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Correlations of Skull Measurements of *Lepus europaeus* Pallas, 1778

Korelacja wymiarów czaszki *Lepus europaeus* Pallas, 1778

[With 3 Figs.]

I. INTRODUCTION

One of the methods used in craniometry is the method of correlation of measurements. It is most frequently applied in anthropology, where together with the diagram of Czekanowski (1913) it serves to analyse the racial make-up of human skulls. The method of correlation pleiads, worked out by Terentev (1931, quoted after Terentev, 1943), was utilized by this author to pick out the measurements of body of *Rana ridibunda* Pallas, 1771 such as are useful in systematics. In Terentev's opinion (1943; 1960), in this way it is possible to select a character representative of the remaining ones from a series of strongly correlated measurements or indices. Measurements showing no distinct correlations with the others constitute autonomic pleiads, independent and such as cannot be characterized by other measurements. Terentev (1960) also suggests a possibility of wider application of this method in biological researches.

The method of correlation pleiads has been introduced into craniometry by Rossolimo (1962) in her study on the variability of *Clethrionomys glareolus* (Schreber, 1780). The objective of this study was a trial to reduce the number of measurements taken on the skull by picking out a few of them, which might be used to characterize the whole skull and form a craniometric basis for the systematics of this species.

The purpose of the present paper is to present the mutual relations and interdependences between the particular measurements of the skull of *Lepus europaeus* Pallas, 1778 in various age groups. Working out the results of the correlations I compared the diagram of Czekanowski (1913) and the method of correlation pleiads. The results obtained from the comparison were used to estimate the usefulness of correlation pleiads for picking out significant measurements for the skull of *L. europaeus*.

II. MATERIAL AND METHOD

The material used for this study was collected in some dozen districts of the Poznań Province (Western Poland). The hares were shot for 15 months, from December 1958 to February 1960. Out of the total of 460 skulls, 100 skulls of age class IV and varying numbers, from 37 to 62, of skulls of classes I and II, treated together because these series of specimens were not numerous, were chosen at random for studies on correlations. Twenty-six linear measurements of skull were taken, of which 12 were selected applying a trial correlation table for further studies. Among these, 10 were strongly correlated with each other, while 2 were characterized by a low coefficient of correlation.

The correlation coefficients were calculated by the formula $r = \frac{\text{Cov}}{\text{st}\bar{x} \cdot \text{s}\bar{y}}$ Student's test was used to check the significance of correlation. The correlation coefficients were arranged in the diagram of C z e k a n o w s k i, on which were based the correlation circles that I formed next.

The determination of age was carried out on the basis of the ossification of skull sutures (C a b o ń - R a c z y ń s k a, in preparation). The material was grouped in four age classes: class I consisting of specimens about 3—6 months old, class II of those 6—8 months old, class III including animals about 1 year of age, and class IV with specimens older than 1 year. No specimens of class III were used for the present study, since the differences obtained from the comparison of the absolute measurements in this class with those in class IV were small and very often statistically not significant. I shall use these denotations of age classes in the further parts of this paper.

III. CORRELATIONS OF MEASUREMENTS

In accordance with the conception of this study the correlations of measurements were considered separately in two groups. The first group comprises young animals (age classes I and II), showing a fairly intense growth of the skull, observed in the increments of the particular measurements (C a b o ń - R a c z y ń s k a, in preparation). The second group includes the skulls of fully grown-up specimens (age class IV) characterized by only individual variation. This group exhibits no statistically significant differences in size. Such a distinction assured the homogeneity of the groups compared.

The correlation of the measurements of the growth group (classes I and II together) is illustrated in the diagram in Fig. 1a. Out of the 12 measurements compared, 10 have high correlation coefficients, the means of which range from 0.588 to 0.757. Seven of them are very strongly correlated with each other and with the remaining measurements. These are the basal length, condylobasal length, profile length, rostral length (measured from the intermaxillary to the constriction in the frontal), nasal length, length of mandible, and that of maxillary tooth-row. It is worthy to emphasize that they are exclusively longitudinal measurements. The lowest correlations appear in 2 measurements: the depth of brain-case and the greatest breadth of both nasals together. In the last case no statistically significant correlation with the nasal length ($r = 0.32$ at $P_{0.05}$) and the palatine height ($r = 0.34$ at $P_{0.01}$) were found. At the same time, however, these characters are fairly strongly correlated with some other measurements ($r > 0.50$).

The relations described are clearly visualized by the graphical presentation of correlation coefficients on the correlation circle (Fig. 2a). According to the rules of formation of the correlation circle (Terentev, 1943; Rossolimo, 1962) the proper limits of the coefficients, facilitating the discrimination of the degrees of correlations of characters, were established. A pleiad of characters with coefficients $r > 0.70$ and a mixed group with coefficients ranging between 0.50 and 0.70 were formed as a result. The inter-group pleiad, in which $r < 0.50$, did not occur in this material. Thus, only two sorts of relations were present, an intra-pleiad relation (marked with a solid line) and a mixed pleiad (marked with a broken line). The mean coefficients of correlation were calculated for the particular measurements of first pleiad, takeing the relation of the given character to the others within the pleiad, i.e., at $r > 0.70$, as a basis for calculation.

Judging by the greatest correlation coefficient of measurements (Rossolimo, 1962), the profile length should be recognized to be a distinctive character of the skull in this period of life, for in the pleiad of the 10 most correlated measurements it is the one that has the highest mean coefficient ($r = 0.84$).

The correlations between the skull measurements in the group of adult specimens (class IV) appear different (Fig. 1b). The values of correlation coefficients are, as a rule, smaller, often even statistically not significant. Only three longitudinal measurements — the condylobasal length, profile length, and basal length — have retained high correlations between each other, at the same time maintaining correlations with all the other measurements uniformly similar. The significance of correlation amounts to 0.25 at $P_{0.01}$ and to 0.19 at $P_{0.05}$. The number of correlations and their degree have decreased considerably compared with the results obtained for still growing skulls. None the less, the many-sided interrelations of longitudinal measurements, well visible in the correlation circle, have persisted (Fig. 2b). Besides those mentioned above, they include the length of diastema, nasal length, rostral length, and length of mandible. The length of maxillary tooth-row, correlated more distinctly only with the condylobasal length is an exception. The remaining measurements do not show any close relations with the others ($r < 0.50$). Practically, the length of maxillary tooth-row and the zygomatic breadth may be reckoned in this group.

Measurement	Diastema	Palatine height	Zygomatic breadth	Nasal lenght	Rostral lenght	Profile lenght	Cb. - lenght	Basal lenght	Lenght of mandible	Maxillary tooth-row	Depth of brain-case	Greatest breadth of both nasals together	r
Diastema													0.588
Palatine height	.50												0.623
Zygomatic breadth	.57	.58											0.626
Nasal lenght	.50	.62	.68										0.660
Rostral lenght	.71	.73	.76	.83									0.727
Profile lenght	.76	.70	.65	.77	.90								0.745
Cb.- lenght	.74	.76	.58	.85	.87	.95							0.754
Basal lenght	.74	.73	.68	.75	.84	.93	.96						0.757
Lenght of mandible	.56	.70	.69	.74	.74	.84	.83	.83					0.705
Maxillary tooth-row	.57	.67	.73	.71	.76	.71	.74	.76	.73				0.659
Depth of brain-case	.41	.52	.41	.49	.39	.46	.54	.58	.59	.40			0.471
Greatest breadth of both nasals together	.41	.34	.56	.32	.47	.53	.48	.53	.51	.47	.39		0.454

r = 0.90 - 1.00 0.80 - 0.89 0.70 - 0.79 0.60 - 0.69

a

'ig. 1. Correlation of skull measurements in age classes I and II (a)

The differences in correlations of skull measurements between the young hares (age classes I and II) and the old, grown-up, ones (age class IV) reflect the changes taking place in the course of the process of final formation of the skull shape in individual development. This process leads to the lowering of the correlations between particular elements of the skull, which has already been shown at the description of the graphical presentation of correlation coefficients on the correlation circles. To illustrate the course of this phenomenon in time a correlation table was made for the four successive age classes, comparing the pairs of characters whose coefficient values, high for classes I and II, underwent a remarkable decrease in age class IV. Then, the decrease of correlations from age

Measurement	Zygomatic breadth	Palatine height	Nasal lenght	Rostral lenght	Profile lenght	Cb. - lenght	Basal lenght	Diastema	Lenght of mandible	Maxillary tooth-row	Greatest breadth of both nasals together	Depth of brain-case	r'
Zygomatic breadth													0.343
Palatine height	.44												0.364
Nasal lenght	.24	.45											0.415
Rostral lenght	.30	.33	.58										0.455
Profile lenght	.40	.41	.61	.68									0.544
Cb.- lenght	.33	.30	.49	.69	.88								0.506
Basal lenght	.31	.37	.44	.61	.85	.88							0.482
Diastema	.28	.29	.55	.58	.59	.58	.56						0.387
Lenght of mandible	.53	.41	.41	.50	.66	.66	.66	.41					0.484
Maxillary tooth-row	.23	.12	.28	.36	.45	.51	.38	.03	.45				0.290
Greatest breadth of both nasals together	.40	.48	.32	.15	.27	.16	.20	.38	.39	.23			0.306
Depth of brain-case	.31	.38	.20	.23	.18	.09	.14	.01	.24	.15	.39		0.211

0.50 – 0.59 ● 0.40 – 0.49 $r < 0.40$

b

and in age class IV (b).

class III upwards, that is to say, in the skulls of specimens about 1 year of age, was observed as a general regularity. Such age changes in correlations of the palatine height and condylobasal length are shown in Fig. 3 by way of example.

It will be seen from these considerations that the skulls of specimens of class IV, i.e., the animals in which the process of intense development and growth of the whole skull has been completed, are fit for systematic studies. The correlation coefficients of skull measurements in this age class are given in the form of a diagram (Fig. 1b). The arrangement of the coefficients proves that the material under study is heterogeneous in respect of morphology and its differentiation lies within the limits of variation of the systematically uniform group.

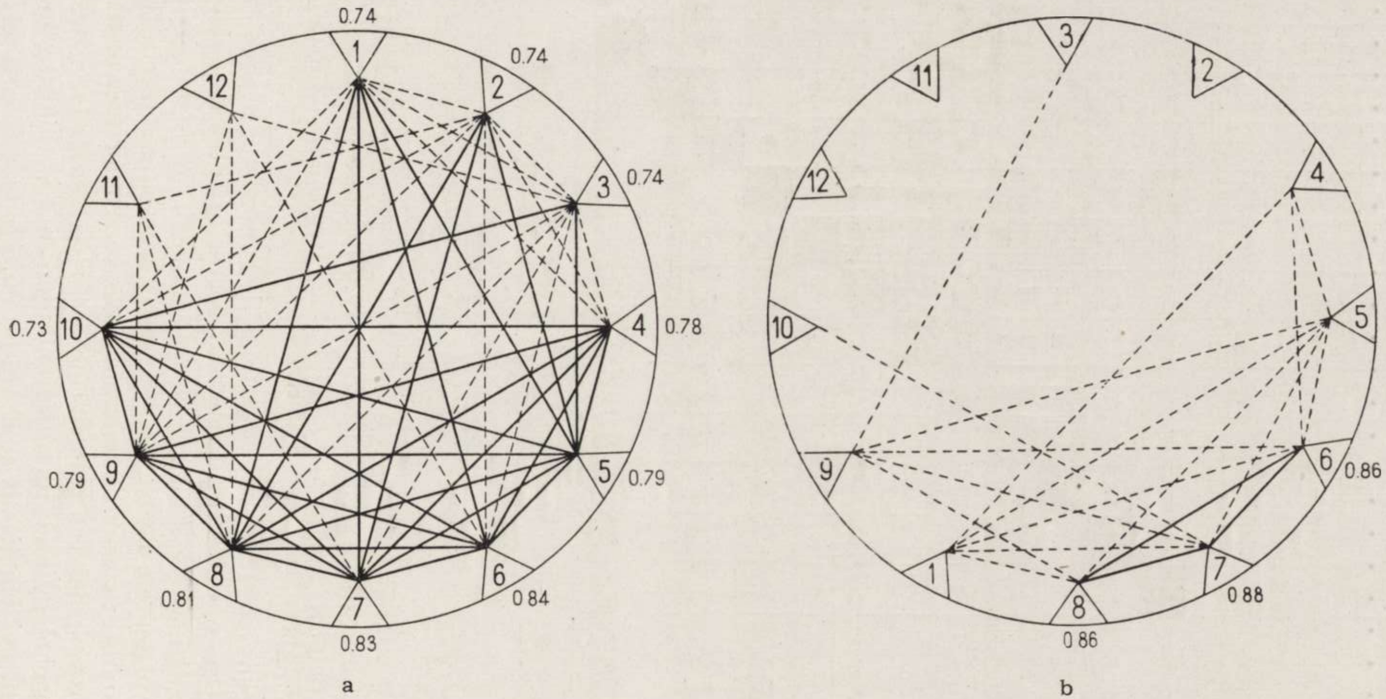

Fig. 2. Correlation circle, a — age classes I and II, b — age class IV. 1. diastema. 2. palatine height, 3. zygomatic breadth, 4. nasal length, 5. rostral length, 6. profile length, 7. condylobasal length, 8. basal length, 9. mandible, 10. maxillary tooth-row, 11. depth of brain-case, 12. greatest breadth of both nasals together.

——————— $= r > 0.70$ — — — — — $= 0.70 > r > 0.50$

IV. DISCUSSION

As a result of the present study I obtained a picture of correlations of the craniological measurements of *L. europaeus* within the age classes representing young and adult specimens. The interpretation of the results from the viewpoint of craniometry can be carried out in two directions: 1) with regard to the usefulness of the method of correlation for working

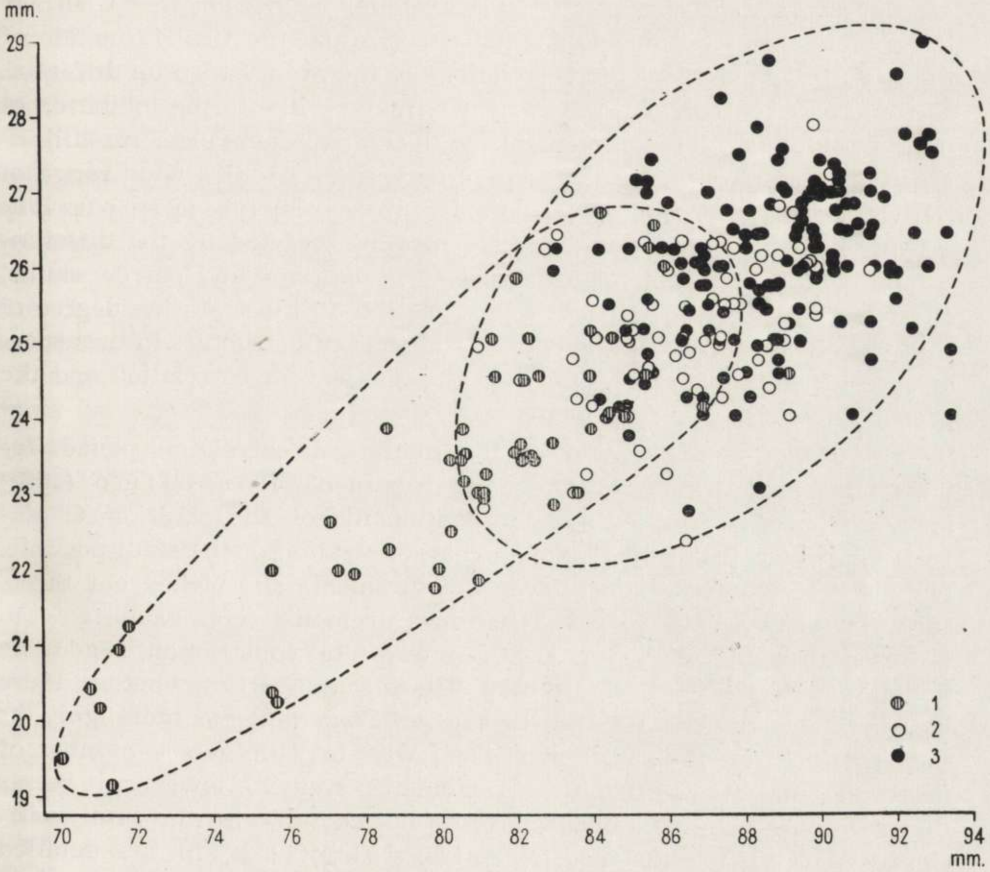

Fig. 3. Correlation of palatine height with condylobasal lenght. 1. age classes I and II, 2. age class III, 3. age class IV.

out age variation in the skull and 2) to find the value of this method applied for systematics.

From the comparison of correlations of the two age groups we can conclude about the differences essential to the characteristics of the skull in the process of growth. The significantly high correlation coefficients in classes I and II can be explained by the fact that in this period the particular skull measurements of the hare undergo the process of intense growth to the same degree. The tendency towards growth being general, the individual differences are slight. This tendency is particularly well seen in the group of longitudinal measurements, which have the highest correlations with each other, pointing to a great similarity in the course of longitudinal growth between skulls. The general growth trend brings about the fact that the mutual relations between the breadth measurements, as well as between the breadth, height and length measurements are expressed also by a fairly high correlation coefficient ($r = 0.50$). On the completion of the developmental changes and the final formation of the skull in age class IV the correlations of the groups turn up different. The decrease of correlation coefficients may by due to the inhibition of the growth of some cranial elements, with the remaining elements still increasing. Some additional differences may result from a wide range of individual variation in the particular measurements (C a b o ń - R a c z y ń s k a, in preparation), or they may be effected by the differentiation of certain morphological types of skulls (long and narrow skulls, short and broad skulls, etc.). It seems possible to illustrate the degree of mutual relations of particular elements of the skull structure in the aspect of age sufficiently clearly, applying the method of correlation and the proper selection of measurements.

The question of application of the method of correlation pleiads for taxonomic purposes needs a critical treatment. R o s s o l i m o (1962) made a trial of sorting out such measurements of the skull of *C. glareolus* as would make the thorough characterization of the skull possible. Out of the eight correlated linear measurements she picked out three, each representing one pleiad. These measurements refer exclusively to the breadth of skull and include the interorbital constriction, zygomatic breadth, and breadth of brain-case. The question arises whether these measurements can characterize the skull of *Clethrionomys* thoroughly, as the intention of R o s s o l i m o (1962) was to eliminate a number of measurements so as to facilitate craniometric studies. However, it seems that the characters mentioned above do not characterize the skull sufficiently. And so, for instance, W a s i l e w s k i (1952), in his detailed craniometric study on *C. glareolus,* pointed among others to a wide range of age variation in the zygomatic breadth, which might even be regarded as a criterion for determination of age. Consequently, this character must not be used for systematic purposes in spite of what R o s s o l i m o (1962) suggested. Comparing the systematic differences between *C. glareolus* and *C. frater* (T h o m a s, 1908) in her later paper (R o s s o l i m o, 1963) the authoress does not confine herself exclusively to the measurements she has sorted out but analyses many more of them. It seems to me that the taxonomic value of the measurements under study can be finally determined by a trial carried out, for instance, on two "genuine" subspecies. This trial connotes the keeping of close homogeneity of the material in all respects, as proved by the present study, in which the differences in age are responsible for essentially different results.

Applying the method of Terentev (1943; 1960) and Rossolimo (1962) for picking out characters, one character, i.e. the one having the highest mean correlation coefficient, should be chosen for age classes I and II, in the case of the hare the profile length ($r = 0.84$). Instead, for class IV only three longitudinal measurements show high correlation: the condylobasal length, profile length, and basal length of skull. These lengths are similarly correlated with the remaining skull measurements, which, besides, results from the fact that they have a common measuring point and their absolute values are similar, as well. I will hazard the couclusion that in this case one measurement having the highest mean coefficient, and so the condylobasal length ($\bar{r} = 0.88$), can be used instead of three. The remaining 10 measurements, being independent of each other in class IV, should also be taken into consideration in the studies on the hare.

The present considerations suggest that the selection of some measurements by the method of correlation does not determine their value for taxonomy, but only, defines the mutual relations between them. The systematic differences may occur in the measurements and characters eliminated by the application of this method.

V. SUMMARY

It was shown by comparison of the correlation circles that there is a strong interdependence of skull measurements in the group of intensely growing hares (age class I and II), which next decreases significantly in specimens fully grown up (class IV).

An analysis of correlation of the measurements revealed that the skulls with their proportions thoroughly fixed, in the case of the hare as late as the second year of life, are fit for craniometric-taxonomic studies.

Three measurements in the fourth class of age, the profile length, condylobasal length, and basal length of skull, exhibit high correlation with each other and have similar correlation coefficient with the other skull measurements. Thus, it is possible to take only one of them, i.e. the condylobasal length, into account in all sorts of craniometric studies of the hare.

The authoress thinks that Terentev's method of correlation pleiads can be used for characterization of the age groups, but she questions the value of craniological measurements selected by means of correlation pleiads for taxonomic purposes.

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STRESZCZENIE

Przebadano korelację 12 pomiarów czaszki zająca szaraka *Lepus europaeus* P a l l a s, 1778 w aspekcie różnic wiekowych, dysponując serią 37—62 czaszek okazów młodych (I i II klasa wieku) oraz serią 100 czaszek dorosłych (V klasa wieku). Materiał pochodził z terenu województwa poznańskiego. W opracowaniu wyników korelacji posługiwano się diagramem C z e k a n o w s k i e g o (1913) i metodą plejad korelacyjnych T e r e n t e v a (1943).

Stwierdzono wysoką korelację większości analizowanych pomiarów u okazów młodych. w fazie wzrostu czaszki. W IV klasie wieku stwierdzono istotne zmniejszanie się korelacji pomiarów, jedynie długość kondylobazalna, długość profilu i długość podstawy czaszki wykazały między sobą wysokie związki korelacyjne. Na tej podstawie uznano, że długość Cb. może zastąpić dwa pozostałe pomiary w opracowaniach kraniometrycznych *L. europaeus*. Analiza pomiarów wskazuje, że do opracowań systematycznych zająca szaraka przydatne są czaszki okazów w wieku powyżej jednego roku życia. Stwierdzono przydatność metody plejad korelacyjnych dla charakterystyki grup wiekowych, poddano natomiast krytyce wartość pomiarów kraniometrycznych wybranych tą metodą dla celów taksonomicznych.