AN INTRODUCTION TO THE STUDY OF

SKELETAL CORRELATIONS

IN THE N.Z. ROMNEY MARSH.

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PART 1

PART 11

P A R T   1.

FOREWORD.

When this work was undertaken it was quite impossible
to have anticipated the difficulties that were encountered. It
soon became apparent however, that the approach to a new study
involved a great deal of work of a collateral nature, having
little direct bearing on the actual object of the investigation.
In particular it was necessary to become generally familiar
with vcertain branches of statistical method and to become
very fully acquainted with the real signigifance of certain
mathematical devices.

Statistical studies consumed the greater proportion of the
time available for this work with the result that only a portion
of the information contained in the data could be extracted.
Indeed, a complete analysis of the data collected and recorded,
using the methods evolved in this paper, would itself involve
many months' work.

However, since the development of the analytical
methodology has no direct bearing on the subject of skeletal
correlations the paper has been divided into two parts.

Part 1 deals with the measurements made and the interpretation
and discussion of the correlation coefficients that were
calculated.

In Part 11 has been collected, all those considerations
which were essentially incidental to the investigation - that is,
selection of material technique of measuring etc. and in
particular, the discovery of appropriate analytical devices
for treating the data.

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INTRODUCTION.

Correlation may be defined as the degree of inter-relationship that exists between any two variables and it is measured by a mathematical device which expresses the tendency of the two variables to fluctuate in sympathy. This means, in the present work, the interrelationship between the size or shape of one portion of the sheep's skeleton and the size or shape of another portion and the extent to which variations in one portion are attended by variations in another.

Correlation relating to the sheep has been regarded as divisible into two types -

(a) Correlation of external with internal characters - that is, correlation between conformation and such characters as fattening qualities, constitution etc.

(b) Correlation between various external characters, that is, relating to the relationships between the portions of the sheep's skeleton which together constitute what is known as conformation. This paper deals with this type of correlation and seeks to discover whether there is any relationship between the sizes of such portions, e.g. length of head and the length of pelvis, etc.

A knowledge of correlations of both types forms part of the "stock-in-trade" of the breeder and breed standards in regard to conformation,are defined by breed societies on the basis of supposed correlations of type (a) above. It is probable that this standard type defines with fair accuracy, the ideal sheep from the utility point of view and it most certainly does so to a much greater extent than do the so-called "perfect types" of dairy cattle defined by their respective breed societies. It would, perhaps, be desirable that a scientific investigation be undertaken with regard to this type of correlation in sheep with a view to defining type standards of

excellence with greater accuracy, but it was felt that, at present, the greater service to breeders would be provided by information on the relationships between the component parts of the skeleton as measurable on live sheep. It was hoped that this would assist the breeder to attain the standard laid down by the breed society - a standard which, probably, would not be greatly modified by a scientific investigation of the nature of that mentioned above.

A series of measurements were made on twenty Romney ewes from the Massey Agricultural College wool experimental flock and the data so obtained subjected to appropriate mathematical analysis.

The measurements were, in themselves, a matter of considerable difficulty and it was discovered that a great deal depended on the skill of the investigator. The difficulty of measuring live sheep will be quite apparent and considerable care and patience was necessary in order to attain a reasonable degree of accuracy.

The selection of appropriate mathematical devices for the analysis of the data also required lengthy consideration. The value of statistical method applied to biological data is the subject of considerable controversy and there is no doubt that arbitrary/methodology can be legitimately applied to such
analytical
data, only when due regard is paid to the possible limitations of the methods employed. It is essential to remember that mathematical methods can only be regarded as convenient modes of expression, not as infallible devices for discovering natural laws. Utter familiarity with the data is a prerequisite to successful deductions from the results of mathematical analysis. It was necessary, therefore, to obtain an understanding of the more common statistical devices and an understanding of the information contained in the data collected, in order to select from the former, the method which most accurately expressed the facts contained in the latter.

When an endeavour was made to fulfil the intentions
expressed in the above paragraph, it was soon discovered that
the matter was going to involve a great deal of study on
questions with no direct bearing on skeletal correlations.
It was realised that the limitations attendant on the application
of mathematics to livestock work were very real and further, there
is the feeling that many research workers in Animal Husbandry
have either been unaware of those limitations or have preferred
to accept such methods/superficially spectacular results.
                    in order to produce
In this work,the choice had to be made whether methods should
be adopted with no more than a cursory enquiry as to their
value or whether a vast amount of time was to be spent in the
study and consideration of the applicability of the simpler
statistical devices to the material in hand. Further, the
fact was fully appreciated that such study might do no more than
confirm conclusions reached in a much more casual manner and
in this event, the only return for the work would be an
increased understanding of the matter by the author.

On the other hand, the scientific investigation of
skeletal relationships in sheep is an entirely new field of
research and it was felt, that the only course to pursue was
one which would ensure that a firm foundation was laid for
future work by a thorough examination of the analytical
methodology.

The scope of this work was also restricted to some extent,
by the fact that in many cases it is impossible to express in
precise terms of measurement all that is apparent to an expert
judge of sheep. For example, a judge may see in the facial
expression of an animal, indications of a lack of robustness
which will enable him to forecast with considerable accuracy,
the weaknesses of general conformation to be expected; again
a look of"nervous excitement" is frequently seen in animals of
poor fattening ability., Such indefinableimpressions would
obviously be obtained only by expert observers and it would
be quite impossible to express them in mathematical terms.

When all the measurements had been made, an enquiry was undertaken with a view to discovering the more common beliefs held by breeders relating to correlations. This enquiry was postponed until after the completion of the measurements because it was realised that preconceived ideas may often unconsciously bias an investigator in a particular direction. The aim of this work is neither to prove nor to disprove beliefs current among breeders but to approach the question with an open mind, unbiased by expected relationships.

THE MEASUREMENTS.

In the majority of cases, the measurements will require no more description than the names and the numbers which refer to the diagrams. The difficulties/have been discussed in Part 11 encountered in making the measurements and in few cases, will additional remarks be necessary.

Figs 1 and 11 show the outline of a shorn ewe from the side and from the front; the reference points are shown by numbers. In order to avoid the confusion of too much detail on one diagram, a separate sketch (Fig 111) is given of the skeleton of a sheep, the actual points of reference being enclosed by small red circles. This sketch is not intended to be beyond criticism but is sufficiently accurate to show the position of reference points.

1. Width of Nose. Fig. 11. a ----- a.

In such small measurements as this, it is apparent that a very small actual error would be a large relative error. Actually this measurement was comparatively easy to make but most measurements of this size are not regarded with confidence.

2. Width between eyes; Fig 11; b ---- b.

3. Width of (outside) eye-setting Fig 11; c---c.

4. Width between ears. Fig. 11; d --- d.

This measure was made immediately in front of the ears.

5. Width between shoulders points Fig 11; e --- e.

This was a fairly difficult measurement to make and is therefore less reliable than most.

NOTE: The remainder of the measurements and their reference numbers are all to be found on Figs. 1 and 111.

6. Width between jaw points - point 5A on each side.

7. Length of face; 1 --- 2.

o 8. Length of head; 1 --- 4.

9. Length of lower jaw; 5 --- 6.

10. Poll to jaw angle; 3 --- 5A.

11. Length of neck; 4 --- 7.

This measurement was attempted but it was found quite impossible to obtain reliable results.

12. Length of shoulder-blade (scapula); 11 --- 12.

13. Breadth of scapula; 11 --- 17.

This measurement also proved unreliable owing to lack of clear definition of the posterior border of the blade, due to the fact that it was held so closely to the body.

14. Length of humerus; 12 --- 13.

It will be seen that this measurement actually includes more than the humerus proper as it is made to the point of the elbow (olecranon process) as indicated in the diagram.

15. Length of radius; 13 --- 14.

Strictly speaking this portion contains two bones, the radius and the ulna; the olecranon process (point 13) being part of the latter.

16. Length of fore-cannon; 14 --- 15.

This really includes the carpal bones of the joint. It would have been preferable for point 14 to be below rather than above the carpals but a more clearly defined point of reference was obtained in the position indicated.

17. Length of fore-pastern; 15 --- 16.

Not only was this measurement small (see remarks on width of nose) but also was very difficult to make. For similar reasons an attempt to measure pastern slope was also unsuccessful.

o 18. Length of pelvis (Hook to pin) 20 --- 22.

19. Hook to thurl 20 --- 21.

20. <u>Thurl to pin; 21 --- 22.</u>

A clearly defined point at the thurl (acetabulum) was difficult to obtain for the above two measurements and no great confidence should be placed in them.

21. <u>Length of femur 21 --- 23.</u>

The thurl point was easier to locate from this angle.

22. <u>Length of tibia; 23 --- 24.</u>

This is of the same type as the humerus etc. - the measuremen is named according to the principal bone but really includes more.

23. <u>Length of hind cannon 24 --- 25.</u>

24. <u>Length of hind pastern; 25 --- 26.</u>

This measurement like "fore pastern" was quite unreliable.

25. <u>Length of thoracic vertebrae; 7 --- 9.</u>

26. <u>Length of loin; 9 --- 10.</u>

27. <u>Body depth; 8 --- 19.</u>

Point 19 was located between the legs on the brisket.

28. <u>Wither height; ground level to 8.</u>

During all measuring the sheep were standing on a concrete floor.

29. <u>Shoulder point to last rib; 12 --- 27.</u>

30. <u>Body width (at girth); 18.</u>

That is, the width through the body at point 18.

31. <u>Body width (at last rib) 27.</u>

For obvious reasons this will be less reliable than the measurement immediately above.

32. <u>Width of loin (front) at point 9.</u>

33. <u>Width of loin (rear).</u>

This measurement was made immediately in front of the hooks.

34. <u>Width between hooks.</u>

This was taken from the outside boundary of each hook (point 20).

35. <u>Width between pins.</u>

This measure was not easy to make and was taken between the most posterior "points" of the pin bones (22).

36. Girth.

Taken behind the elbow.

37. Height to hook; ground level to 20.

38. Height to pin; ground level to 22.

39. Body Length; 12 --- 22.

40. Angle of hook.

This is the angle enclosed by the points 23 to 24 to 25. This measure is recorded but it is not felt that it can be relied on to any great extent but would be useful only in indicating future lines of investigation.

41. An endeavour was made to secure some expression of the development of the brisket but no reliable measure could be found.

42. It is necessary also that some method be evolved for measuring slopes (e.g. pelvis, shoulder, etc.) which will give reliable results. The method employed in this paper, although probably more accurate than direct measurement, is not considered to be entirely satisfactory.

THE MEASUREMENTS.
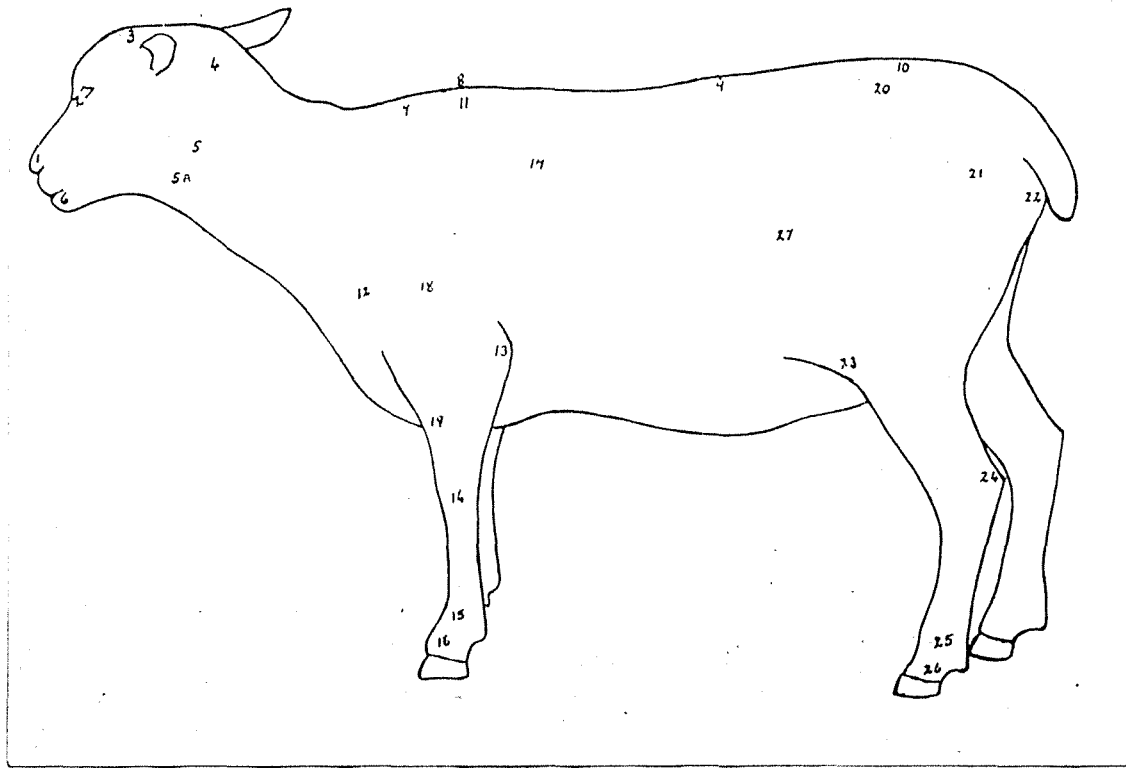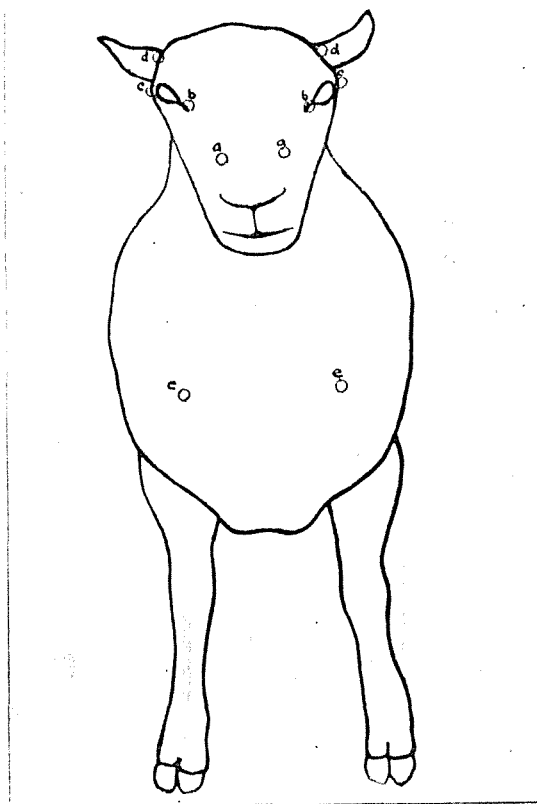
FIG 1

FIG. 11

THE MEASUREMENTS.

FIG 111

[ALL SKETCHES BY AUTHOR.]
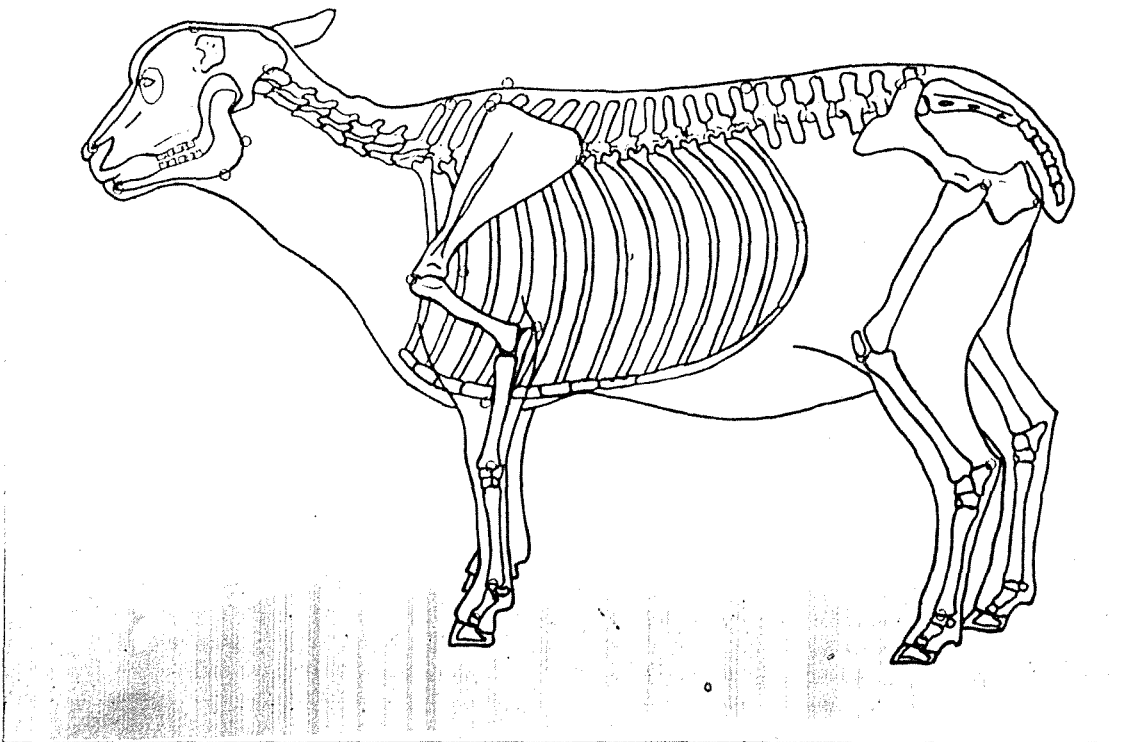
MEASUREMENTS.	893	E37	E676	743	E558	E544	x921	E20	E589	E168	E240	E10	E119	E36	E886	E25	E184	1076	E564	E11
1. Width of nose	2.1	2.0	2.0	2.2	2.2	2.1	2.0	2.1	2.0	2.1	1.9	2.1	2.0	2.1	2.1	2.0	2.0	2.0	2.0	2.2
2. Width between eyes	2.2	2.7	2.7	2.8	3.2	2.8	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.8	2.8	2.8	2.7	2.6	2.8	2.7
3. Width outside eye-setting	4.8	5.3	4.9	5.3	5.3	5.0	5.1	5.2	5.2	5.3	5.1	5.0	5.2	5.2	5.2	5.2	5.1	5.2	5.0	5.0
4. Width between ears	3.8	3.9	3.8	4.1	3.9	4.0	3.7	4.2	4.0	4.0	3.9	4.0	4.1	3.8	3.9	4.1	3.8	3.9	4.2	3.8
5. Width between points of jaw	3.6	3.4	3.7	3.8	3.6	3.5	3.6	3.3	3.6	3.5	3.2	3.5	3.3	3.2	3.6	3.8	3.3	3.7	3.8	3.6
6. Length of face	5.1	5.3	4.8	5.3	5.5	5.2	4.7	5.4	4.9	5.1	5.1	5.3	5.1	5.2	5.2	5.2	4.7	4.9	5.1	5.3
7. Length of head	9.8	10.0	9.6	10.3	10.3	10.1	9.4	10.4	9.6	10.3	9.6	10.1	9.6	10.1	10.2	10.0	9.5	9.8	10.1	10.3
8. Length of Lower Jaw	7.3	8.2	7.4	7.7	7.8	7.7	7.7	7.9	7.6	7.6	7.7	7.4	8.0	7.6	7.9	7.7	7.7	7.7	8.0	7.8
9. Poll to jaw angle	5.8	6.1	6.0	6.2	6.0	5.8	6.0	6.3	6.0	5.7	5.9	5.8	5.9	5.8	6.0	6.0	5.8	6.1	6.0	6.0
10. Length of shoulder blade	8.3	8.2	8.1	8.9	8.4	8.2	8.0	9.0	8.5	8.3	8.0	8.5	8.0	8.4	8.8	8.2	8.2	8.2	8.6	8.3
11. Length of humerus	6.9	6.7	6.3	7.1	6.9	7.1	6.9	6.9	7.0	6.9	6.7	6.9	6.3	7.0	6.5	6.8	7.3	6.8	7.2	7.3
12. Length of radius	7.0	7.7	7.3	7.9	7.7	7.8	7.1	7.7	7.2	7.7	7.2	7.3	7.3	7.3	7.8	7.6	7.4	7.4	7.9	7.3
13. Length of fore-cannon	5.0	5.4	4.8	5.3	5.3	5.5	5.3	5.5	5.3	5.2	5.1	5.3	5.1	5.3	5.5	5.3	5.2	5.3	5.4	5.5
14. Length of pelvis	8.7	9.3	9.0	9.2	9.2	9.0	8.9	9.8	8.8	9.1	8.9	9.4	8.8	9.1	9.3	9.1	9.2	9.1	9.8	9.5
15. Hook to thurl	4.8	5.0	4.5	5.0	5.2	5.0	-	5.2	4.5	5.1	4.3	5.0	4.8	5.3	5.2	5.2	5.2	5.5	5.1	5.0
16. Thurl to pin	4.8	4.7	4.6	5.0	5.2	5.0	4.6	5.0	4.6	5.1	4.4	5.0	4.4	4.8	5.0	4.7	4.8	4.8	5.2	5.0
17. Length of femur	7.3	7.8	7.5	7.2	7.4	7.6	7.4	7.8	7.3	7.4	7.3	7.2	6.8	7.7	7.9	7.8	7.7	7.4	8.1	7.6
18. Length of tibia	10.0	10.4	10.3	10.3	10.3	10.3	10.0	10.7	9.7	10.2	9.6	9.9	9.3	10.2	10.3	10.4	10.0	10.0	10.8	9.7
19. Length of hind cannon	5.8	6.2	5.8	6.1	6.3	6.4	6.2	6.3	6.2	6.1	6.2	6.3	5.7	6.5	6.2	6.2	5.8	6.1	6.4	6.1
20. Length of thoracic vertebrae	9.5	10.7	9.9	11.8	9.8	10.7	9.8	10.9	10.6	10.2	10.6	10.0	10.3	10.0	10.0	10.3	10.6	10.9	10.8	10.6
21. Length of loin	7.8	8.1	7.4	8.3	8.2	7.8	7.5	8.0	8.3	7.8	7.4	8.6	7.8	7.7	7.8	8.5	7.6	7.5	8.2	7.6
22. Body depth	11.4	12.0	11.5	12.3	11.9	12.1	11.5	13.0	11.8	12.2	12.0	11.8	11.7	12.2	11.8	12.3	12.2	12.1	11.9	11.8
23. Wither height	23.9	25.0	23.7	24.7	24.4	24.1	22.2	25.8	24.5	24.1	24.8	24.9	23.4	23.9	25.2	24.8	23.1	24.8	25.1	25.6
24. Shoulder pt. to last rib	13.5	14.0	14.0	14.6	13.7	13.5	13.7	14.3	13.8	14.0	14.2	13.0	13.2	13.8	14.5	14.4	14.0	14.0	14.6	14.3
25. Width between shoulder pts	7.6	7.5	7.2	7.7	8.2	7.4	7.0	7.6	7.8	7.6	7.8	7.6	7.2	7.4	7.6	6.9	7.0	7.3	7.8	7.7
26. Width of body, (girth)	7.3	7.2	6.9	7.2	6.8	7.2	6.5	6.9	6.8	8.2	7.1	7.4	6.8	7.0	7.8	7.6	7.4	7.2	7.3	7.8
27. Width of body (last rib)	10.3	10.5	10.7	9.6	9.8	9.7	9.4	11.5	9.0	10.7	10.5	10.3	10.3	10.7	10.6	10.6	10.1	10.5	10.2	10.6
28. Width of loin (front)	4.7	5.2	5.0	5.1	5.0	5.2	4.4	5.3	5.0	5.3	4.9	5.0	4.9	5.3	5.9	5.0	5.0	4.9	5.0	5.0
29. Width of loin (rear)	5.3	6.2	5.8	6.1	6.0	6.2	5.5	6.3	6.0	6.3	6.2	6.1	6.1	6.0	6.9	6.2	6.0	6.0	6.1	6.3
30. Width between hooks	7.9	8.3	8.2	7.8	7.9	8.0	7.4	8.2	7.7	7.9	7.6	7.8	7.8	7.7	8.2	8.2	8.0	7.9	8.2	7.9
31. Width between pins	2.7	2.5	2.8	2.4	2.7	2.4	2.5	2.4	2.2	2.4	2.3	2.6	2.2	2.5	2.4	2.3	2.3	2.2	2.3	2.7
32. Girth.	34.0	33.8	33.3	34.8	33.4	34.2	30.8	34.5	33.5	36.0	33.2	33.5	34.0	34.0	35.3	35.8	34.3	34.2	35.3	34.5
33. Height to hook	24.4	25.3	24.7	24.6	25.4	25.0	24.3	26.6	25.5	25.0	24.8	24.9	23.4	24.2	25.2	25.2	23.9	24.2	25.8	24.5
34. Height to pin	19.7	22.0	20.4	21.8	20.3	20.5	20.1	20.8	21.2	20.6	20.2	19.7	18.4	19.8	20.2	19.8	19.4	20.8	21.3	19.5
35. Body length	26.0	29.2	27.5	30.0	29.0	28.7	27.8	29.0	27.2	28.7	27.2	28.0	27.1	28.7	29.1	29.2	28.2	28.2	30.0	28.8
36. Angle of hock (in degrees)	122	133	128	122	131	128	120	127		131	125	122	132	125	127	123	118	133	124	
37. Size index	27.1	28.3	27.3	28.5	28.1	28.0	26.3	29.0	27.7	28.5	27.5	27.8	27.0	27.7	28.7	28.8	27.4	27.9	29.1	28.4

THE RESULTS.

It is apparent that the maximum number of correlation coefficients that could be calculated from the data collected, would number many hundreds and since the time involved in the preliminary work was so great it was, unfortunately, necessary to limit the number of coefficients calculated.

As was mentioned earlier in this paper, an enquiry was made to discover the more common opinions held by breeders in regard to skeletal correlations. As a result of this enquiry, it appeared that the majority of ideas were concerned with the relation of various parts of the body to the length of the cannon and to head measurements.

It seemed appropriate, therefore, in selecting the limited number of coefficients to be calculated at present, to compute those which were apparently of greatest interest to breeders, viz. those relating to the cannon and to head measurements.

The general principles involved in the interpretation of the coefficients, are discussed in those sections (Part 11) which concern the development of suitable analytical devices for treating the data. The application of these principles to particular cases will not, therefore, require to be considered here in detail.

The results are summarised in tabular form below. As discussed in Part 11 the significance of a correlation coefficient depends on its relation to its probable error and in this work a simple expedient was adopted to save time from unnecessary calculation. As a result, the lowest significant coefficient was found to be ± 0.47. The effect of error of measurement is, however, to reduce the coefficients below their true value; it will be seen in the discussion that for this reason, coefficients smaller than ± 0.47 are regarded as significant.

TABLE 1.

CORRELATION COEFFICIENTS (r) BETWEEN "THE SIZE
INDEX" AND VARIOUS MEASUREMENTS; WITH THE PERCENTAGE
INDEPENDENT VARIABILITY (P.I.V.) OF THE LATTER.[+]

MEASUREMENT	r.	P.I.V.
(1) Length of head	+0.81	59%
(2) Length of face	+0.62	79%
(3) Width (outside) eye-setting	+0.33	94%
(4) Width between ears	+0.65	76%
(5) Poll to jaw	+0.36	93%
(6) Length of fore-cannon	+0.59	81%
(7) Wither height	+0.82	57%
(8) Body Depth	+.62	78%
(9) Length of shoulder-blade	+0.67	74%
(10) Shoulder slope	-0.30	95%
(11) Girth	+0.79	61%
(12) Length thoracic vertebrae	+0.47	88%
(13) Width body (at girth)	+0.54	84%
(14) Width body (at last rib)	+0.39	92%
(15) Height to hook	+0.69	72%
(16) Hind cannon	+0.47	88%
(17) Body length	+0.78	62%
(18) Length of pelvis	+0.75	66%
(19) Length of loin	+0.49	87%
(20) Width between hooks	+0.66	75%
(21) Pelvis slope	-0.02	100%
(22) Ratio head length to width of (outside) eye-setting	+0.44	89%

+ The "percentage independent variability" is obtained by
using Sumner's factor (see Part 11).

TABLE 11.

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN
"LENGTH OF FORE CANNON" AND OTHER MEASUREMENTS.

MEASUREMENT.	GROSS r.	NET r.
(1) Length of face.	+0.48	+0.18
(2) Length of head	+0.59	+0.24
(3) Poll to jaw	+0.27	+0.08
(4) Length of pelvis	+0.60	+0.30
(5) Length of hind-cannon	+0.69	+0.58
(6) Length of thoracic vertebrae	+0.39	+0.16
(7) Length of loin	+0.33	+0.06
(8) Body depth	+0.47	+0.16
(9) Wither height	+0.52	+0.08
(10) Width body (at girth)	+0.22	-0.15
(11) Width body (at last rib)	-0.01	-0.32
(12) Width between hooks	+0.18	-0.35
(13) Girth	+0.25	-0.44
(14) Width of (outside) eye setting	+0.34	+0.19
(15) Body Length	+0.66	+0.40
(16) Pelvis slope	-0.03	-0.02
(17) Shoulder slope	-0.13	+0.06

TABLE 111.

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN
"LENGTH OF HEAD" AND OTHER MEASUREMENTS.

Measurement	Gross.r	Net.r
(1) Length of face	+0.84	+0.73
(2) Body depth	+0.51	+0.02
(3) Width body (at girth)	+0.48	+0.09
(4) Width body (last rib)	+0.36	+0.08
(5) Shoulder slope	-0.28	-0.07
(6) Pelvis length	+0.64	+0.10

TABLE 1V

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN
"WIDTH OF (OUTSIDE) EYE-SETTING" AND OTHER
MEASUREMENTS.

Measurement	Gross r.	Net r.
(1) Width between ears	+0.28	+0.09
(2) Width body (at girth)	+0.02	-0.20
(3) Width body (at last rib)	-0.01	-0.16
(4) Width between hooks.	-0.02	-0.34

TABLE V

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN THE
RATIO OF "HEAD LENGTH" TO "WIDTH OF (OUTSIDE) EYE-SETTING"
AND OTHER MEASUREMENTS.

Measurement	Gross r.	Net r.
(1) Fore cannon	+0.24	-0.03
(2) Body depth	+0.02	-0.36
(3) Body width (at girth)	+0.40	+0.21
(4) Body width (at last rib)	+0.32	+0.18
(5) Width between hooks	+0.36	+0.10

TABLE V1.

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN
"WIDTH BETWEEN EARS" AND OTHER MEASUREMENTS.

Measurement	Gross r.	Net r.
(1) Body width (at girth)	+0.09	-0.41
(2) Body width (at last rib)	+0.14	-0.16
(3) Width between hooks	+0.36	-0.12

TABLE V11.

GROSS AND NET CORRELATION COEFFICIENTS BETWEEN
"POLL TO JAW" AND OTHER MEASUREMENTS.

Measurement	Gross r.	Net r.
(1) Body depth	+0.20	-0.03
(2) Girth	-0.02	-0.53.

TABLE V111

SUNDRY GROSS CORRELATIONS.

1.	Length of head - wither height	+0.69
	" " " - girth	+0.60
	" " " - height to hook.	+0.53
2.	Length of pelvis - wither height	+0.65
	" " " girth	+0.38
	" " " height to hook	+0.59
	" " " body length	+0.74
3.	Wither height - Height to hook	+0.64
	" " girth	+0.54
	" " body length	+0.46
	" " scapula	+0.59
	" " humerus	+0.13
	" " radius	+0.46
	" " fore cannon	+0.52
	" " shoulder slope	-0.55
4.	Height to hook - body length	+0.44
	" " femur	+0.61
	" " tibia	+0.67
	" " hind cannon	+0.57
5.	Girth - body length	+0.49
	" height to hook	+0.25

DISCUSSION.

In Table 1 it is seen that, as would be expected, most measurements exhibited high correlation with general size. However, if we accept the validity of Sumner's factor (see Part 11), it appears that even fairly high correlation with general size allows a portion a considerable amount of independent variability. If the percentage of "net" to "gross" standard deviation(column headed P.I.V., Table 1) is high it means in Sumner's own words that - "the greater part of the variation in the size of these structures is independent of variations in the size of the body as a whole".

Hence,it appears that the various parts of the sheep provide comparatively flexible material on which the breeder may work. The contribution of any portion to general size may vary between sheep of the same general size and so give rise to differences of type among sheep that conform to the same general standards. The sheep measured in this work exhibited wide variation in general conformation but it was found that the variation of each separate part was by no means as great as expected. It appears then,that the wide variation in general conformation was due to the aggregate effect of small and indiscriminate variations in many parts,rather than to large variations in a few.

On the other hand, however, while this plasticity of material increases the possible different types of conformation that could be evolved, it renders the immediate task of the breeder very complex and difficult. It means that, to a large extent, each portion must be considered as a separate unit in the blending of parts into a well-balanced whole.

This brings us to the real aim of this paper which is to discover relationships between parts and so reduce the number of separate factors that the breeder requires to consider. The method of analysing the data to secure the best expression of such relationships is discussed in detail in Part 11, so that only the bare conclusions reached need be mentioned here.

Gross correlation coefficients in the Tables 11, 111, etc. are of little value as their magnitude is largely due to the sympathetic variation that is superimposed to a greater or less degree on all portions, in accordance with their relationship with size.

"Net" or "partial" coefficients have, therefore, been calculated; these express the relationship between any two portions which is independent of their mutual relationship to size.

The manner in which general size variation may obscure true relationships, is strikingly exemplified in the case of the correlation between cannon length and girth in Table 11. It is seen that the gross coefficient between these two portions, though not significant, is definitely positive, while on eliminating the "size factor" a significant negative correlation is obtained. It is possible also that some correlations believed by breeders to exist, are really "gross correlations"; that is, the supposed mutual relationship is merely the result of a fairly high correlation between each portion and the general size of the animal. For example it will be seen that "length of head" and length of pelvis are both very highly correlated with general size (+0.81 and +0.75. respectively), and the fairly high gross correlation between them i.e. +0.64 would be expected. However, on calculating the partial coefficient the mutual relationship is shown to be artificial and only due to the common relationship of the two parts to size. It is interesting to note in this connection that the majority of breeders interviewed, believed that this correlation did exist and only one was definitely of the opinion, supported by this work, that no real relationship existed.

It will be seen from a perusal of the tables that most relationships are of the same type as the above and that most of the portions considered are capable of variation independent of other parts. However, there are some "net" relationships which appear to exist and in the following paragraphs only

"net" correlations are referred to, except where speci-
fically mentioned otherwise.

A common belief among breeders, which is supported by this
work, is that a sheep with a long cannon bone will be "long-
bodied" and "slab-sided". In Table 11 it is seen that a
significant negative correlation (net) exists between cannon-
length and girth; also definite indications of negative
correlation with width of body and positive correlation with
body length. The correlations between cannon length and
pelvis dimensions are barely significant when considered
separately but a coefficient of +0.30 with length of pelvis
and -0.32 with width between hooks may be regarded as
justifying the statement that a long cannon means a narrow
shaped pelvis.

On the other hand, the breeders opinion that a long cannon
is associated with a straight shoulder is not borne out by
this investigation. The coefficient between cannon and
shoulder slope does not depart significantly from zero but, as
pointed out elsewhere, the latter measurement is not very
reliable so that this matter had best be left open. Also the
opinion that length of cannon and length of head are
correlated is not supported as the value +0.24 cannot be
considered significant.

Definite opinions were also expressed by many, concerning
relationships between head length and other portions. The
probable reason for these opinions has been discussed above and
Table 111 shows that this work fails completely to substantiate
breeders' opinions on this point; The only significant
coefficient, being the very high one with length of face which
would be expected.

It might be emphasized here that the net coefficients,
which are being discussed, relate to actual, not relative
measurements i.e. "length of head" refers to the actual length
of this portion and not to relative length or shape. The
other dimensions of the head are dealt with separately and

finally the actual shape of the head is considered.

It appears from Table 1V that the shape of the head about its long axis can vary as no correlation is found between width of (outside) eye-setting and width between ears. Other correlations with width of eye-setting do not reach significance although that with width between hooks suggests a tendency to negative correlation - (which is contrary to expectation).

A similar position is revealed in the case of width between ears and body width (at girth). In Table V1 a negative coefficient (-0.41) which closely approaches significance is found between these two portions. It is quite contrary to expectation to find that increase in width between ears is attended by a probable decrease in body width at girth but no explanation can be offered. It is probable however, that an explanation would be forthcoming if a study of the growth rates of these parts were made.

No opinions were expressed by breeders in regard to correlations between depth of head and other portions and it is interesting to note therefore in Table V11 that there is a definite negative correlation between the poll to jaw measurement and girth.

When breeders' opinions were sought in regard to correlations between head measurements and other portions, it was found difficult to distinguish those concerned with actual dimensions and those concerned with the shape of the head.

In order to investigate this point, coefficients were calculated between various portions and the ratio of "length of head" to "width outside eye-setting" (Table V). Only one of the coefficients calculated, differed from zero by anything approaching significance and that was a negative figure - 0.36 between the ratio and body depth; meaning that a sheep which has a narrow head will lack depth.

In Table V111 sundry gross correlation coefficients are recorded. These have little real value, for reasons indicated

above, but they are recorded as their calculation was incidental to other parts of the work.

It will be noted that there is indication of negative correlation between wither heights and shoulder slope. As this is of considerable practical interest the net coefficient was calculated and found to be -0.56. That is to say, a high wither is correlated definitely with a straight shoulder.

It is fully realised that the above discussion merely touches a small section of a very big field. The few points mentioned above represent an exceedingly small proportion of the information that could be extracted from the data already collected. Restrictions of time, unfortunately, prevented further calculation but the above points indicate the principles involved,so that the extraction of further information from the data given,would be almost entirely a matter of mechanical calculation of the correlation coefficients.

CONCLUSION.

The aim of this paper was to open up a new field of research which would provide the breeder with more exact information in regard to skeletal correlations. Briefly, we may regard the task of the breeder as two-fold; not only must he seek to breed an animal in which each portion is of the desirable shape but also must all parts be blended together so as to form a well-balanced whole.

It is apparent that, if definite relationships between parts were found to exist, it would simplify the breeders' task by reducing the number of separate and independent factors that he is required to consider. As a result of this investigation, it is felt that there is little likelihood of such a hope being realised to an unqualified extent. Certain relationships have been established which should be of some assistance to the breeder but few are of a sufficiently high order to justify the propounding of definite rules from them.

As emphasized in other parts of this paper, a significant correlation coefficient does no more than indicate the direction which more specialised investigation should take and cannot be regarded as proof in itself, of the existence of definite causal relationships.

Hence it is suggested that extensions of this investigation be made in conjunction with detailed studies of growth rates of various parts of the sheep's skeleton. The conformation of a sheep is really a function of the differential growth rates of the parts and at any particular stage of its life, the shape of its skeleton may be regarded as a "cross-section" of the growth rates of the various parts of that skeleton.

This work deals with the animal at maturity and the existence of significant correlation between two parts suggests therefore, that just prior to the onset of maturity

and consequent cessation of growth, there existed a mutual relationship between the growth rates of the two portions; consequently it is to be expected that studies of skeletal correlations would require to be made conjointly with growth rate studies if a full understanding is desired of the fundamental causes of differences in conformation.

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AN INTRODUCTION TO THE STUDY OF
SKELETAL CORRELATIONS IN THE N.Z. ROMNEY MARSH.

PART 11.

FOREWORD.

It is quite obvious that the value of any investigation finally depends on the care with which the ground has been prepared. Particularly does this apply in the present work which is opening up a new field of research and a great deal of consideration has been given to the general procedure adopted and in particular to the statistical devices used. In the case of both these points, but in particular the latter, very little assistance was available in the form of precedents established. Furthermore, there is no doubt that there are definite limitations in the use of precise mathematical formulae when applied to the analysis of relatively abstruse biological phenomena.

For these reasons, what is generally an incidental part of an investigation, has, in the present instance, become a most important section of the paper and a separate part has been devoted to it.

THE BASIS OF CORRELATION

In such work as this, it is apparent that the validity of the results will depend, not only on the method of obtaining and analysing the data but, to an even greater extent, on the appropriateness of the material used. This, in turn, will depend on the care employed in ensuring that all relevant factors have been considered and catered for, in selecting the "sample" of sheep on which the measurements were made. In this connection it is necessary to consider the theoretical basis of correlation.

It is realised that to go fully into this matter would lead to discussion of an involved and rather speculative nature, and the following is merely intended to briefly outline the position in order to render more apparent the significance of the sampling considerations in later paragraphs.

Let us assume that a significant positive correlation between two characters A and B has been calculated from a number of casually selected sheep and consider what may be the cause of this relationship.

1. "Species" correlations.

The two characters A and B may be the expression of the same hereditary factor or of very closely "linked" hereditary factors that were present in and have been handed down from the ancestors of all modern sheep. It is possible, too, that A and B, if not genetically related, have become fixed in/natural selection. the ancestors of sheep by It is possible therefore, that such correlations would be encountered in all breeds of sheep.

2. "Breed" correlations.

In addition to the above, a further cause of correlation would be the fixing of the two characters, in the process of evolution of the Romney as a breed. That is to say, the characters A and B, though genetically unrelated, may both have been considered desirable by the founders of the breed.

The effect of constant selection would then be to cause an association between these two characters.

3. "Strain" correlations.

This process of association of characters by deliberate selection is one that has, of course, persisted to the present day, with the result that in certain strains we may expect to find correlations peculiar to those strains; such correlations being established by a consistent breeding programme or by the extensive use of a very prepotent sire by the breeder who established or maintains that strain.

It is obviously impossible to draw a sharp distinction between "Breed" and "Strain" correlations as the difference is manifestly one of degree rather than of essence. However, it was hoped that as far as possible "strain" correlations would be eliminated and only those discovered which were "species" or "breed" correlations and which would, therefore, be applicable to the breed as a whole and not merely to any one strain.

It would be an interesting and valuable extension of this work to conduct an investigation into some of the more prominent stud flocks in order to discover the correlations existing in each and then to analyse such data as a whole. At present, however, in opening up the subject of skeletal correlations, it was felt that efforts should be directed towards the discovery of the more fundamental relationships which would, in any case, be the logical preliminary to a more specialised investigation.

MATERIAL.

(a) Selection of Sample.

The fundamental principles in sampling are that the sample shall represent all factors contributing to the matter under review and shall be free from all factors that may lead to erroneous conclusions. The "matter under review" in this paper is correlations of parts insofar as they are common to all members of the Romney breed.

On first thoughts it may seem impossible to obtain a representative sample of the Romney breed which is free from "strain correlations" except by carefully selecting individual sheep from each strain. Not only would such a method result in expense and inconvenience through having the material scattered over a wide area but also it is quite unnecessary.

Briefly, the point hinges on the fact that what is required is not a sample of typical Romney sheep but a sample of the true correlations inherent in the Romney breed. A little consideration will show that poorness of type from the breeders point of view cannot affect the existence of true inherent correlations. Whereas good quality sheep will evidence true and also "artificial" or strain correlations, only the former will exist in a flock more or less indiscriminately bred from the conformation aspect and such a flock was found conveniently at hand in the College wool experimental flock. This flock has been accumulated from various sources on the sole basis of fleece type displayed and has been bred without any consideration being paid to conformation; that is, both with reference to its source and to its maintenance this flock can be regarded as "indiscriminately bred" in regard to conformation.

Assume for the purpose of discussion that a true inherent correlation exists between shortness of cannon and good spring of rib. This would not only mean that a short cannon would be associated with a well sprung rib but also that a long cannon would be associated with a poor spring of rib. In other words a true relationship would be apparent irrespective of the actual

length of cannon or the actual spring of rib - it would be
evident in good quality animals or in poor quality animals that
were "long-shanked" and "slab-sided".

On the other hand, assume there is no true inherent correlation
between cannon length and spring of rib. In an indiscriminately
bred flock the lack of correlation would be revealed by
investigation; but a short cannon and a well sprung rib are both
desirable characters in the breeder's eyes and he would endeavour
to eliminate their opposites by culling. The tendency would be
therefore for two such desirable characters to become associated
in a well bred flock purely as a result of the breeder's efforts
and not because of any inherent relationship.

For these reasons it is considered that significant correlation
based on data obtained from the wool experimental flock will be
applicable to the Romney breed as a whole; if these calculations
show no correlation between two characters, it means that mutual
relationship is not common to the breed and, whether it exists
in a particular strain, can only be decided by a special investi-
gation.

Two further points considered in relation to the selection
of the material were sex and age. The existence of a typical
masculine and a typical feminine conformation is undisputed.
Such differences depend largely on different proportions between
parts in each sex and it is possible that the same true correlations
would be common to both. However, the investigation of such
relationships would need to be undertaken separately for each
sex, as the existence of different proportions between parts would
be a disturbing factor if the sexes were mixed. In the present
work, therefore, the investigations were confined to ewes.

It will be seen below that it was necessary to eliminate the
effect of heterogeneity of size amongst the sheep measured.
The effect of age must, however, be considered apart from its
effect of general size, because, as is well known, the ratios
between parts vary at different stages of growth. For this

reason it was necessary that the sheep measured be approx-
imately of the same age.   Furthermore, the effects of external
factors such as nutrition are more apparent when the sheep are
still growing; if a growing animal receives a check due to
nutrition or disease, the effect of that check will be most
apparent while the animal is young and as maturity approaches there
will be a tendency for the animal to recover the lost ground.   In
order to eliminate such factors as far as possible, the sheep
chosen were all mature ewes, aged 4th or 6th.

In selecting the sample of sheep on which to work, it has
been seen that certain influences had to be eliminated viz.
"strain" correlations, sex and age, in order to ensure that the
material employed was appropriate to the matter that was being
studied.   In accordance with the principles of sampling, a random
selection of twenty was made from sheep in the wool experimental
flock which satisfied the above special conditions.

(b) Size of Sample.

The second essential in sampling is that the sample be large
enough to ensure that conclusions based on it are applicable to
the whole.   Strictly speaking,it is impossible to regard
"adequacy" of sample as distinct from representativeness.   The
former is often used to refer to the size of the sample but it is
obvious that size is really one of the factors that determine
"representativeness".   In a sense the sample must be large
enough to adequately represent the amount of variation between the
individuals.

A formula[+] is provided by statisticians for testing "adequacy",
based on the relation of the probable error of the mean of the
sample to the standard deviation.   It is considered that the sample
is adequate if the standard deviation is at least six times the
probable error of the mean.   A consideration of the value of such
arbitrary tests is not within the scope of this paper;   suffice
to say,that the application of this test to the sheep used,showed
that they provided a theoretically adequate sample.   Furthermore,it
was found that twenty sheep were more than sufficient to occupy the
time available for this work.

COEFFICIENT OF CORRELATION.

The degree of correlation between any two variables is expressed as a correlation coefficient. Perfect positive correlation is indicated by a coefficient of +1.0, lack of correlation by a zero coefficient and perfect negative correlation by a coefficient of - 1.0. In practice, however, a coefficient of unity, positive or negative, is rarely obtained and certain rules have been evolved for einterpreting the cowefficient. These rules vary slightly among different authorities but the following represent the general opinion:-

(1) Significant correlation is indicated where the coefficient (accepted symbol r) is at least four times its probable error.

(2) When r is 0.3 and the probable error is sufficiently small, it is regarded as indicating moderate correlation. A coefficient of less than 0.3 is of doubtful significance.

(3) When r is 0.5 and the probable error sufficiently small, there is evidence of decided correlation.

The coefficient of correlation is obtainable from various formulae which have been evolved for various purposes. The two most commonly used which were considered in the present work are:-

(i) Coefficient of concurrent deviations.

This is obtained from the formula -

$$r \;=\; \pm \sqrt{\frac{2c - n}{n}}$$

$$c. \quad = \text{Number of concurrent deviations.}$$

$$n. \quad = \text{Number of pairs of items.}$$

This method measures the tendency of the items of each series to deviate in a like direction from their respective means; it is concerned only with the directions of the deviations and not with their size. The attractiveness of this coefficient is its simplicity but it is apparent that it would not be very reliable where, as will be seen later, a certain amount of personal error is involved. It would be possible for "personal error" to cause a deviation to be very slightly on the wrong side of the mean and

by this method such a deviation would be given as much weight as one whose position was unquestionable.

(ii) Pearsonian coefficient.

This method, evolved by Pearson, is that most commonly employed in statistical work and is subject only to the restriction that it is not applicable to any but linear or nearly linear relationships. There is no apparent reason for expecting that relationships in the present work should depart from the linear to any extent, if at all. Scatter graphs are at best difficult to interpret but when these were plotted (see later) there were no indications of definite non-linear relationships.

Furthermore the Pearsonian coefficient is designed to reflect the magnitude as well as the directions of the deviations and despite the somewhat laborious calculations involved, it was decided to employ in in this paper.

The coefficient is calculated from the formula -

$$r = \frac{\sum d_x \cdot d_y}{N. \sigma_x \cdot \sigma_y}$$

$\sum d_x \cdot d_y$ = the algebraic sum of the products of the deviations of each pair of and variables from their respective means.

N. = the number of paired items.

σ_x and σ_y = the standard deviations of the and the variables.

The following example of the method of calculation of the coefficient indicates how it expresses the tendency of the variables to fluctuate in sympathy -

(a) Method of Calculation of Correlation Coefficient.

Gross correlation between wither height and fore cannon.

Wither x	Fore Cannon y	Devns. d_x	Devns. d_y	Product $d_x \times d_y$ +	Product $d_x \times d_y$ -	Devns. 2 d_x^2	Devns. 2 d_y^2
23.9	5.0	-.5	-.28	.14	-	.25	.0784
25.0	5.4	+.6	+.12	.072	-	.36	.0144
23.7	4.8	-.7	-.48	.336	-	.49	.2304
24.7	5.3	+.3	+.02	.006	-	.09	.0004
24.4	5.3	-	+.02	-	-	-	.0004
24.1	5.5	-.3	+.22	-	.066	.09	.0484
22.2	5.3	-2.2	+.02	-	.044	4.84	.0004
25.8	5.5	+1.4	+.22	.308	-	1.96	.0484
24.5	5.3	+.1	+.02	.002	-	.01	.0004
24.1	5.2	-.3	-.08	.024	-	.09	.0064
24.8	5.1	+.4	-.18	-	.072	.16	.0324
24.9	5.3	+.5	+02	.010	-	.25	.0004
23.4	5.1	-1.0	-.18	.180	-	1.00	.0324
23.9	5.3	-.5	+.02	-	.01	.25	.0004
25.2	5.5	+.8	+.22	.176	-	.64	.0484
24.8	5.3	+.4	+.02	.008	-	.16	.0004
23.1	5.2	-1.3	-.08	.104		1.69	.0064
24.8	5.3	+.4	+.02	.008	-	.16	.0004
25.1	5.4	+.7	+.12	.084	-	.49	.0144
25.6	5.5	+1.2	+.22	.264	-	1.44	.0484
488.0	105.6	-	-	1.722	0.192	14.42	0.6120

Mean x = $\frac{488.0}{20}$ = 24.4 Inches. $\sigma_x = \sqrt{\frac{14.42}{20}}$ = 0.849

Mean y = $\frac{105.6}{20}$ = 5.28 Inches. $\sigma_y = \sqrt{\frac{.612}{20}}$ = 0.175

$d_x d_y$ = 1.722 - 0.192 = +1.530.

$r = \dfrac{+1.530}{20 \times 0.849 \times 0.175}$

= +0.52

(b)   Interpretation of coefficient.

An exact interpretation of the term "correlation" is difficult to make and the statistical literature studied did not provide a satisfactory definition.   However, some observations can be made which will indicate the conception of correlation held by the author and, therefore, the conception on which the discussions in this work are based.   The purpose of these observations is primarily to render the results of this work more intelligible to those who are not familiar with correlation coefficients; but there is also reason to believe that many, who are more or less familiar with correlation work, are inclined to attribute a significance to the coefficients in excess of that which is strictly justified.   For these reasons it was felt that some brief observations on the point would not be out of place.

For the sake of simplicity the discussion below deals with positive coefficients but the remarks apply, of course, equally well to negative coefficients and it is necessary simply to substitute for the latter, "opposite" for "same" direction of deviation.

It appears that a significant positive coefficient may be regarded as indicating that there is a tendency for the two variables to fluctuate in sympathy, but that the relationship is not an invariable one but only a general rule.   This point will be apparent from inspection of the example above where it will be seen that concurrency between the deviations is only general not invariable.

It is very difficult to go beyond this point in defining the properties of a correlation coefficient and some authorities appear to avoid doing so.   It is stated however, that a significant positive correlation means that a change in one variable is likely to be accompanied by a change in the second, in the same direction and of like magnitude;   presumably the degree of "likelihood" depends on the actual size of the

coefficient. The statement has already been made that
concurrency as regards direction of deviation is only a "likeli-
hood" and it seems probable, therefore, that concurrency in
regard to the magnitude of the deviations involves a still
greater element of doubt. Indeed, even the term "like magnitude"
required comment. Consider for example two series of values A
and B as given below; the coefficient between these would be
+1.0 i.e. perfect positive correlation.

> A - 14 : 12:: 10 : 8 : 6.
>
> B - 16 : 13 : 10 : 7 : 4

The deviations of the A variables are two units and of the
B variables, three units but actually the deviations are of
"like magnitude" when considered in relation to the range of
variation - the range of A variables being 8 units and that of
B, 12 units.

It will be seen, also, from the above example that the
ratio of A : B varies from greater to less than unity. So that
perfect positive correlation does not necessarily mean that the
ratio between the parts is constant.

It will be apparent that an accurate definition of a
correlation coefficient is difficult, if not impossible, to make.
Readers may feel that the above brief discussion has confused
rather than clarified their conception of correlation. In a
sense, this is the purpose of the discussion; to emphasize the
impossibility of attributing specific and rigid properties to the
coefficient. We are not justified in regarding the coefficient
in any but the broad sense - that of a measure of general
tendency to sympathetic fluctuation - and the exact nature of
the relationship or its cause cannot be deduced from the
coefficient itself but requires further investigation.

(c) Probable error of the coefficient.

It has already been pointed out that the significance of the
correlation coefficient depends in part on its probable error;
the coefficient is required to be at least four times its
probable error to be considered significant.

The probable error of the correlation coefficient is
calculated from the formula -

$$\text{P.E.} = \frac{0.6745 \ (1 - r^2)}{\sqrt{N}}$$

where   r = the correlation coefficient.

     N = the number of sheep.

A simple expedient can be adopted to save time from calculating
the probable error of each coefficient. It is seen that the
lowest signinificant value for r is that which satisfies the
equation -

$$r = 4 \ x \ \frac{0.6745 \ (1 - r^2)}{\sqrt{N}}$$

Since N is constant throughout this work, r is the only
unknown and it is then simply a matter of solving the quadratic
equation. The value for r so obtained was ±0.47 and this is the
lowest value for r which can be regarded as significant in the
present work.

(d) The calculations.

It will be readily appreciated that the mathematical
calculations involved in this work would in themselves require a
very great deal of time. It was considered essential, however,
that the author should become thoroughly familiar with the
methods themselves in order to gain some appreciation of their
limitations and ensure that the analytical devices employed gave
a reasonably accurate reflection of the physical facts. The
particular problems encountered in this work have not yet
received the critical attention of statisticians and their
solution required considerably more time than could be antici-
pated. This, unfortunately, left little time for the
interpretation of the results except in so far as their general
interpretation would follow from the discussion of the methods.
Nevertheless, it was felt that the cautious course pursued was
a much wiser one than endeavouring to draw conclusions from
results obtained by a method whose reliability had not been
thoroughly investigated.

TECHNIQUE OF MEASURING.

The original intention was to cover the sheep in as much detail as possible and a list of nearly fifty items was accordingly drawn up. It was hoped that this would be merely a preliminary survey and that a condensed list of measurements would be compiled as a result of the experience so obtained and extended over a larger number of sheep. Measurements were to be eliminated which were too difficult to be reliable and for which alternatives could be obtained; further, it was thought that some correlations would be unquestionable and extension to a larger number of sheep would only be necessary in doubtful cases. It soon became obvious, however, that this hope had been based on a lack of appreciation of the difficulties ahead. The only sound basis for discrimination between measurements would be a thorough understanding of the data already collected; this involved the estimation of personal error by repeating all measurements and also the discovery of suitable analytical devices for treating the data.

In other words, it was discovered that the preliminary work in entering an entirely new field of research - that of skeletal correlations in sheep - was, in itself, a project that would fully occupy the few months available.

(a) Difficulties encountered.

The principal difficulties encountered in the actual measuring of the parts and the manner in which they were met, are given below.

(1) Location of points.

The difficulties consequent on making the measurements on live sheep can readily be appreciated and not the least of these, was that of obtaining points of reference which could be located with accuracy in different sheep. In few cases were the ends of bones sharply delineated and considerable care and patience was necessary in acquiring the necessary skill. A few days were spent before the main work was actually

commenced, in becoming familiar with the pointsof reference,^{13.}
the measurements so obtained being discarded. It soon became
apparent that in some cases it would be necessary to sacrifice
strict anatomical detail in order to obtain well defined points
of reference. (See Fig 111). It was felt, however, that this
was warranted since the approach to the subject was primarily
from the breeder's conception of conformation.

The effect of this difficulty of locating points on the
accuracy of measurements, depended largely on the skill of the
investigator although a certain amount of assistance was obtained
by the use of simple instruments to be considered below.

(2) Wool and curvature.

These two may be considered together as they both prohibited
the use of a plain rule or tape measure. It would be difficult
to measure with rule or tape the distance between two points on
a more or less flat surface when those points, even apart from
their covering of wool, were not visible but had to be located
by touch. Where there was an actual curvature between the
points and also a covering of wool the use of tape or rule was
manifestly impossible if an accurate "straight-line" measurement
was to be obtained.

It was fortunate that the work was done in the late summer
when the ewes were not in very good condition. Beyond
rendering the location of points a little more difficult,
condition was not really a serious problem in view of the methods
employed.

(3) Stance.

When the individual measurements are considered it will be
seen that in very few cases could the stance of the animal
affect the reading. As far as possible, however, the sheep were
held in a normal standing position to eliminate the possibility
of influences that were not anticipated. In those cases, for
example - length from shoulder point to last rib, where it was
obvious that stance could have an effect, both sides were
measured while the sheep was held firmly and the mean recorded.

Where stance could have no effect it was not considered necessary to measure and average measurements on each side. It is exceedingly doubtful whether any variation due to bilateral asymmetry would be recorded within the limits of accuracy obtained and a brief preliminary trial supported this view. There is no doubt that if such variations did exist they would be so small and so rare that the effect on the correlation coefficient would be negligible.

(4) Restlessness of Sheep.

The sheep used were, fortunately, accustomed to handling but they naturally became very restless when held in one position for long periods. This was not conducive to speed and accuracy of measurement but it was a difficulty that could only be met by patience; to a certain extent the instruments used enabled the investigator to meet slight movements on the animal's part.

(b) Measuring instruments (Fig. 1V).

After a little consideration three simple wooden instruments were evolved which proved quite satisfactory.

(a) (Fig 1V A). The majority of measurements were made with the simple dividers as illustrated; the most convenient size being with arms about fifteen inches long. A smaller divider was used for a few of the small measurements but this was not essential.

The arms of the dividers were held, one in each hand, with the index fingers lying along the points. In this way the wool could be parted, the reference points located with the index fingers and the points of the instrument held in position at the same time. This light simple instrument was particularly useful for restive sheep as small movements could be followed fairly easily.

(b) An adaptation of the above was necessary for measurements of the nature of diameters e.g. body depth and width. The instrument (Fig 1V B) served this purpose and also had the advantages of the above in regard to simplicity and convenience.

(c) For large measurements such as body length and for perpendicular heights e.g. wither height, an instrument

(Fig 1V C) was used - this consisted of a graduated rod with two arms at right angles, one being fixed and the other capable of sliding and rotating on the rod. There were two limitations in the use of this instrument which could not be overcome; it was by no means independent of restlessness and further the measurements for which it was used were liable to be affected by stance. It was found that restlessness generally increased the longer the sheep was held but that the stance was generally most unnatural at the beginning of the measuring process. In this case, restlessness was the lesser evil so that the use of this instrument was postponed until the sheep had relaxed.

Scales were attached to all three instruments so that the values could be read quickly; furthermore most recordings could be made while the instruments were being applied to the portions and were firmly held, so that possible errors due to twitching of the skin etc. were eliminated. Checks were also made at frequent intervals to ensure that the scales were giving true readings and had not suffered warping etc.

In order to eliminate the effect of the wool on the girth measurement a thin strong cord was used; the wool being parted so that the cord lay close to the skin.

An attempt was also made to measure various angles and slopes. With the possible exception of the angle of the hock, it was found quite impossible to measure angles and slopes directly with any accuracy. It will be obvious that angles would be particularly affected by comparatively slight movements and it is felt that it is not possible to place much reliance on them. The indirect method employed can be best explained by an illustration - slope of pelvis (see Fig V).

By subtracting the 'height to pin (BG_2) from the 'height to hook' (AG_1) we get the distance A C; the length of pelvis A B is known and the calculation of the angle of the slope is then a matter of simple trigonometry. The angle is A B C which equals the angle of slope of the pelvis from the horizontal(θ). The same principles may be applied to the slope of the shoulder etc.
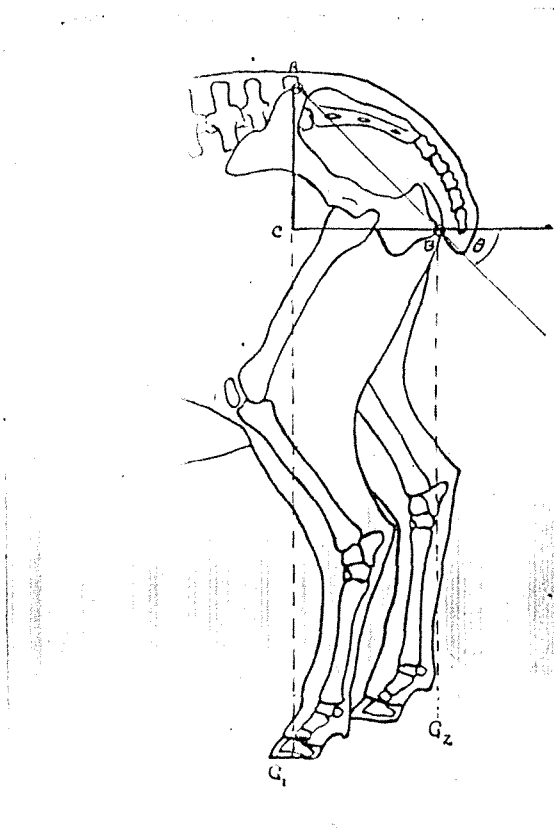
MEASURING INSTRUMENTS
FIG. IV.

A.

B.

C.

SKELETAL CORRELATIONS

SKETCH BY AUTHOR.
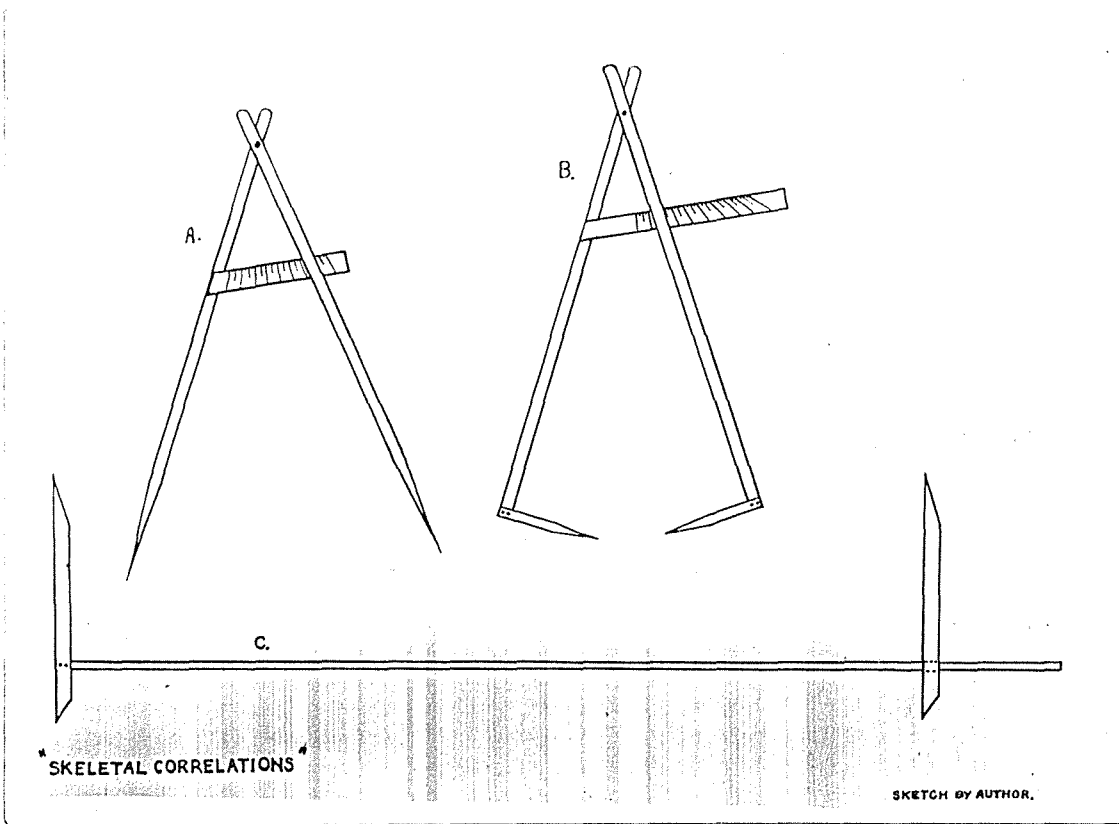
ESTIMATION OF PELVIS SLOPE
FIG. V.

ACCURACY OF MEASUREMENTS.

From the above discussion, it will be apparent that a certain amount of error of measurement would be expected, owing mainly to the difficulty of locating reference points with accuracy. To some extent, of course, the difficulties were beyond the control of the investigator but, it is obvious that the personal skill acquired, would be a very important factor. In order to obtain some measure of the error and also to develop skill, all measurements were repeated. When this was done it was found that the differences between the two recordings ranged from zero up to 10% in the case of a few difficult measurements and, in two or three instances, it was apparent that the measurements were quite unreliable.

It is obvious however, that the difference between these two recordings would not give a just measure of the error associated with the second series because of the skill developed by the time the latter were made; a certain number were therefore again repeated. Over 150 measurements were selected for repetition where the difference between the first and second recordings had been of a high order. It was felt that by so choosing the more difficult measurements, the error evaluated from them, could be regarded with confidence as representing the maximum error that could be attributed to the second series.

The mean error of measurement calculated in this way was very nearly 4% of the second recordings - a figure which, under circumstances is gratifyingly low/need hardly be mentioned that
It
in all cases where repeat measurements were made, it was quite impossible for the investigator to remember previous readings.

An expression of the precise effect of this error on the correlation coefficient, apparently, would involve very complex mathematics and no method could be suggested by mathematicians whose assistance was sought. The general opinion was, however, that the effect of the error would probably not be great. Furthermore, according to Yule[+] the effect of error is to reduce

+ J.V. Yule: "An introduction to the theory of statistics" - 1929.

the correlation coefficient below its true value. This reduction will be more or less the same on all coefficients and will not, therefore, affect their value for purposes of comparison.

THE SIZE FACTOR

(a) Effect of the "size factor".

There have been references in the above paragraphs to the limitations of mathematical method in its application to biological data and a certain amount of doubt was felt, therefore, as to how far the use of complex and intricate mathematical method was justified. On the other hand, however, would not the very existence of such limitations emphasize the necessity for accuracy in the methods themselves? Furthermore, since this work is opening up a new field of research, it was felt that the time spent on the "size factor" problem was well advised.

It is no more than a truism that the size attained by the various parts of the body is in a large measure dependent on the size attained by the body as a whole; that is to say, a large sheep would have a longer head and longer pelvis, for example, than a small sheep.

In effect, this means that variation of general size amongst the sheep would superimpose a variation on a portion   in addition to that which might be the independent property of that portion.

Since the nature of this superimposed variation is the same on all portions of the body, the "size factor" would of itself tend to produce a sympathetic variation between any two portions. If the portions were actually capable of independent variation the "size factor" would tend to obscure this fact while any real tendency to association between the portions would be accentuated.

The influence of the "size factor" on the correlation coefficient would therefore be -

(a) In cases of true zero correlation - to produce an apparent positive correlation

(b) In cases of true negative correlation - to produce a lower negative, a zero or even a slight positive correlation.

(c) In cases of true positive correlation - to produce an abnormally high coefficient.

On theoretical grounds, there is no doubt that the influence of general size is a factor that demands consideration but, on the other hand, there is considerable evidence to show that it has not been seriously considered, if at all, by many workers in allied subjects. The question arises as to whether the effect of the size factor was of sufficient magnitude, to warrant elaborate devices for its elimination.

As stated above, the sheep measured were all mature ewes and consequently, the variation in size amongst them was not very great. It will be seen, however, that the variation among separate portions was also small, so that the relative effect of size variation might be considerable. It soon became obvious that the problem could not be solved by casual observation but that it would actually be necessary to devise means for eliminating the effect, before it would be possible to judge its influence.

(b) Methods of elimination.

(1) The most obvious method that would suggest itself is to express the measurements in terms relative to size, for example as percentages and this device has been employed in related work. However, on testing this method in an example, it was discovered that it contained a very serious flaw.

The correlation between humerus and radius calculated from actual measurements in inches was +0.15 whereas, when the values were expressed as percentages of wither height (using this as a size index) the correlation rose to +0.39. Since, as was pointed out above, the effect of the size factor on a positive correlation would be to produce an erroneously high figure, this result seemed inexplicable. The point was rather outside the field of statisticians to whom the matter was referred and only indirect information was available in textbooks. However, the idea of

simply abandoning the method with its flaw undiscovered did
not appeal. In accordance with the conviction expressed in earlier
sections - that a full understanding of statistical devices was
prerequisite to their successful application - it was felt that
the consideration of any matter likely to promote such understanding
was more than justified.

Consideration in the present case made it possible to provide
an explanation which seemed satisfactory.

It is apparent that the elimination of the size factor should
decrease the variability of a portion, as it would reduce the range
of variation without materially affecting the mean; in a sense,
its elimination would cause the extreme values to shrink towards
the mean. It was discovered, however, that in the above example
the variability of the percentages was actually greater than
that of the actual values in inches.

The coefficients of variability were:-

Humerus - from actual values in inches   3.95%

    "   "   percentages   5.09%

Radius   "   actual values in inches   3.63%

    "   "   percentages   3.66%

It is seen that the increase in variability was greater in
the case of the humerus; the key to the solution of the problem
was obtained when it was noted that the correlation coefficient
between humerus and wither height was less than that between
radius and wither height - the values being +0.13 and +0.46 respect
ively. A little consideration suggested that the 'percentage
method' for eliminating the size factor involved an assumption
which could not be made - namely, the assumption that the
particular portion varies directly with size. Where the portion
did not so vary the expression as percentages would tend to
increase the variability. As we have seen above, this is
precisely what took place; the effect being greater in the case
of the humerus than in the case of the radius - that is, inversely
as the degree of relationship between each of these portions and

wither height.

The percentage method would only be applicable where the portion considered varied directly with size - that is, exhibited perfect positive correlation with size; the obvious solution therefore, was to seek some method of eliminating the "size factor" which involved the actual correlation between the characters and size.

(11) The position is that there are two variables (any two portions of the sheep) whose true relationship is obscured by the influence of a third variable (general size). Mathematicians have devised a formula for the elimination of such a third variable which gives the "partial" or "net" correlation between two variables. Applied to the present work, partial correlation should express the mutual relationship between any two parts, independent of their common relationship to the general size of the animal.

The formula for "net" or "partial" correlation coefficient is:-

$$ r_{12.3} = \frac{r_{12} - r_{13}.\ r_{23}}{\sqrt{(1 - r_{13}^2)(1 - r_{23}^2)}} $$

$r_{12.3}$ = the partial correlation between portions 1 and 2 with the effect of 3 eliminated.

r_{12}, r_{13} etc = the gross correlations between portions 1 and 2, 1 and 3 etc.

When this formula was applied to the example of humerus and radius used above, the partial correlation between the two portions was calculated to be +0.10 (gross = ±0.15) and from the above discussion it will be understood that such a reduction was the anticipated result of the elimination of the "size factor".

However, when a statistician was consulted with a view to obtaining confirmation of the value of this method, certain doubts were expressed. It appears that an American worker, Montgomery D. Anderson[+] has expressed doubts as to the reliability

+   Reference not available.

of the method when applied to factors which are concomi-
tantly related.   It is considered that reliability is not
obtained where the factor "partialled out" (i.e. size) is
appreciably affected by either of the two factors between which
partial correlation is sought.   The point is obvious if we
consider such an example as crop yield, weight of fertiliser
per acre and rainfall.   It is apparent that either fertiliser
or rainfall could be "partialled out" whereas crop yeild could
not; in this case, for perfectly obvious reasons. Unfortunately
no information could be obtained as to the exact reasons for
Andersons opinion and the question remains as to whether there
are other reasons besides the obvious common-sense one that
would apply to the case above/of crop yield etc.   Furthermore, it is
somewhat debatable whether a small portion of the sheep could
be regarded as "appreciably" affecting general size.

A study of statistical textbooks threw no light on the
problem but it was felt that recourse to complex theoretical
considerations was unnecessary and possibly even futile.
Mathematical methods are not being used in this paper in order
to prove the existence of skeletal relationships but rather
as strictly mechanical devices for the expression of information
that was apparent from a thorough understanding of the data.
The opinion is held, therefore, that the validity of mathematical
method in general and in this instance, partial correlation,
must be judged, not by excursions into the intricacies of
mathematical theory, but rather by careful consideration of the
simple question - does it express the result to be anticipated
from intelligent understanding of the data?

On this basis, it was concluded that the partial correlation
method could be used with confidence.

It was at this stage of the work that a paper was accident-
ally discovered/written by an American worker - F.B. Sumner[+] who had

+ Proceedings of the National Academy of Sciences,
      Vol. 9, No 11, November 1923.

calculated correlation coefficients between various
portions of the deermouse (Peromyscus). Unfortunately, he
gave very little detail of the methods he employed and the cross
references given, were not obtainable in the libraries available.
The question at issue in Sumner's paper was the extent to which
the sizes of various portions were inherited independently but
there are one or two points in his paper which have a bearing
on the present work.

One interesting point was that Sumner criticised the work
of Castle who had calculated correlation coefficients between
parts of the rabbit, on the grounds that the latter had
neglected to eliminate the "size factor". Sumney states that
the extent to which the variation of a portion is independent of
general size factors is indicated by the percentage ratio of the
"net" to the "gross" standard deviation. The latter is the
ordinary standard deviation obtained from actual measurements
and the "net" standard deviation is obtained from the "gross"
by multiplying the latter by a factor $\sqrt{1-r^2}$, where r is
the correlation coefficient between the portion and size. On
applying this factor to the humerus of the sheep the "independent
variability" of the portion was calculated to be 98.8% a
result to be expected from the low correlation between humerus
and wither height (using this as a size index). This factor
of Sumner's has been mentioned as it was considered possible
that it might be useful in later sections or extensions of this
work.

Sumner also employed the partial correlation method but,
unfortunately, he did not discuss its use and apparently did not
question its validity. It was gratifying, however, to find the
conclusions in regard to this method, supported by precedent
provided by an American worker of repute.

(c) The size index.

The question remained as to the choice of a suitable measure
of "general size". At first, it was felt that the best method
would be to use the major measurement appropriate to the

particular portion under consideration, for example,
wither height when considering cannon length or body length when
considering length of loin. The obvious difficulty arose when
considering the correlation between portions from distant parts
of the body, e.g. cannon length and loin length and it became
apparent that a single size index would need to be evolved.

It is obviously impossible to define "general size" as it
is no more than a general impression to which all parts of the
animal contribute. It was considered therefore, that a single
major measurement such as wither height or body length would not
be a good index of size but rather would it be necessary to use
a composite index that would, as far as possible, represent all
portions of the body. Furthermore, it was realised that any
attempt to express general size in very precise terms would be
absurd; actually, the elimination of the "size factor" amounts
to little more than an arbitrary reduction of the correlation
coefficient to an extent that depends on the estimated effect of
size on the portions concerned.

The index, then, must be a general, "all-embracing" thing
which reflects all those dimensions which contribute to the
general impression of size; in effect, this would be obtained
from a compound of the four major measurements - wither height,
height to hook, girth and body length.

The gross correlation coefficients between these four
measurements were not very large (considering that they were
gross coefficients) and this gave more weight to the conclusion
that all four be compounded in evolving the index.

The coefficients actually were:-

Wither height	- Height to hook		$+0.64 \pm 0.09$
"	"	Girth	$+0.54 \pm 0.11$
"	"	Body Length	$+0.46 \pm 0.12$
Girth	- Body Length		$+0.49 \pm 0.11$
"		Height to hook	$+0.25 \pm 0.14$
Height to hook	Body Length		$+0.44 \pm 0.12$

The "size index" was obtained by calculating the mean

of these four major measurements. It was suggested that it
might be advisable to employ a method that would give to each
of the four measurements an equal "weight" in the index; in the
simple arithmetic mean as used the largest measurement has, of
course, the greatest "weight" in the index. On the other hand,
however, the largest measurement contributes most towards
"general size" and one would expect therefore that it should
merit greatest "weight" in an index designed to represent
general size.

It was considered that the validity of the "size index" would
be tested by the correlation it exhibited with the four major
measurements taken together i.e. by the method of multiple
correlation.   This multiple correlation was calculated to be
+0.998.   In this work this may be regarded as perfect positive
correlation and it is considered that this indicates that the
"size index" as calculated above fulfils the purpose for which
it was designed; viz. to measure the composite effect of the
four major measurements.

In other words the calculation of partial correlation
coefficients with the "size index" held constant is equivalent
to holding the four major measurements constant and so eliminating
the effect of general size variation on the correlation
coefficients - an effect, which will be seen from the results,
to be very important.

SCATTER GRAPHS.

Scatter graphs are, at best, difficult to interpret but to some extent they indicate the extent of the correlation that exists and graphs have been plotted for different degrees of correlation. It is seen that where high correlation exists the points tend to lie in a diagonal band across the page while lack of correlation is indicated by an indiscriminate "scatter".

Regression Lines.

These may be drawn from the equation (referring to the intersection of the means) :-

$$d_x = r\frac{\sigma_x}{\sigma_y} d_y$$

d_x and d_y = deviations of x and y variables.

σ_x and σ_y = standard deviations of x and y variables.

r = correlation coefficient between x and y.

$r. \frac{\sigma_x}{\sigma_y}$ = the regression coefficient of x on y.

If we substitute various values for d_y in the above equation we get values for d_x which lie in a straight line. The values of d_x so obtained, represent the average values of the deviations of x variables which will be associated with particular values of the deviations of y variables. In a similar way, the regression of y on x may be calculated simply by substituting y for x throughout the above equation.

This process is illustrated in graphs 1 and 11. The whole red line in graph 1 represents the regression of 'pelvis' on 'head length' and in graph 11 the regression of 'width eye-setting' on 'width between hooks' - the broken red lines indicate the reciprocal relation in each case.

It will be seen that the regression lines in graph 11 do not deviate greatly from the mean values of 'width eye setting' and of 'width between hooks'; in graph 1 where the correlation is greater the situation is very different. It appears then, that the position of the regression lines indicates the degree of correlation that exists.

At the present stage of this work, however, regression is

of little practical interest. The above brief mention of it
has been made merely to show the further information obtainable
from correlation data which may prove of value in extensions
of this work.

———————————————

SUMMARY OF PART 11.

(1) It was necessary to exercise great care in selecting the sheep on which to work. A brief discussion of the theoretical basis of correlation in its bearing on this problem revealed a somewhat complex situation but an endeavour was made to secure material which would contain only "true" correlations. The effect of sex and age was also considered and finally a 'sample' of twenty mature ewes was selected from the College Wool Experimental flock.

(2) Difficulties encountered in the actual measuring,were to some extent overcome by the use of simple instruments. The development of a certain amount of skill in measuring reduced the error to a reasonable figure whose influence on the correlation coefficient was not serious.

(3) The results were expressed by Pearsonian correlation coefficients. An exact definition of the term " correlation " is difficult and it is necessary to emphasize that attributing very precise meanings to the coefficients is not justified.

(4) The most involved problem encountered was the elimination of the influence of general size variation on the coefficients. This was finally accomplished by using the "partial" or "net"correlation method and employing a composite size index.

(5) A few "scatter graphs" have been plotted to illustrate the nature of these graphs; examples of repression lines are also provided, but at present these are of little practical value.
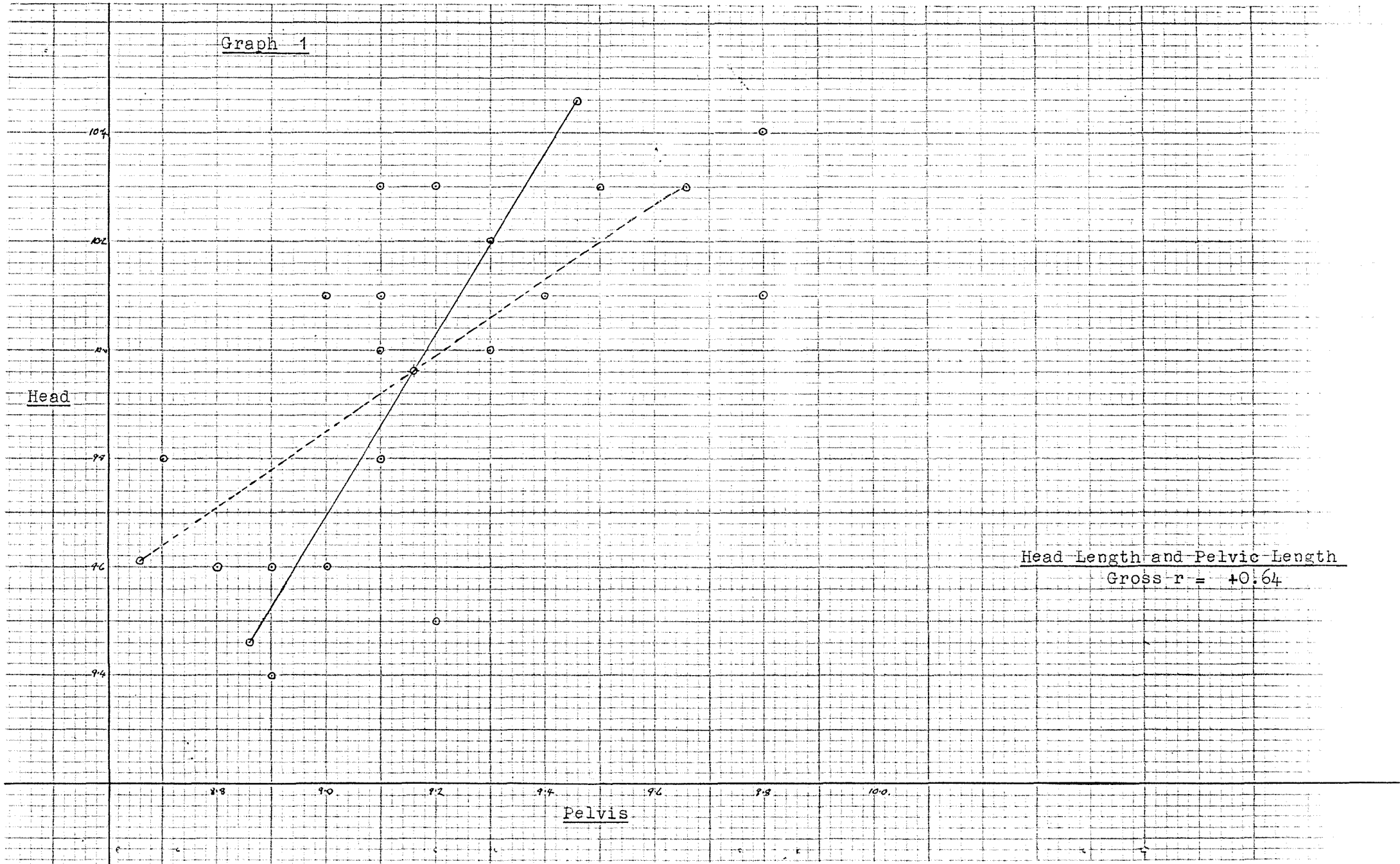
Graph 1

Head

Pelvis

Head Length and Pelvic Length
Gross r = +0.64

Graph 11

Width (Outside) eye-setting ε
Width between hooks.
Gross r = -0.02.
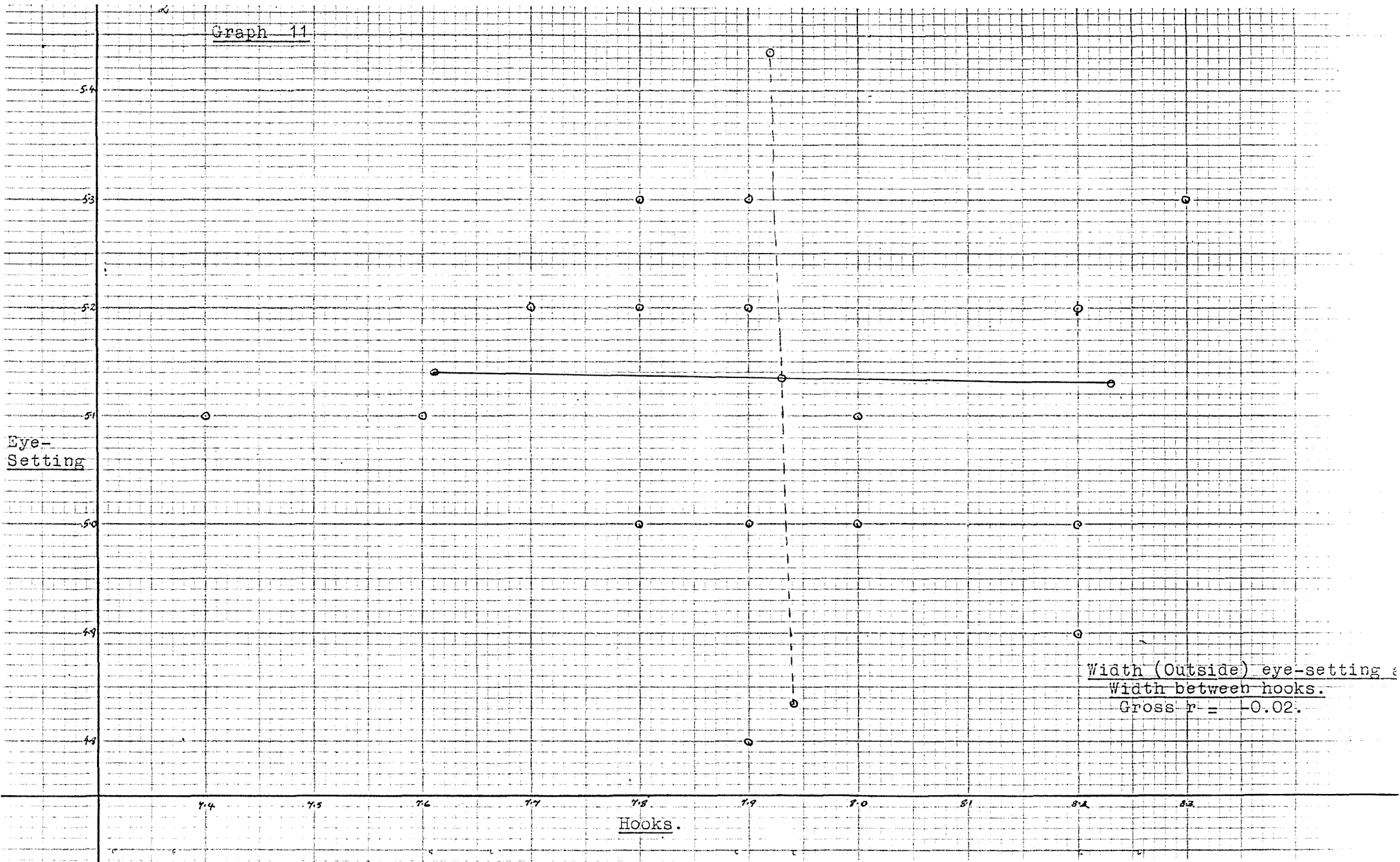
Graph 111

Head

Head Length and Size Index
r = +0,80

Size Index

Graph 1V

Fore Cannon and Hind Cannon
Gross r = + 0.69

Hind

Fore