A Preliminary Analysis of Cranial Size Difference in the Genus Callicebus

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INTRODUCTION

The South American Titi, genus *Callicebus*, is a small to medium sized, frugivorous monkey. Previous studies of cranial size difference among *Callicebus* species were known by HERSHKOVITZ (1963, 1988 and 1990). However, his studies were on the basis of the basic statistics of several measurements, and the overall cranial size itself has not been discussed based on the multivaliate analysis. This paper aims to analyze the overall size of *Callicebus* skull applying the multivaliational statistical method.

MATERIALS AND METHODS

The classification and nomenclature of *Callicebus* were taken from HERSHKOVITZ (1988). The size differences of the following seventeen forms of *Callicebus* were analyzed: *C. modestus, C. donacophilus, C. olallae, C. brunneus, C. caligatus, C. cupreus cupreus, C. c. discolor, C. c. ornatus, C. dubius, C. hoffmannsi hoffmannsi, C. h. baptista, C. moloch, C. personatus, C. torquatus lucifer, C. t. lugens, C. t. medemi, C. t. purinus.* The materials used in the present study consist of the dried skull of *Callicebus* male and female combination because of no sexual dimorphism (HERSHKOVITZ, 1990). They were obtained from the collection of the American Museum of Natural History (New York, U.S.A.), the Field Museum of Natural History (Chicago, U.S.A.), the U.S. National Museum of Natural History (Washington, D.C., U.S.A.), the Museu

Table 1. Sample size in the present study.

	N
Callicebus modestus	1
C. donacophilus	10
C. olallae	1
C. brunneus	16
C. caligatus	26
C. dubius	1
C. cupreus cupreus	35
C. c. discolor	75
C. c. ornatus	57
C. hoffmannsi hoffmannsi	26
C. h. baptista	12
C. moloch	39
C. personatus	13
C. torquatus lucifer	13
C. t. lugens	65
C. t. medemi	10
C. t. purinus	6

Nacional do Rio de Janeiro (Rio de Janeiro, Brazil) and the Royal Natural History Museum (Stockholm, Sweden). The sample size used in each form of *Callicebus* is listed in Table 1.

The twenty-three following cranial measurements were employed:

(1) nasion—rhinion.

(2) rhinion—prosthion.

(3) nasion—prosthion.

(4) left maxillofrontale—right maxillofrontale.

(5) left frontomalare orbitale—right frontomalare orbitale.

(6) left zygomaxillare superior—right zygomaxillare superior.

(7) left frontomalare orbitale—left zygomaxillare superior.

(8) left zygomaxillare superior—left zygomaxillare inferior.

(9) greatest width across outer margins of orbits.

(10) left zigion—right zigion.

(11) smallest width of strictured parts in postorbital portion.

(12) left euryon—right euryon.

(13) prosthion—bregma.

(14) nasion—bregma.

(15) bregma—lambda.

(16) prosthion—lambda.

(17) basion—bregma.

(18) left zygomaxillare inferior—right zygomaxillare inferior.

(19) left kondilion laterale—right kondilion laterale.

(20) left koronion—right koronion.

(21) infradentale—left kondilion laterale.

(22) infradentale—gnathion.

(23) left koronion—left gonion ventrale.

These measurements are illustrated in Figure 1. When the left side of skulls was damaged and could not be measured, the right side was measured since a cranial feature is expressed more or less similarly on the left and right sides of the skull.

Penrose's size distance was used for the analysis of size difference among the forms of *Callicebus*. Principal coordinate analysis was applied to the distance matrix to reduce multiple dimensions to single dimension with a minimum loss of total information. EPSON personal computer model PC-286 was used for these calculations.

RESULT

The resultant matrix from the Penrose's size distance is shown in Table 2. The distance between *C. donacophilus* and *C. torquatus purinus* is the largest, and that between *C. personatus* and *C. t. medemi* is the smallest.

On the basis of this matrix, the affinities of the seventeen forms of *Callicebus* can be depicted in one-dimensional space. The score of principal coordinates in each form is drawn in Figure 2. The cumulative proportion of first coordinate is about 100%; it is a very good interpretation because of its very little information loss. These seventeen forms can be divided into three main groups on the basis of their size affinity. The smallest group consists of two species, *C. donacophilus* and *C. olallae*. The score of their first coordinates is from −2.0071 for *C.*
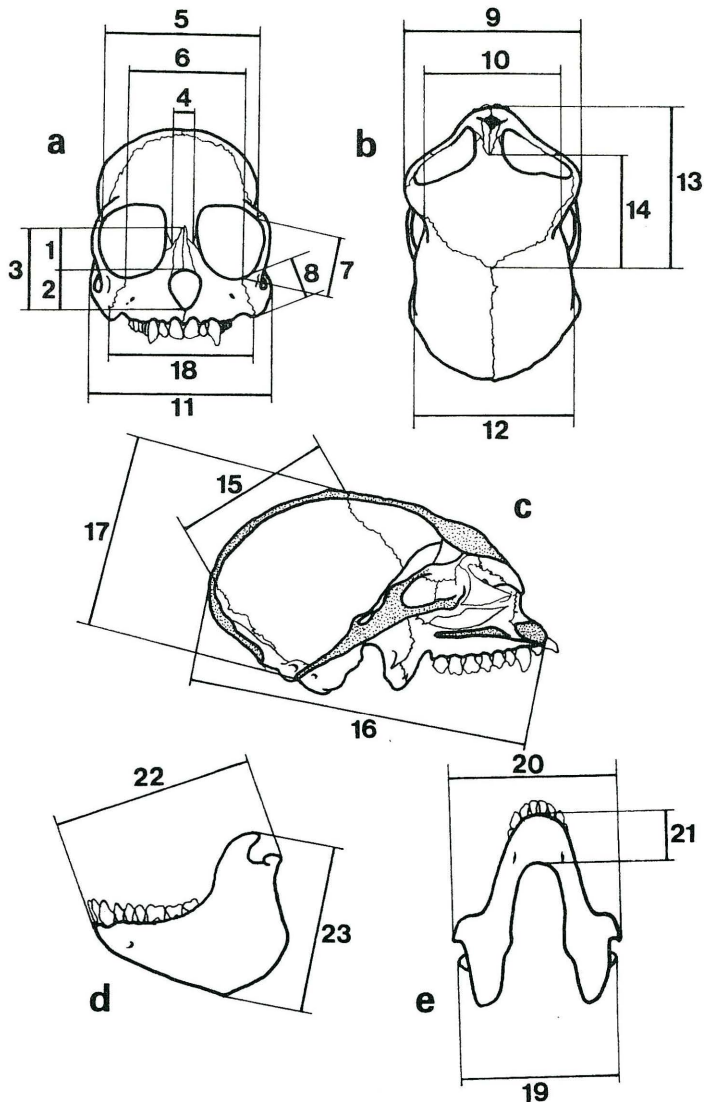
Fig. 1 Skull measurement of *Callicebus* in this study.
a: frontal view of skull; b: dorsal view of skull; c: saggital section of skull; d: lateral view of mandible; e: ventral view of mandible.

donacophilus to −1.5805 for *C. olallae*, its range 0.4266. The middle-sized group involves following seven species, ten forms; *C. modestus, C. brunneus, C. caligatus, C. dubius, C. cupreus cupreus, C. c. discolor, C. c. ornatus, C. hoffmannsi hoffmannsi, C. h. baptista* and *C. moloch*. The smallest coordinate score is −0.6846 for *C. modestus* and the largest one is −0.0542 for *C. brunneus*, its range 0.5501. The seeming affinity of each form in this group more highly correlates than those of the other two groups. The largest group consists of two species, five forms, that is *C. personatus, C. torquatus lucifer, C. t. lugens, C. t. medemi* and *C. t. purinus*. In the largest group, the smallest score is 1.1755 for *C. t. lugens* and the largest one is 1.8117 for *C. t.*

Table 2. Penrose's size distance matrix calculated from cranial measurements

	MOD	OLA	DON	BRU	CAL	CUP	DIS	ORN	HOF	BAP	MOL	PER	LUC	LUG	MED	PUR	DUB
MOD	0.0000																
OLA	0.4014	0.0000															
DON	0.8745	0.0910	0.0000														
BRU	0.1987	1.1649	1.9069	0.0000													
CAL	0.1700	1.0938	1.8157	0.0011	0.0000												
CUP	0.0214	0.6083	1.1697	0.0896	0.0707	0.0000											
DIS	0.0749	0.8232	1.4615	0.0296	0.0192	0.0162	0.0000										
ORN	0.0032	0.4765	0.9838	0.1513	0.1264	0.0080	0.0471	0.0000									
HOF	0.0682	0.8004	1.4310	0.0341	0.0229	0.0132	0.0002	0.0418	0.0000								
BAP	0.0276	0.6397	1.2131	0.0781	0.0606	0.0004	0.0116	0.0120	0.0090	0.0000							
MOL	0.0867	0.8611	1.5118	0.0229	0.0139	0.0219	0.0004	0.0565	0.0011	0.0164	0.0000						
PER	2.1637	4.4290	5.7894	1.0510	1.1207	1.7545	1.4333	2.0000	1.4638	1.7023	1.3843	0.0000					
LUC	2.7094	5.1964	6.6624	1.4406	1.5220	2.2489	1.8831	2.5258	1.9180	2.1897	1.8268	0.0306	0.0000				
LUG	1.7298	3.7977	5.0642	0.7560	0.8152	1.3662	1.0846	1.5838	1.1112	1.3202	1.0421	0.0243	0.1094	0.0000			
MED	2.1389	4.3933	5.7486	1.0337	1.1028	1.7321	1.4131	1.9761	1.4433	1.6802	1.3644	0.0001	0.0337	0.0217	0.0000		
PUR	3.1156	5.7535	7.2913	1.7407	1.8300	2.6202	2.2241	2.9185	2.2620	2.5563	2.1629	0.0865	0.0142	0.2024	0.0916	0.0000	
DUB	0.0066	0.5106	1.0325	0.1331	0.1098	0.0043	0.0372	0.0006	0.0324	0.0073	0.0456	1.9320	2.4493	1.5233	1.9085	2.8362	0.0000

MOD: *C. modestus*; OLA: *C. olallae;* DON: *C. donicophilus;* BRU: *C. brunneus;* CAL: *C. caligatus;* CUP: *C. cupreus cupreus;* DIS: *C. c. discolor;*
ORN: *C. c. ornatus;* HOF: *C. hoffmannsi hoffmannsi;* BAP: *C. h. baptista;* MOL: *C. moloch;* PER: *C. personatus;* LUC: *C. torquatus lucifer;* LUG: *C. t. lugens;*
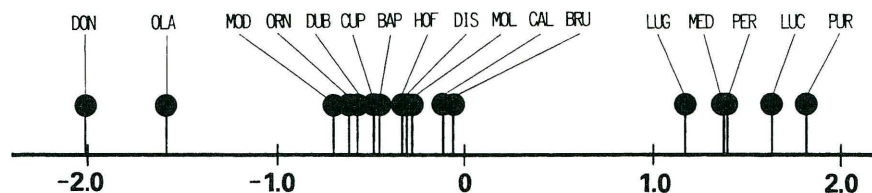MED: *C. t. medemi;* PUR: *C. t. purinus;* DUB: *C. dubius.*

Fig. 2. One dimensional expression of Penrose's size distance based on the method of principal coodinate analysis. The abbreviations are explained in Table 2.

purinus, its range 0.6362. The score of *C. personatus* is put middle position in the order of five forms. Each distance within a group is quite larger than each distance between the groups.

DISCUSSION

HERSHKOVITZ (1990) divided *Callicebus* species into the following three classes of size based on the basic statistics of three cranial measurements of the greatest skull length, the condylobasal length and the brain case volume:

Class 1—small; *C. modestus, C. donacophilus* and *C. olallae.*

Class 2—medium; *C. oenanthe, C. cupreus, C. moloch, C. dubius, C. hoffmannsi, C. brunneus, C. caligatus* and *C. cinerascens.*

Class 3—large; *C. torquatus* and *C. personatus.*

Although the result of the present analysis supports his size classification for the most part, *C. modestus* is classified into the middle-sized group on the basis of overall size from the Penrose's size distance. HERSHKOVITZ (1990) recognized the distinction of *C. modestus* which had more elongate shape of skull and the smallest volume of brain case among Cebidae species. However, the extant specimens of *C. modestus* are only one lectotype of adult male and one paralectotype of subadult male. There is no information of the *C. modestus*'s variation of any character. Therefore, it is unknown whether these distinctive characters are a settled feature of *C. modestus* or not. The systematic position of *C. modestus* seems to be still debatable. In the New World monkeys, it is thought that the two types of size transition at generic level exist in their evolutionary way. One way is the size increase or "gigantism" and another one is the size decrease or "dwarfism" (FORD, 1980). According to KOBAYASHI (1990), based on the upper molars morphology, *C. torquatus* had the most primitive characters, and the other forms had more derived features. If his interpretation is relevant to the *Callicebus* evolution, the reduction of size in *Callicebus* has been occurred from the large-sized ancestral group led directly to *C. torquatus* and *C. personatus* to small and middle-sized groups led to the other forms in their evolutionary process. Furthermore, HERSHKOVITZ (1990) also mentioned that the size of *C. personatus* was slightly larger than that of *C. torquatus*. If *C. torquatus* is more closely related to the ancestral form than *C. personatus*, the tendency of size enlargement has been existed within the large-sized group itself. Therefore, it seems to conclude that there are the two directions of size transition in the genus *Callicebus*, that is, both the dwarfism and gigantism. At least, in the New World monkeys, this is still an unknown case that has two phyletic size transitions becoming both larger and smaller at the same time in the same genus.

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