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# Estimation of Body Weights From Craniometric Variables in Baboons

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*KEY WORDS* Body weight, Baboons, Craniometrics, Weight estimation

*ABSTRACT* Body weights of adult baboons (genera *Papio, Mandrillus*, and *Theropithecus*) were gathered from notes of collectors and museum records. However, these data were insufficient to establish mean body weights for all baboon groups. Thus, log cube roots of mean body weights were regressed as functions of the logs of several cranial and dental variables. The resulting least squares regression coefficients were used to estimate weights for 503 adult baboons from cranial measurements. The ability of the various regression functions to assess baboon body weight was determined by comparing reported and estimated mean and individual body weights. The best estimator of baboon body weights was the function derived from the factor scores of a principal components analysis of seven craniometric variables regressed on body weight. However, each of these craniometric variables singly was nearly as precise an estimator of body weight as the multivariate combination of all seven. Other measurements such as dental dimensions and foramen magnum area estimated weight less accurately. Body weight estimates derived from the regression analyses coupled with museum and literature records allowed an assessment of size relationships among all baboon groups.

Body weights of wild primates are useful in morphological, paleontological, ecological, and biomedical studies. However, such data are often unavailable or limited for many primate species resulting in the use of other measures as estimates of body size. For instance, morphological studies that account for changes in shape relative to body size (allometry) of body parts must often rely on morphometric variables other than weight to approximate the body size relationships. Such variables may include, for example, molar dimensions (Kay, 1975; Gingerich, 1977), maxillary postcanine area (Gould, 1975), incisor dimensions (Pilbeam and Gould, 1974; Hylander, 1975), cranial dimensions such as skull length (Wood, 1979; Gould, 1975; Pirie, 1978), postcranial measurements such as femur length or pelvic dimensions (Mobb and Wood, 1977; Steudel, 1981), cranial capacity, and foramen magnum area (Radinsky, 1967). Some studies (Thorington, 1972; Hursh, 1976; Corruccini, 1978) use Jolicoeur's (1963a,b) logarithmic principal component technique to generate an independent size variable from a data set that lacks one. Likewise, size comparisons are difficult in paleontological studies where not only body weight data is lacking but body remains are confined to teeth or skeletal fragments. In these cases, body weight estimates are based on the relationship between morphometric and body weight data in related living animals. The usefulness of weight estimates for the fossils can be judged by comparing how well morphometric variables estimate weights in related living groups with known body weights.

The first goal of this study is to summarize and compare body weight data for living baboons (genera *Papio, Mandrillus, Theropithecus*). To this end, body weight data were collected from museums and the literature. Unfortunately, the data do not represent all baboon groups. Thus, the relationship be-

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tween body weight and various cranial and dental variables is delineated to estimate body weight in those baboon groups that lack weight data. The second goal of this study is to determine the accuracy of various cranial and dental variables in estimating baboon body weights. This information is useful in selecting size variables for allometric and functional studies of baboon morphology (Dechow, 1980a,b, 1981) and paleontological studies (Dechow, 1982).

## MATERIALS AND METHODS

Members of the three African primate genera, *Papio Mandrillus*, and *Theropithecus*, commonly considered baboons, are included in this study. The various groups of *Papio* are refered to by vernacular names, namely, guinea, olive, yellow, chacma, and hamadryas baboons. According to the classification of Hill (1970), these refer, respectively, to the following taxa: *Papio papio*, *P. anubis*, *P. cynocephalus*, *P. ursinus*, and *P. hamadryas*. One group of *Papio*, called *P. cynocephalus kindae* by Hill (1970), which is distinctive by its small body size, is separated from other yellow baboons and referred to as kinda baboons. To maintain this use of vernacular names throughout, the two species of *Mandrillus*, *M. sphinx* and *M. leucophaeus*, are called mandrills and drills while members of the species *Theropithecus gelada* are referred to as geladas.

Body weight data of adult baboons (third molars in occlusion) were obtained from museum records, notes of professional animal collectors, and the literature. As far as can be ascertained, the majority of the weight measurements were made on the animals at or near the time of capture or shooting. The following museums were the source of weights: American Museum of Natural History (2); British Museum of Natural History (9); Field Museum of Natural History (1); Florida State Museum (37); United States National Museum of Natural History (17), and the Laboratoire de Zoologie of the Museum National d'Histoire Naturelle, Paris (14). Weight records were also supplied by Drs. C. Jolly of New York University (6) and D. Starck of Senckenbergische Anatomie in Frankfort am Main (25). An additional 15 records were found in the literature (Drake-Brockman, 1910; Hill, 1970; Malbrant and Maclatchy, 1949; Napier and Napier, 1967; Walker, 1968).

A total of 124 baboon body weights were collected; 91 of these were associated with cranial remains. An additional 412 crania without associated body weights from adult wildshot or captured baboons were also examined. Most cranial measurements were derived from cartesian coordinate data taken with a diagraph, and digitized and processed with the aid of a PDP11 microcomputer. Dental and foramen magnum measurements were made with Helios dial calipers. Cranial capacities were measured with millet seed and a graduated cylinder. Error analyses indicated that all measurement techniques led to replicative results (Dechow, 1980a).

Least squares regressions were carried out with the natural log cube root of mean body weight as functions of the natural logs of various mean dental and cranial measurements. The cranial measurements included alveolare-staphylion length, alveolare-glabella length, glabella-basion length, glabella-staphylion length, glabella-inion length, basion-inion length, and a measurement of cranial vault width between two points located at the most lateral extents of the articular surfaces of the mandibular fossae of contralateral temporal bones. An additional cranial size variable consisted of the factor scores from the first principal component of an analysis of the logs of the above seven craniometric variables. The remaining cranial measurements were cranial capacity and foramen magnum area. Foramen magnum area was computed by adapting the formula for an ellipse: area = ½ length × ½ width × $\pi$. Dental measurements included upper tooth row length (mesial edge of upper third premolar to distal edge of third molar), upper cheek teeth occlusal surface area (upper tooth row length × ½ (upper fourth premolar width + upper second molar mesial width), upper second molar occlusal surface area (length × mesial width), and lower second molar length. One additional variable consisted of factor scores from the first principal component of an analysis of the logs of six dental measurements including upper tooth row length, upper fourth premolar width, upper fourth premolar length, upper second molar width, upper second molar length, and the width of the maxillary incisors measured at the base of the incisors near the enamel-dentine junction. Sequential least-squares regressions were carried out with the cube root of the log of body weight as a function of the two sets of factor scores, the logs of the linear measurements, the logs of the square roots of the area measurements, and the logs of the cube roots of the volumetric measurements.

Function coefficients were also generated for the major principal axes.

The least-squares regression coefficients were used to estimate body weights for the 503 baboons for which cranial remains were examined. In order to test which sets of coefficients were most useful in estimating body weight, (1) estimated mean weights were compared to the reported mean weights of the 15 baboon groups from which weight data were available, and (2) estimated individual weights were compared to reported individual weights of the 91 baboons with known weights and associated crania. These tests were done by subtracting the estimated weights from the reported weights, taking the absolute values of the differences, and then comparing the means of the absolute values between those generated for each set of coefficients. The distributions of the absolute values of the differences between reported and estimated weights were also examined to ascertain that they approximated the expected one-tailed normal curve. All data manipulation and statistics employed either FORTRAN programs written for this purpose or the MIDAS statistical analysis package on the MTS computer system at the University of Michigan.

## RESULTS

The 124 reported baboon weights are summarized in Table 1. Note that the sample sizes for different groups range from 1 to 37 with the majority of groups (11/15) containing less than 10 weights. The means and 90% confidence intervals of the means for the weights are graphically presented in Figures 1 and 2. Male savannah baboon groups range in order of mean weight from largest to smallest as follows: chacma, olive, yellow and hamadryas, kinda. Male olive-yellow hybrids are similar in size to male olive, yellow, and hamadryas baboons. Male mandrills are as large as male chacma and anubis baboons while male geladas are closer in size to male hamadryas and kinda baboons. The similarity of the weight of male drills and olive-hamadryas hybrids to other baboon groups cannot be determined as the weight for only one animal is available for each of these groups.

As expected, the female baboon weights indicate smaller body size than the males (Table 1 and Fig. 2). However, no significant differences are evident between the female groups; the $F$ value (1.95) is not significant at $p > 0.90$ (Fig. 2).

The regression coefficients for the log cube root of mean body weight as functions of the logs of various mean cranial and dental measurements are presented in Table 2. Note that these coefficients are identical to those of the log-transformed version of Huxley's (1932) power function, $y = bx^k$, where $k$ is the slope of the regression line and $b$ is the intercept. Most of the $k$ coefficients associated with the neurocranium are larger than unity indicating that the cube root of body weight increases more quickly (positive allometry) than linear neurocranial dimensions or the cube root of cranial capacity. The exceptions are basion-inion length, which increases at a similar rate as the cube root of body weight, and cranial vault width, which increases more quickly. Likewise, the cube root of body weight is positively allometric with respect to the dental variables. However, the cube root of body weight is negatively allometric to facial variables, especially those measuring the length of the face such as alveolare-glabella length, indicating that facial length increases faster than the cube root of body weight among adult baboons.

The coefficients from the principal components analysis of the seven cranial and six dental measurements used to generate the two sets of factor scores are given in Table 3. These coefficients have similar values ranging between 0.36 and 0.40 for the cranial measurement analysis and 0.37 and 0.44 for the dental measurement analysis. The eigenvalues indicate that a high proportion of the variance is explained by a single vector in either analysis: 84% for the cranial measurements and 80% for the dental measurements.

The summary of the differences between estimated and reported weights for mean group weights and individual weights are reported in Tables 4 and 5, respectively. These two tables show a similar result in the ranking of the sets of regression coefficients from those that most accurately to those that least accurately estimate weight in baboon groups (Table 4) or individuals (Table 5) with known weights. On the whole, cranial dimensions more accurately estimate body weight than dental dimensions. The factor scores from the principal components analysis of the cranial dimensions are the best measurements for estimating weight for individuals and second best for the group means. However, some of the single cranial measurements produce regression coeffients that are nearly as accurate in estimating body weight including glabella-

*TABLE 1. Summary of data on baboon body weight*[1]

| Baboon group | Sex | N | Mean | S | Range |
|---|---|---|---|---|---|
| Chacma | m | 3 | 31.2 | 2.7 | 28.2-33.6 |
| Olive | m | 37 | 25.1 | 4.6 | 18.6-37.3 |
| Yellow | m | 20 | 22.8 | 2.7 | 18.8-28.6 |
| Hamadryas | m | 13 | 21.3 | 4.0 | 16.8-30.4 |
| Kinda | m | 2 | 16.3 | 1.3 | 15.4-17.2 |
| Drill | m | 1 | 20.0 | | |
| Mandrill | m | 7 | 26.9 | 6.5 | 19.5-39.0 |
| Gelada | m | 5 | 19.0 | 1.9 | 16.5-20.5 |
| Olive-yellow | m | 6 | 22.8 | 1.8 | 20.9-26.1 |
| Olive-hamadryas | m | 1 | 20.0 | | |
| Olive | f | 16 | 14.1 | 2.7 | 8.3-17.9 |
| Yellow | f | 1 | 15.9 | | |
| Hamadryas | f | 2 | 12.0 | 0.4 | 11.7-12.3 |
| Mandrill | f | 2 | 11.5 | 0.7 | 11.0-12.0 |
| Gelada | f | 8 | 11.7 | 2.1 | 8.3-13.8 |

[1]All weights are in kilograms.

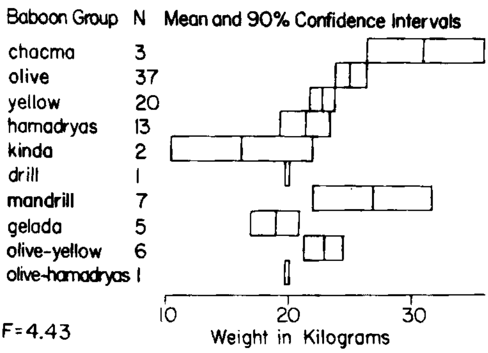


Fig. 1. Comparison of body weight statistics for male baboon groups. The central line in each bar represents the mean while the bar represents the 90% confidence interval. Confidence intervals are not given for drills and olive-hamadryas hybrids as their small sample sizes lead to such large intervals as to make comparisons with other groups useless.

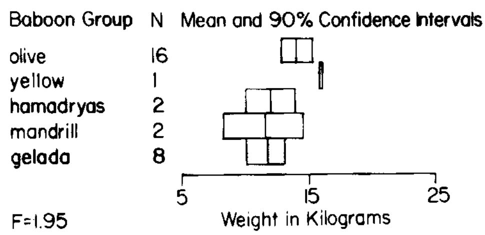


Fig. 2. Comparison of body weight statistics for female baboon groups. Representation of means and confidence intervals is the same as in Figure 1. Confidence intervals are not given for yellow baboons due to small sample size.

inion length, glabella-staphylion length, glabella-basion length, alveolare-glabella length, and alveolare-staphylion length. Cranial vault width and basion-inion length are the least accurate of the single linear cranial dimensions. Cranial capacity also rates poorly; foramen magnum area is the poorest, leading to errors in the estimation of individual body weights of up to 23.64 kg.

On the whole, the dental measurements produce regression coeffients that estimate baboon body weight less accurately than the cranial measurements. Upper tooth row length and the factor scores from the principal components analysis are the best of the dental measurements for estimating weight; upper cheek teeth occlusal surface area, upper second molar occlusal surface area, and lower second molar length are the poorest among the dental measurements and in general.

The estimated weights presented in this study were generated from the least-squares regression of log mean cube root of body weight as a function of the mean factor scores from the cranial principal components analysis (Fig. 3). No particular group of baboons shows a large deviation from the regression line; the correlation coefficient ($r = 0.97$) is highly significant. Other correlation coefficients between the log cube root of body weight and the logs of the remaining dental and cranial variables decrease in a fashion similar to that found for the differences between estimated and reported weights.

A plot of reported versus estimated body weights for the 91 individual animals is presented in Figure 4. As expected, the correla-

*TABLE 2. Least-squares regression and major axis coefficients for the log cube root of mean body weight as a function of the log of various mean cranial and dental measurements*[1]

| Variable | Least-Squares Regression | | | Major axis | | |
|---|---|---|---|---|---|---|
| | Slope | | Y-intercept | Slope | | Y-intercept |
| First principal component–cranial measurements | 0.045 | (0.003) | 1.004 | 0.044 | (0.003) | 1.004 |
| Glabella–inion length | 1.60 | (0.12) | −2.79 | 1.69 | (0.12) | −3.00 |
| Alveolare–glabella length | 0.48 | (0.06) | −0.15 | 0.49 | (0.05) | −0.19 |
| Glabella–staphylion length | 0.86 | (0.08) | −0.61 | 0.90 | (0.07) | −0.68 |
| Glabella–basion length | 1.33 | (0.13) | −1.83 | 1.44 | (0.13) | −2.07 |
| Alveolare–staphylion length | 0.49 | (0.07) | −0.06 | 0.52 | (0.06) | −0.12 |
| Upper tooth row length | 1.12 | (0.20) | −0.78 | 1.41 | (0.23) | −1.23 |
| Basion–inion length | 0.84 | (0.12) | −0.48 | 0.94 | (0.12) | −0.65 |
| Cranial vault width | 0.29 | (0.04) | 0.12 | 0.30 | (0.04) | 0.10 |
| First principal component–dental measurements | 0.050 | (0.010) | 1.00 | 0.051 | (0.009) | 0.996 |
| Upper cheek teeth occlusal surface area (square root) | 1.17 | (0.25) | 0.07 | 1.64 | (0.34) | −0.29 |
| Cranial capacity (cube root) | 1.98 | (0.39) | −2.37 | 2.84 | (0.54) | −3.82 |
| Upper second molar occlusal surface area (square root) | 1.32 | (0.29) | 0.79 | 1.93 | (0.40) | 0.71 |
| Lower second molar length | 1.16 | (0.27) | 0.79 | 1.70 | (0.38) | 0.71 |
| Foramen magnum area (square root) | 1.25 | (0.35) | 0.37 | 2.16 | (0.62) | −0.06 |

[1]The standard error of the slope is in parentheses to the right of the slope. All least-squares regressions use the log cube root of body weight as the dependent variable (*Y* axis) and the log of one of the above variables as the independent variable (*X* axis). For major axis, the variables are positioned in a like fashion on the *X* and *Y* axes although neither is strictly dependent or independent. Surface measurements use the log square root of the measurement and volumetric measurements use the log cube root.

*TABLE 3. Principal components analysis for cranial and dental measurements—first principal components*

| Cranial measurements | | Dental measurements | |
|---|---|---|---|
| Variable | Coefficient | Variable | Coefficient |
| glabella–inion length | 0.3782 | tooth row length | 0.4399 |
| alveolare–glabella length | 0.3918 | upper fourth premolar width | 0.3940 |
| alveolare–staphylion length | 0.3868 | upper fourth premolar length | 0.4074 |
| glabella–staphylion length | 0.3840 | upper second molar width | 0.4171 |
| glabella–basion length | 0.3765 | upper second molar length | 0.4120 |
| basion–inion length | 0.3654 | maxillary incisor width | 0.3762 |
| cranial vault width | 0.3621 | | |
| Eigenvalue = 5.94 | | Eigenvalue = 4.85 | |
| Proportion of explained variance = 85% | | Proportion of explained variance = 81% | |

*TABLE 4. Summary of differences between estimated mean weights and reported mean weights for baboon groups*[1]

| Variable used to estimate weight | Number of groups | Mean | S | Range |
|---|---|---|---|---|
| Glabella–inion length | 15 | 1.16 | 0.72 | 0.13–2.43 |
| First principal component–cranial measurements | 15 | 1.32 | 0.74 | 0.16–2.36 |
| Glabella–staphylion length | 15 | 1.43 | 1.09 | 0.25–3.42 |
| Glabella–basion length | 15 | 1.48 | 1.02 | 0.13–3.33 |
| Alveolare–glabella length | 15 | 1.57 | 1.19 | 0.13–3.86 |
| Alveolare–staphylion length | 15 | 2.11 | 1.49 | 0.59–5.11 |
| Upper tooth row length | 15 | 2.12 | 1.41 | 0.14–5.19 |
| Cranial vault width | 15 | 2.25 | 1.66 | 0.30–6.43 |
| Basion–inion length | 15 | 2.27 | 1.91 | 0.19–6.94 |
| First principal component–dental measurements | 15 | 2.43 | 1.69 | 0.01–5.45 |
| Cranial capacity | 15 | 2.57 | 1.57 | 0.42–5.75 |
| Upper second molar occlusal surface area | 15 | 2.59 | 1.73 | 0.13–6.44 |
| Lower second molar length | 15 | 2.60 | 1.74 | 0.16–5.67 |
| Upper cheek teeth occlusal surface area | 15 | 2.66 | 1.51 | 0.41–5.38 |
| Foramen magnum area | 15 | 3.57 | 2.26 | 0.09–7.71 |

[1]Weight differences are in kilograms.

*TABLE 5. Summary of differences between estimated weights and reported weights for individual baboon specimens*[1]

| Variable used to estimate weight | Number of individuals | Mean | S | Range |
|---|---|---|---|---|
| First principal component–cranial measurements | 87 | 2.02 | 1.90 | 0.08– 9.77 |
| Alveolare–staphylion length | 91 | 2.38 | 2.39 | 0.06–11.70 |
| Alveolare–glabella length | 91 | 2.62 | 2.36 | 0.02–10.72 |
| Glabella–basion length | 87 | 2.64 | 2.56 | 0.07–12.84 |
| Glabella–staphylion length | 91 | 2.73 | 2.54 | 0.01–12.06 |
| Glabella–inion length | 91 | 2.85 | 2.09 | 0.01– 9.67 |
| Basion–inion length | 87 | 3.21 | 2.75 | 0.05–12.48 |
| Cranial vault width | 91 | 3.33 | 2.33 | 0.02–12.34 |
| First principal component–dental measurements | 87 | 3.34 | 3.02 | 0.01–14.87 |
| Upper tooth row length | 89 | 3.43 | 2.94 | 0.03–17.07 |
| Upper cheek teeth occlusal surface area | 89 | 3.45 | 3.09 | 0.00–16.06 |
| Cranial capacity | 91 | 3.74 | 2.66 | 0.09–15.13 |
| Upper second molar occlusal surface area | 91 | 3.61 | 3.11 | 0.00–16.52 |
| Lower second molar length | 91 | 4.06 | 3.30 | 0.05–15.85 |
| Foramen magnum area | 80 | 5.56 | 5.09 | 0.02–23.64 |

[1]Weight differences are in kilograms.

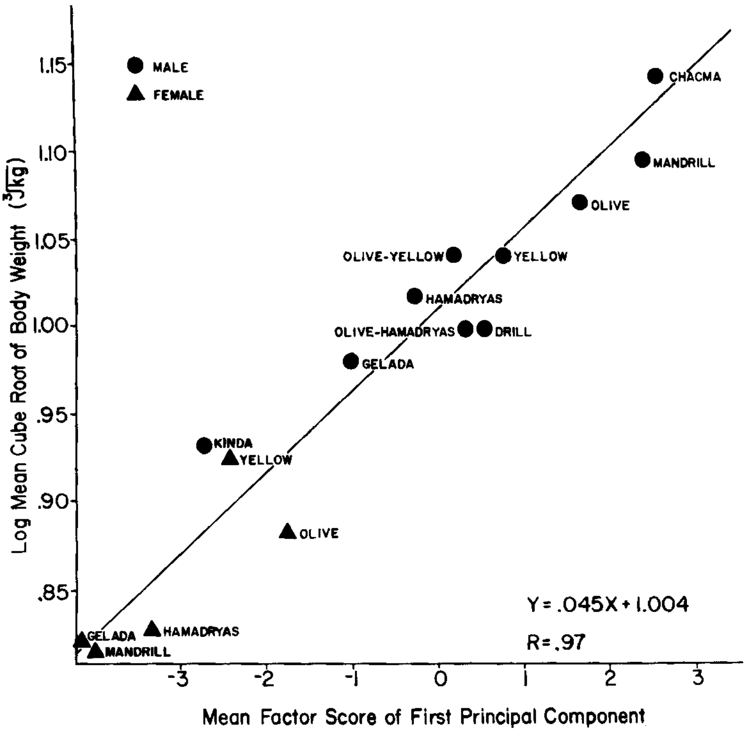


Fig. 3. Plot of log mean cube roots of body weights versus mean factor scores of the first principal component from the analysis of the cranial variables. The correlation coefficient ($r = 0.97$) is significant ($p < 0.01$). The equation found at the lower right of the plot is derived from the least-squares regression coefficients (as discussed in the text); the line in the plot is an illustration of this equation.

tion between these two is high ($r = 0.88$). The breakdown of the individuals in the plot by group demonstrates that no one group of baboons is eccentrically placed with regard to any other about an imagined central axis.

The values of estimated body weight for the various baboon groups based on the cranial principal components analysis are given in Table 6. The means for the various groups along with the 90% confidence intervals are depicted in Figures 5 and 6. A comparison of mean weight values of Tables 1 and 6 shows that group means differ by little more than an average of a kilogram between reported and estimated weights with a maximum of a 2.36 kg difference (see also Table 4). A comparison of Figures 5 and 6 with Figures 1 and 2 shows similar weight relationships between groups in the two sets of figures. However, some additional information is found in those Figures (5 and 6) based on the estimated weight data. Mean estimated weights for male savan-

*TABLE 6. Summary of data on estimated baboon weight*[1]

| Baboon group | Sex | N | Mean | S | Range |
|---|---|---|---|---|---|
| Chacma | m | 59 | 28.9 | 2.9 | 22.3-36.6 |
| Olive | m | 139 | 25.8 | 3.9 | 17.7-36.4 |
| Yellow | m | 42 | 22.6 | 2.4 | 18.2-28.4 |
| Hamadryas | m | 44 | 19.8 | 2.3 | 13.3-24.0 |
| Guinea | m | 10 | 20.2 | 1.8 | 17.6-24.3 |
| Kinda | m | 18 | 14.1 | 1.9 | 12.0-18.2 |
| Drill | m | 21 | 22.0 | 2.3 | 16.9-26.8 |
| Mandrill | m | 14 | 28.5 | 4.4 | 19.8-36.2 |
| Gelada | m | 19 | 17.8 | 2.4 | 14.2-21.8 |
| Olive-yellow | m | 6 | 20.9 | 1.6 | 18.6-23.0 |
| Olive-hamadryas | m | 2 | 21.2 | 1.4 | 20.3-22.2 |
| Chacma | f | 21 | 18.3 | 2.1 | 14.9-22.6 |
| Olive | f | 37 | 16.2 | 2.5 | 10.8-21.3 |
| Yellow | f | 9 | 14.8 | 2.1 | 11.8-17.8 |
| Hamadryas | f | 11 | 13.1 | 1.0 | 10.7-14.4 |
| Guinea | f | 2 | 15.4 | 4.7 | 12.1-18.8 |
| Kinda | f | 14 | 10.0 | 2.0 | 8.4-15.7 |
| Drill | f | 13 | 9.9 | 1.4 | 7.7-12.0 |
| Mandrill | f | 8 | 11.9 | 1.3 | 10.0-14.0 |
| Gelada | f | 13 | 11.7 | 1.6 | 8.2-14.3 |
| Olive-hamadryas | f | 1 | 12.1 | — | — |

[1]All weights are in kilograms; m, male; f, female.

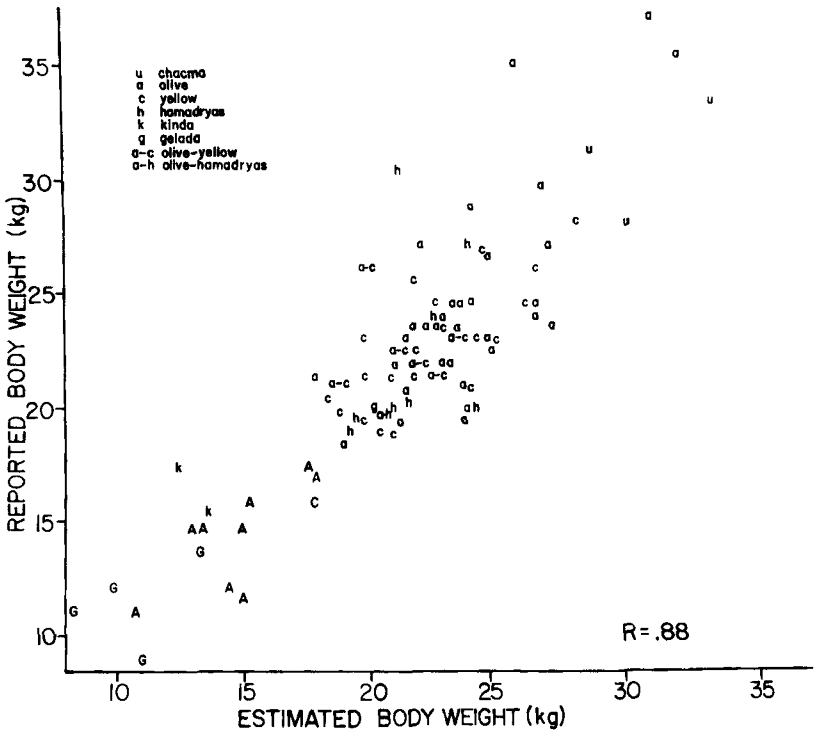


Fig. 4. Plot of reported body weights versus estimated body weights for the 91 baboon crania with known weights. The correlation coefficient ($r$ = 0.88) is significant ($p$ < 0.01). Small letters indicate male individuals while large letters indicate females.

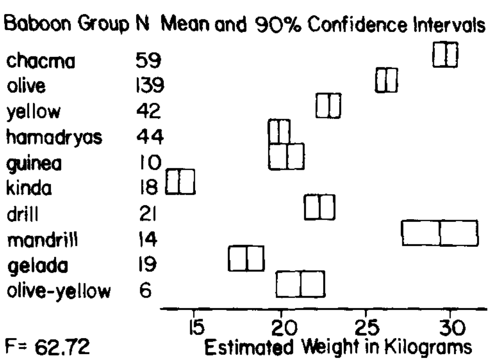


Fig. 5. Comparison of estimated body weight statistics for male baboon groups. Representation of means and confidence intervals is the same as in Figure 1.

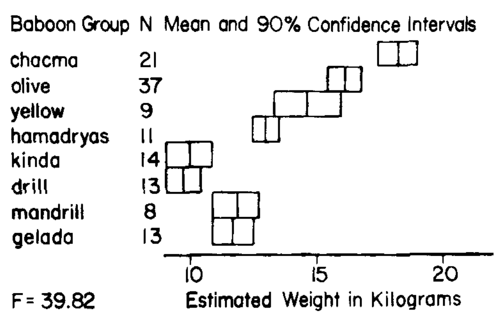


Fig. 6. Comparison of estimated body weight statistics for female baboon groups. Representation of means and confidence intervals is the same as in Figure 1.

nah baboons (Fig. 5) show the following order from largest to smallest: chacma, anubis, yellow, hamadryas and guinea, kinda. Male olive–yellow hybrids are similar in mean weight to male yellow, hamadryas, and guinea baboons. Male mandrillas are similar to male chacma baboons while male drills are near male yellow, hamadryas, and guinea baboons. Male geladas are small being closest to male hamadryas and guinea baboons. Male olive–hamadryas hybrids are also close in weight to male hamadryas, yellow, and guinea baboons although their sample size (n = 2) is too small to compute a reasonable confidence interval for comparison.

Overall, mean estimated weights among the female baboon groups show the same similarities and differences as among the males (Fig. 6). The most notable exception is the small weight of female mandrills and drills. Among male groups, drills and especially mandrills are relatively much larger.

## DISCUSSION

### *Baboon weights*

Berger (1972) reports a mean of 21.1 kg for 177 male olive baboons from southern Kenya ($s = 3.9$). The mean of Berger's sample is lower by more than 4 kg than either the mean reported (Table 1) or estimated (Table 6) weight found in the present study. This discrepancy may be due to one of the following two factors: first, Berger includes dentally immature animals, in which the canines were not fully erupted, as adults. Second, there are geographic differences in body weight among olive baboons. For instance, animals near the yellow baboon range in southeastern Kenya are smaller than baboons further to the west within the olive baboon range. Phillips-Conroy and Jolly (1981) report smaller anubis baboons (male mean weight = 21.2 kg, $n = 39$, $s = 2.1$, range = 16.2–26.4) in the Awash National Park in Ethiopia near the olive–hamadryas hybrid zone. Berger's sample includes only representatives of olive baboons from southern Kenya while the data reported in the present study represent many specimens from throughout the olive baboon range including individuals representing the extremes of body size for the group.

Hill (1970) reports large weights of 30, 38, and 38 kg for three olive baboons from Tibesti (provided by Dekeyser and Derivot). However, Hill states further that this group of animals is a race of olive baboons that is small in body size. Skulls in the Laboratoire de Zoologie (Paris) also suggest that olive baboons from Tibesti are small in size and cast doubt on the magnitude of the weight figures given above. Thus, these three weights were not used in the analyses in this study.

Hamadryas baboons may also show some variation within their range in body size. Harrison (1964) notes that the body size of hamadryas baboons from Arabia may be slightly less than those from East Africa. Several crania from Arabian hamadryas baboons in the British Museum of Natural History support this statement. The hamadryas baboons in the Awash National Park (Phillips-Conroy and Jolly, 1981) (male mean weight = 16.9 kg, $n = 41$, $s = 1.9$, range = 13.2–24.0; female mean weight = 9.9 kg, $n = 39$, $s = 1.3$, range 7.3–13.2) are on the average smaller than the more geographically diverse sample reported in the present study.

Several authors (Smithers, 1966; Silva, 1970; Maberly, 1965, 1967; Shortridge, 1934) remark on body weights of chacma baboons from several areas in southern Africa. They report that adult males may become as large as 90 pounds (41 kg). No animals in this study are found at this extreme (Table 1) and estimated weights from crania only predict an upper limit of about 37 kg (Table 6).

A body weight of 8.16 kg for one male guinea baboon is given by Hill (1970). However, weight estimations from craniometric data (Table 6 and Fig. 5) suggest this is not a representative weight for an adult male guinea baboon; a body weight in the range of 17.6–24.3 kg would correspond with weights estimated in this study suggesting the possibility that the weight reported by Hill is that of a juvenile.

The best information on body weights in wild adult mandrills is provided by Malbrant and Maclatchy (1949). They report eight male weights of 11.3, 13.2, 21, 24, 27, 28, 30, and 39 kg. However, they do not give data on the age of the animals and it may be that the smallest weights are those of juveniles. Those weights from 21–39 kg are treated as the adult sample (see Table 1) along with a single weight (19.5) given by Napier and Napier (1967). The range corresponds well with the estimated weights (Table 6) for mandrills based on cranial measurements (19.8–36.2; $n = 14$). In contrast, Walker (1968) reports that mandrills may weigh up to 54 kg.

Few data are available on body weights for wild adult male drills. There is a single weight of a male drill of 20 kg given by Malbrant and

Maclatchy (1949). Walker (1968) states that mandrills are "more stocky" than drills. This observation is supported by estimated weight data (Table 6) based on cranial measurements. The range of estimated weights for male drills is 16.9–26.8 kg, which is less than the range of 19.8–36.2 kg for male mandrills discussed above.

There are scarcely any data about female baboon weights (Table 1 and Fig. 6) although a few groups, such as olive baboons, have larger sample sizes. Berger (1972) gives a mean of 12.2 kg ($s$ = 1.8) for 237 female olive baboons from Kenya, which is less than the mean reported in Table 1. This difference is probably due to reasons listed above in the discussion of Berger's adult male weight data. Napier and Napier (1967) report that female olive baboons range in weight from 11–15 kg. This range is more limited than that given in Table 1 for reported weights (8.3–17.9 kg; $n$ = 16) or in Table 6 for estimated weights (10.8–21.3 kg; $n$ = 37). Napier and Napier do not give the sample size on which their figures are based. Phillips-Conroy and Jolly (1981) give a mean female olive baboon weight of 9.9 kg ($n$ = 35, $s$ = 1.3, range = 9.3–14.1) for animals from the Awash National Park in Ethiopia. As discussed above, these animals are smaller than baboons found elsewhere in the olive baboon range.

Female chacma baboon weights are given as up to 45 lbs (20.5 kg) by Smithers (1966), and from 32 to 40 lbs (14.5 to 18.2 kg) by Maberly (1965) and Shortridge (1934). No weights for adult female chacma baboons are reported in Table 1. However, the range of estimated weights (14.9–22.6 kg) in Table 6 is similar to those ranges reported in the literature.

Female weights of 11 and 12 kg are also available for two mandrills (Malbrant and Maclatchy, 1949) and one female gelada (13.6 kg) (Napier and Napier, 1967). These figures are reported with museum data in Table 1 and compare closely with estimated weight data (Table 6).

### *Estimations of baboon weight*

Although the relative worth of the function coefficients used to estimate weight (Table 2) could be more easily determined by considering the correlation coefficients between log body weight and each of the logs of the various cranial and dental variables, the present analysis allows an assessment of the error involved in estimated weight measurements themselves. A comparison of the error ranges in Tables 4 and 5 show that mean weights can be estimated much more accurately than individual weights. In fact, the best estimators of mean weight, glabella-inion length and the factor scores from the cranial principal components analysis, predict all mean weights with a maximum error of only 2.36 kg. The best estimator for individual weights, the cranial principal components analysis factor scores, predicts with a maximum error of 9.77 kg, a figure nearly four times that found for mean weights. However, the analysis presented in this study is not sufficiently sophisticated to indicate the number of individuals needed to accurately estimate mean body weight.

The best craniometric measurements for estimating weight were a multivariate combination of several cranial dimensions or these cranial dimensions singly (see Tables 4 and 5). Cranial capacity, foramen magnum area, and most dental dimensions less accurately estimated body weight. Gingerich (personal communication) suggested that cranial dimensions were better estimators of body weight than dental dimensions because the regression coefficients were calculated from the means of baboons groups of like sex. He predicted that if (1) the average weights of mixed male–female populations were estimated as if sex were unknown (which is often the case in fossil samples) and (2) individual weights were estimated using regressions based on mixed-sex samples, dental dimensions would yield better predictions than cranial measurements. This was not borne out by appropriate tests of Gingerich's predictions; i.e., most cranial variables were better estimators of body weight than most dental variables despite the substitution of mixed sex for single sex samples. This further demonstrates the claim that cranial measurements in baboons are better estimators of body weight and size than measurements of teeth.

The above results also emphasize the usefulness of multiple estimators for weight. Single measurements of any kind but especially of dental measurements may lead to large degrees of error. However, some single cranial measurements estimated weight with as great an accuracy as the principal component scores. Unfortunately, multiple estimators are not always available for fossil specimens. In these cases, conclusions drawn from predictions of biomass should take into consideration the large degrees of possible error and should rely on predictions made from several variables. The coefficients outlined in this study should be of use in estimating body weights for other cranial specimens of extant and fossil baboons. However, extension of these functions to other groups of primates requires additional studies.

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