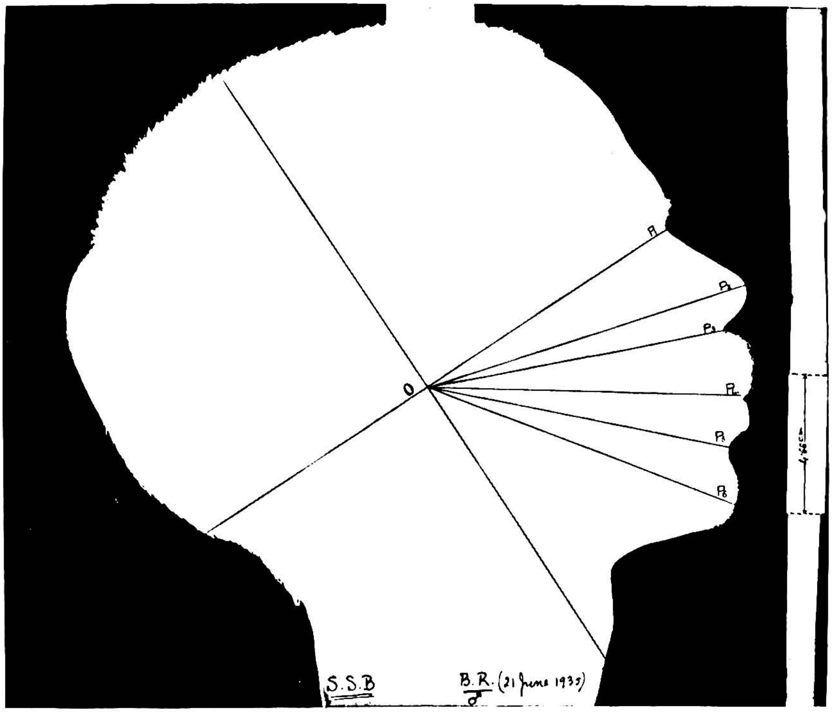

PLATE 3.

Subject : B. R.

Observer : S. S. B.

Reduction : ×0·466

PLATE 4.

Subject : G. S.

Reduction : ×0·440

Reliability of Measurements.

One point may be noticed at once directly from this table. The variability of the readings differ for the different subjects, and was lowest for J. M. S. who it will be seen from (Plate 1) had the sharpest profile, and greatest for B. R. (Plate 3) who had the most blunt outline of face.

The readings in the case of J. M. S. varied from about 1 in 60 to about 1 in 30. For B. R. the variation was greater, from about 1 in 17 to 1 in 23. Speaking generally the maximum discrepancy between repeated single readings on photographs by independent observers was roughly of the order of 1 in 30. The coefficient of variation however gives a more useful measure of the variability of the readings. In the case of J. M. S. the average coefficient was about 0.76, showing that two independent readings on the same character by different observers were likely to differ for this subject by about 1 in 132. For N. R. the discrepancy was of the order of 1 in 109, while for B. R. it was considerably higher and was of the order of 1 in 60. The average coefficient of variation for all three subjects taken together was 1.11. We may conclude therefore that the average degree of precision attained in the present set of measurements was of the order of about 1 in 90 or just over one per cent.

This I think is not altogether unsatisfacory. In actual anthropometric investigations we shall almost always use mean values based on at least 40 or 50 individual photographs. When the size of the sample is of the order of 50, mean values based on profile photographs taken and measured by different observers are not likely to be affected by errors in measurement by more than say one-sixth or one-seventh of one per cent. Even for samples of the order of 20, the errors in measurements are likely to be less than say a quarter or a third of one per cent. It may be claimed therefore that measurements on photographs taken with the profiloscope will have a sufficiently high degree of objective reliability to enable them being used in anthropometric investigations with confidence.

Personal Equations.

The material given in Table 1 can be used with advantage to study a number of interesting questions regarding personal equations in observation. The complete analysis of variance for the whole set of 162 measurements is given in Table 3.

Table 8. Analysis of Variance

Factor of Variation	D.F.	Sum of Squares	Mean Square	Ratio of Variances	
				Observed	One per cent
Character	5	104·7192	20·9438	1662·2068	3·205
Subject	2	21·8227	10·9114	865·9844	4·824
Observer	2	·4633	·2317	18·3889	4·824
Character × Subject	10	11·4144	1·1414	90·5873	2·503
Character × Observer	10	·0653	·0065	·5159	2·503
Subject × Observer	4	·3363	·0841	6·6746	3·513
Character × Subject × Observer	20	·3617	·0181	1·4365	2·067
Total	53	139·1829	2·6261	268·3207	1·425
Residual	108	1·8571	·0126		
Total	161	140·5400			

The difference between the different characters and the different subjects are of course quite objective, and these two factors naturally absorb the largest part of the total sum of squares of deviations. The inter-action between "character" and "subject" is also definitely significant. This shows that the relative size of the different characters were quie different for the different subjects. In other words, apart from differences in size, the shape of the profile was also different for the different subjects.

Diffrences between observers were quite significant showing that the personal equation of the three observers were not equal, a result not altogether unexpected as individual peculiarities in this matter have been known to be in existence for a long time in the classical Theory of Errors. The inter-action between "character" and "observer" is inappreciable showing that the observers did not differ in their relative accuracy when making measurements on different characters. This is satisfactory. The inter-action between "subject" and "observer" however is not insignificant. This shows that the relative accuracy of measurements by the different observers was influenced by the subject under measurement. The second order inter-action between "character" and "subject" and "observer" is insignificant, which shows that in the present set of experiments there was no differential inaccuracy in measurement due to differences in the shape of the profiles.

We may now consider in greater detail the differences in the accuracy of measurement of the different observers, as well as the influence of the subject on the accuracy of measurement by different observers. The mean values for the different observers are given in Table 4, and the analysis of variance for the measurements by each of the observers is shown separately in Table 5.

TABLE 4. MEAN VALUES.

		1	2	3	4	5	6
J. M. S.	D. G.	9·92	11·95	10·65	10·73	11·07	12·89
	S. S. B.	9·89	11·96	10·69	10·78	11·19	13·03
	S. S.	10·03	12·04	10·79	10·84	11·20	12·97
N. R.	D. G.	9·19	11·47	10·25	10·60	10·91	12·29
	S. S. B.	9·26	11·51	10·29	10·49	10·92	12·27
	S. S.	9·21	11·47	10·29	10·60	10·92	12·28
B. R.	D. G.	9·40	11·01	9·85	10·14	10·05	10·77
	S. S. B.	9·55	11·21	10·07	10·39	10·25	10·97
	S. S.	9·73	11·34	10·18	10·45	10·21	10·90

TABLE 5. MEAN SQUARE: OBSERVER.

	D.F.	D.G.		S.S.B.		S.S.		1 per cent Ratio of Variances
		Mean Square	Ratio	Mean Square	Ratio	Mean Square	Ratio	
Between Characters	5	7·0603	954·1	7·2278	425·2	6·6688	287·5	3·627
Between Subjects	2	4·5468	614·4	3·2625	191·2	3·2701	140·9	5·308
Interaction	10	0·3647	49·3	0·3679	21·6	0·4450	19·2	3·018
Residual	86	0·0074	—	0·0170	—	0·0232	--	—

Differences between characters, subjects, and the inter-action between characters and subjects (differences in the shape of profiles), are of course all definitely significant. Eliminating the effect of such differences, it will be seen that the residual variances for the three observers are quite dfferent. If we use the residual standard deviation as a convenient measure of the limit of accuracy attained by each observer, we find that this was of the order of about 0.08 cm. for D. G., 0.13 cm. for S. S. B. and 0.15 for S. S. Taking all the measurements into consideration D. G. was thus almost twice as accurate as S. S. Such large fluctuations in the accuracy of measurements between different observers deserve more careful study.

The analysis of variance is shown separately for the measurement for the different subjects in Table 6.

TABLE 6. MEAN SQUARE: SUBJECT.

	D.F.	J.M.S.		N.R.		B.R.		1 per cent Ratio of Variances
		Mean Square	Ratio	Mean Square	Ratio	Mean Square	Ratio	
Between Characters	5	10·2536	1530·3	9·8929	672·9	3·1305	119·5	3·627
Between Observers	2	0·0523	7·7	0·0005	0·03	0·3464	13·2	5·308
Interaction	10	0·0045	0·7	0·0040	0·3	0·0092	0·3	3·018
Residual	36	0·0067	—	0·0147	—	0·0262	—	—

Differences between characters are of course significant and merely show that the different radii differed widely in size. For two subjects, J. M. S. and B. R., differences between observers are also significant, showing that the observers differed appreciably in their relative accuracy of measurement on these two subjects. For one subject (N. R.) all the observers agreed in their measurements closely. The inter-action between character and observer, as already noted in connexion with Table 3, is negligible in every case. We also find that the residual error was lowest in the case of J. M. S. and highest in the case of B. R.—a point already noted in connexion with Table 1. Apparently measurements were considerably more precise on J. M. S. than on B. R. The character of the profile has probably something to do with such differences in the reliability of measurements.

It is worth noting however that there are considerable differences between the three observers regarding the relative accuracy of measurement on the three different subjects. The residual variances are collected together in Table 7 in a convenient form for comparison.

TABLE 7. RESIDUAL VARIANCES BETWEEN THE OBSERVERS.

Observers	Mean Variance (Residual)			
	J. M. S.	N.R.	B. R.	Pooled Variance
D. G. ..	·0148	0006	·0068	·0074
S. S. B. ..	·0010	·0108	·0391	·0170
S. S. .	·0042	·0826	·0328	·0232
Pooled Variance	·0067	·0147	·0262	·0126

For measurements on J. M. S., both S. S. B. and S. S. show far higher precision than D. G. This is however reversed in the case of N. R. and B. R. for both of whom D. G. shows the highest precision while the other two show considerable discrepancies in their measurements. The differential effect of the nature of the profile on the accuracy of measurements is probably a complicated one. The effect of the same profile on different observers is not identical. With a clear profile like that of J. M. S. two observers attained greater consistency while the other was more confused.

SUMMARY.

A new apparatus for taking silhouette photographs of profiles is described in this paper. The accuracy of measurements on profile photographs was investigated by choosing three subjects with widely differing types of profiles and taking nine profile photographs of each subject, three by each of three different observers. Using the centre of the ear-hole (the position of which was optically recorded on the profile photograph) as origin the length of six different radii were measured on each photograph. This gave 162 measurements in all for 6 characters for 3 subjects on profile photographs taken by 3 different observers.

The measurements were then compared in detail by the method of analysis of variance.

(1) The maximum discrepancy between single reading of the same character was of the order of 1 in 30.

(2) The average coefficient of variation of the same reading was about 1.1 per cent. which shows that the average degree of precision was of the order of 1 in 90.

(3) The accuracy attained by different observers varied widely. Measurements taken by one observer were about twice as accurate as measurements taken by another observer.

Inspite of differences in the personal equation of the three observers the precision and stability of the measurements were remarkably high.

(4) The relative accuracy of measurements by different observers differed for different subjects, showing that the type of the profile had some influence on the precision of the measurements.

(5) The relative accuracy of the observers remained however about the same when making measurements on different characters.

Individual meatsurements of the same character in the same subject by different observers are not likely to differ by more than one per cent. on an average, and not more than say five or six per cent. in extreme cases. For comparisons of group mean values based on measurements of from 25 to 50 individuals the observational errors are likely to be reduced to the order of about a fifth of one per cent. on the average or at least to one per cent. in extreme cases. The photographic profiloscope may therefore be used with confidence as an instrument of precision for comparative studies in anthropometry.

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