COMPARISON BETWEEN Trachypithecus auratus AND Trachypithecus cristatus 
BRAIN SIZE IN INDONESIA

PERBANDINGAN VOLUME OTAK ANTARA Trachypithecus auratus DAN 
Trachypithecus cristatus DI INDONESIA

Endah Dwijayanti*, Anang Setiawan Achmadi, Maharadatunkamsi, Nanang Supriatna, 
Kurnianingsih, Apandi, Haerul 
Museum Zoologicum Bogoriense, Pusat Penelitian Biologi LIPI 
Gedung Widyasatwaloka, Jl. Jakarta-Bogor Km. 46, Cibinong 16911, Jawa Barat 
E-mail: endahdwijayanti1@gmail.com 
(received November 2019, revised April 2020, accepted June 2020)

ABSTRACT

Taxonomic studies on genus Trachypithecus in Indonesia define that this genus separated into two species: Trachypithecus auratus and Trachypithecus cristatus. The aim of this study is to determine relative brain size differences between species of the genus Trachypithecus in Indonesia. This study analyzes the brain volume between both species and examines its relationship with morphometric measurement and variables such as sex, age, and specimen location. Brain volumes were calculated from braincase volumes using 0.5 mm silica gel as mini beads. This study reveals that there are significant differences in relative brain size inter-species, sex, and interaction among variable. Overall, T. auratus have a bigger brain size than T. cristatus, and the brain size of males are larger than females. The older individual tends to have similar brain size with younger ones. Allometric skull size affects the size of the brain directly. Also, there is a clinal trend in relative brain size. Trachypithecus auratus brain size is increasing from Western Java to Lombok Island. Further study is needed to understand the influence of external factor such as ecological and social factors on brain size in Trachypithecus.

Keywords: Brain size, Trachypithecus, clinal variation, Indonesia.

INTRODUCTION

Primates of the genus Trachypithecus are currently divided into 17 recognized species (Napier 1985; Groves 2001; Wilson & Reeder 2005). In Indonesia, there are two species based on Weitzel (1983), namely T. auratus, which has distribution in Java, Bali, and Lombok, and T. cristatus, which has distribution in Sumatra and Borneo. The two species have differences in their teeth. All the teeth of T. auratus are greater than T. cristatus and can be seen clearly from the ratio of body size allometrically. Maryanto et al. (1997) revealed that these two species could be distinguished from the main characters namely the distance between canines and third molars in the lower molars, the distance between the upper molars and the mastoid bone width. Study related to the dermatoglyphics of the palms shows the
differences in the trait direction of palm fingerprint between the two species (Maryanto 1998).

Genetic studies conducted by Roos et al. (2008) reinforce Rosenblum et al. (1997) that Trachypithecus in Indonesia is divide into two species, namely T. auratus and T. cristatus. T. cristatus distributed in Sumatra and Borneo. T. auratus consists of two subspecies namely T. a. mauritus whose distribution area is in western Java and T. a. auratus whose distribution is in eastern Java. Maryanto et al. (1997) state that there are two species of Trachypithecus in Indonesia. Due to differences in environmental factors, the shape of the body and the skull increasingly enlarged to the east. The difference between T. auratus in Java is clinal. There is only one species namely T. auratus, with the population of Central Java, especially populations in the Mount Slamet region as intermediate populations. While the populations of Bali and Lombok is a subspecies from Java, Trachypithecus auratus auratus.

In terms of habitat, there are differences between T. auratus in Java and T. cristatus in Borneo and Sumatra. Most of T. auratus is spread in forests and mountains because T. auratus prefers natural habitats such as primary forests and secondary forests (Sulistyadi 2012). In comparison, T. cristatus prefers lowland forests, riverside forests, peat swamps, tidal areas, mangroves and, coastal areas. Sometimes T. cristatus can be found in rubber forests, primary forests, secondary forests up to a height of 600 meters above sea level (Supriatna & Wahyono 2000; Harrison et al. 2006; Harding 2010). According to Powel et al. (2017), home range in foraging shows the influence on brain size. The wider the field, the larger the volume of the brain. The size of a larger brain supports the ability to strategize in sustaining its life, as mention in Sol et al. (2008).

Based on to determine relative brain size differences between species of the genus Trachypithecus in Indonesia and to examine clinal variation, a study related to brain size and morphological characters that affect the size is carried out. This study analyzes brain size between the two species, sex, age, and location also examines its relationship with linear cranial measurements and other variables.

MATERIALS AND METHODS
The study was conducted at the Zoologicum Bogoriense Museum, Research Center For Biology LIPI from May to July 2018. Age determination of the specimen was seen from the sutures on the fused skull and the number of teeth. From each skull, We measured braincase volume (in ml) and collected eleven measurements (in mm) including Greatest Skull Length (GSL), Zygomatic Breadth (ZB), Braincase Breadth (BB), Post Orbital Width (POW), Least Interorbital Width (LIW), Mesopterygoid Fossa Width (MFW), Mastoid Breadth (MB), Cochlea Width (CW), Upper Canine Width (C1C1), Distance between Molar 3 to Canine on Mandible (C-M3), and Ramus Condylar Process (TH2). The parts measured followed the illustration of primate skull parts in Maryanto et al. (1997) (see figure 1). Mace et al. (1981) used 2 mm glass beads to measure volume, whereas, in this study, silica gel was used as mini beads measuring 0.5 mm. Glass beads have a density of 1.04 g / cm3 while silica gel has a density of 0.7 g / cm3, so it
will not change the skull structure of the specimen. Lineal measurements were collected using digital callipers with an accuracy of ±0.01 mm.

**List of Specimens Used**

Specimens analyzed included 50 individuals divided into 25 individuals *Trachypithecus auratus* and 25 individuals *Trachypithecus cristatus*. The specimens of *T. auratus* consisted of 13 adult individuals (Ad.), seven subadult individuals (S.Ad.), and four juvenile individuals (Jv.). The specimens of *T. cristatus* consisted of 12 adult individuals (Ad.), eight subadult individuals (S.Ad.), and five juvenile individuals (Jv). Each specimen is compared by species, sex, age and location (coordinates defined by decimal degree). The location of specimen origin can be seen in Figure 2.
Comparison Between *Trachypithecus auratus* and *Trachypithecus cristatus* Brain Size in Indonesia

*Trachypithecus auratus* (É, Geoffroy, 1812)
Javan Lutung (Lutung Jawa)


*Trachypithecus cristatus* (Raffles, 1821)
Silvered Leaf Monkeys (Lutung Budeng)


Statistical Analysis

Absolute brain size is rarely used as a correlate of biological significance based upon Jerison's arguments regarding brain-body allometry (Jerison 1979; Lesciotto & Richtsmeier 2019). To account the allometry, several measurements that can be used are body mass, vertebral bodies or cranial measurements (Ruff et al. 1997; Rightmire 2004; Lesciotto & Richtsmeier 2019). Because of the lack of body mass data, we use GSL to account the allometric scaling between brain volume and the skull size, and then we name it relative brain size. The analysis used to differentiate between species, sex, age and variations in brain size related to skull morphology was performed using regression analysis. Analysis of variance is used to determine differences between variables while regression analysis is performed to assess the correlation between variable also to reveal data trends. To understand the clinal variation, we use decimal degree coordinates from west to east in each species distribution. This clinal analysis using adult specimens because the specimens has reached maximum size. Statistical analysis using IBM SPSS Statistics version 25 and visualize in RStudio (RStudio Team 2016; IBM Corp. 2017).

RESULTS AND DISCUSSION

The results of the analysis of variance showed that there were significant differences in the brain volume relative to greatest skull length (volume/GSL) in each species, sex, and age, also a combination between sex and age. Coefficient of determination shows a low correlation (R Square = 0.370) (Table 2). Low R square indicated that although we found
some differences, all variable less influenced the relative brain size to GSL.

Based on this result, we found that

\textit{T. auratus} have a larger brain size than \textit{T. cristatus}. Home range in foraging shows the influence on brain size (Clutton-Brock & Harvey 1980; Powel et al. 2017). The home range of \textit{T. auratus} about 15-23 Ha and \textit{T. cristatus} about 10-20 Ha. Daily travel distance on \textit{T. auratus} about 500-1500 m,

### Table 1. Summary of brain size measurements.

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Age</th>
<th>Category</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{T. auratus}</td>
<td>Java</td>
<td>Adult</td>
<td>A</td>
<td>68.72 ± 7.47 (n=9)</td>
<td>63.167 ± 2.25 (n=3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.669 ± 0.054 (n=9)</td>
<td>0.669 ± 0.036 (n=3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>66.67 ± 12 (n=3)</td>
<td>63.625 ± 5.66 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.726 ± 0.122 (n=3)</td>
<td>0.702 ± 0.093 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>NA</td>
<td>54.75 ± 9.215 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>NA</td>
<td>0.693 ± 0.106 (n=4)</td>
</tr>
<tr>
<td></td>
<td>Lombok</td>
<td>Adult</td>
<td>A</td>
<td>92 (n=1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.91 (n=1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>78.5 (n=1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.933 (n=1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Java &amp; Lombok</td>
<td>Adult</td>
<td>A</td>
<td>71.05 ± 10.186 (n=10)</td>
<td>63.167 ± 2.25 (n=3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.693 ± 0.092 (n=10)</td>
<td>0.669 ± 0.036 (n=3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>66.67 ± 12 (n=3)</td>
<td>63.625 ± 5.66 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.726 ± 0.122 (n=3)</td>
<td>0.702 ± 0.093 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>78.5 (n=1)</td>
<td>54.75 ± 9.215 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.933 (n=1)</td>
<td>0.693 ± 0.106 (n=4)</td>
</tr>
<tr>
<td>\textit{T. cristatus}</td>
<td>Sumatra</td>
<td>Adult</td>
<td>A</td>
<td>62.87 ± 4.64 (n=4)</td>
<td>58.37 ± 4.62 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.646 ± 0.044 (n=4)</td>
<td>0.62 ± 0.043 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>60.5 ± 6.36 (2)</td>
<td>56.1 ± 6.93 (n=5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.647 ± 0.006 (n=2)</td>
<td>0.63 ± 0.075 (n=5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>NA</td>
<td>57.67 ± 4.39 (n=3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>NA</td>
<td>0.66 ± 0.015 (n=3)</td>
</tr>
<tr>
<td></td>
<td>Borneo</td>
<td>Adult</td>
<td>A</td>
<td>63.75 ± 2.47 (n=2)</td>
<td>56 ± 2.83 (n=2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.66 ± 0.021 (n=2)</td>
<td>0.632 ± 0.021 (n=2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>NA</td>
<td>66 (n=1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>NA</td>
<td>0.708 (n=1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>66 (n=1)</td>
<td>57 (n=1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.796 (n=1)</td>
<td>0.65 (n=1)</td>
</tr>
<tr>
<td></td>
<td>Sumatra &amp; Borneo</td>
<td>Adult</td>
<td>A</td>
<td>63.167 ± 3.79 (n=6)</td>
<td>57.58 ± 3.99 (n=6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.651 ± 0.036 (n=6)</td>
<td>0.624 ± 0.035 (n=6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub Adult</td>
<td>A</td>
<td>60.5 ± 6.36 (2)</td>
<td>57.75 ± 7.4 (n=6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.647 ± 0.006 (n=2)</td>
<td>0.646 ± 0.074 (n=6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Juvenile</td>
<td>A</td>
<td>66 (n=1)</td>
<td>57.5 ± 3.58 (n=4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R</td>
<td>0.796 (n=1)</td>
<td>0.66 ± 0.013 (n=4)</td>
</tr>
</tbody>
</table>

A (Absolute brain size), R (Brain size relative to GSL / Relative brain size); NA (Not Available).
farther than *T. cristatus* that only travel 300-600 m (Supriyatna & Wahyono 2000). The wider home range and daily travel distance on *T. auratus* influenced by a lot of degradation in forest habitat in Java Island. This factor is causing limited food source for *T. auratus*. Larger brain size on *T. auratus* helps to accommodate processing complex information about food distribution in their habitat.

The following result is about different brain size on sex. *Trachypithecus* species are smaller and less sexually dimorphic in size than most other colobine genera, but more dimorphic than *Presbytis* (Pan & Groves 2004; Harding 2010). *T. cristatus* females differ with the male from irregular white patches on the inside flanks. Also, females, only 89% of males body weight (Roonwal & Mohnot 1977), and males have larger canine-sectoral teeth (Groves 2001). *T. auratus* sexually dimorphic, females have yellowish-white pubic patches, and males are not (McCarthy 2019). The analysis showed that the relative brain size in the two sexes has a significant difference (p-value < 0.01). The measurement of absolute brain size in males is indeed greater (Table.1). This result is in line with studies on other primates such as Rhesus monkey (*Macaca mulatta*) which states that adult male individuals have a larger brain size than adult female individuals by 10% or even less than 20% during juvenile age to adolescence (Franklin et al. 2000). Larger male body size will require a larger nervous system to coordinate his body (Deaner *et al.* 2007). The results of studies in humans show differences in the size of the brain size caused by sexual maturity in females faster than males, so that affects the cognitive abilities of females that mature faster than males, as mention in Lynn (1999).

The results also showed that the growth stage has a significant difference in relative brain size (p-value < 0.01). Based on measurement results, the relative brain size of juveniles is greater than adults, but the absolute brain size tends to be similar. The difference in GSL size is the cause of the difference in relative brain size. The GSL on adult reaches maximum size on the species. With the same brain size but a larger GSL in adults, it is causing a relatively larger brain size in juveniles. Brain development does not increase the size of the brain, and it's just that inability, the brain has increased. The brain experiences maturation as the species get older. This study indicated that cranial growth rate is higher than brain volume gain. According to Martin (1983), prenatal brain growth in primates, in general, will decrease after birth, except in humans which decreases after one year of birth. Walker *et al.* (2006) found that old world monkey brain size correlates with body size and diet; however, new world monkey brain size is influenced by body size and life span. *Trachypithecus* belongs to the old world monkey group, so the brain size is influenced by body size and diet.

### Table 2. Analysis of Variance on Relative Brain Size.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sig.</th>
<th>R Square all variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>0.017*</td>
<td>0.370</td>
</tr>
<tr>
<td>Sex</td>
<td>0.007**</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.008**</td>
<td></td>
</tr>
<tr>
<td>Species * Sex</td>
<td>0.439</td>
<td></td>
</tr>
<tr>
<td>Species * Age</td>
<td>0.794</td>
<td></td>
</tr>
<tr>
<td>Sex * Age</td>
<td>0.041*</td>
<td></td>
</tr>
<tr>
<td>Species * Sex * Age</td>
<td>0.737</td>
<td></td>
</tr>
</tbody>
</table>
Comparison Between *Trachypithecus auratus* and *Trachypithecus cristatus* Brain Size in Indonesia

The results of linear regression analysis on parts of the skull that affect the size of the brain size can be seen in Table 3. Based on these results, there is a significant correlation between the size of the brain with parts of the skull ($R^2 = 0.797$, $p$-value $< 0.001$). The parts of the skull with the most significant correlation are GSL and POW, with the regression equation as follows:

$$\text{Volume} = -85.76 + 0.64 \text{GSL} + 0.11 \text{ZB} - 0.72 \text{LIW} + 1.21 \text{POW} + 0.43 \text{CW} - 0.19 \text{MFW} - 0.23 \text{MB} + 1.08 \text{BB} - 0.36 \text{C1C1} - 0.52 \text{C-M3} - 0.18 \text{TH2}$$

The difference in brain size in *Trachypithecus* causes different sizes in GSL and POW. The greater the size of the brain, the greater the size of GSL and POW in this genus. POW is the distance between the curve behind the orbital bone called postorbital constriction. Increased brain size causing the widening of the gap in postorbital constriction. It is causing postorbital constriction will be shallower. Another study in human skull reveals that postorbital constriction was confirmed a strong relative correlation with the upper facial breadth and maximum cranial breadth (Asfaw *et al.* 2008; Bruner & Holloway 2010; Kubo *et al.* 2012).

Regression analysis on the adults relative brain size and coordinates shows that *T. auratus* has a significant data trend, increasing from west to east ($R^2 = 0.37$; $p$-value $< 0.05$). Contrast with *T. cristatus* that does not show any correlation and significance between relative brain size and coordinates ($R^2 = 0.0117$; $p$-value $= 0.74$) (see Fig.3).

Based on the results of the analysis, the data shows that the relative brain size of

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Skull Length (GSL)</td>
<td>0.034*</td>
</tr>
<tr>
<td>Zigomatic Breadth (ZB)</td>
<td>0.761</td>
</tr>
<tr>
<td>Least Interorbital Width (LIW)</td>
<td>0.462</td>
</tr>
<tr>
<td>Post Orbital Width (POW)</td>
<td>0.009***</td>
</tr>
<tr>
<td>Cochlea Width (CW)</td>
<td>0.236</td>
</tr>
<tr>
<td>Mesopterygoid Fossa Width (MFW)</td>
<td>0.824</td>
</tr>
<tr>
<td>Mastoid Breadth (MB)</td>
<td>0.600</td>
</tr>
<tr>
<td>Braincase Breadth (BB)</td>
<td>0.064</td>
</tr>
<tr>
<td>Upper Canine Width (C1C1)</td>
<td>0.424</td>
</tr>
<tr>
<td>Distance between Molar 3 to Canine on Mandible (C-M3)</td>
<td>0.297</td>
</tr>
<tr>
<td>Ramus Condylar Process (TH2)</td>
<td>0.630</td>
</tr>
<tr>
<td>p-value</td>
<td>$&lt; 0.000***$</td>
</tr>
<tr>
<td>Adjusted R Squared = 0.7109</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.** Regression analysis between brain volume and cranial parts.
T. auratus is getting bigger eastward from Western Java to Lombok (Multiple R-squared = 0.37; p-value < 0.05). This result in line with Maryanto et al. (1997) which states that there are clinal variations in the type of T. auratus from western Java to the east in terms of the size of the skull, teeth, and dental characteristics. Lombok specimens have a distinct and the largest relative brain size (Table 1.), this result supporting Maryanto et al. (1997) that state T. auratus from Lombok Island is subspecies from Java. This case is not found in T. cristatus. This result means home range or habitat of T. cristatus in Sumatra and Borneo does not influence the brain size.

CONCLUSION
This study shows that there are differences of relative brain size inter-species, sex, age either some interaction among variable caused by home range, body size and the size of the skull. Brain volume has a significant positive-correlation with Greatest Skull Length and Post Orbital Width. Greatest Skull Length can substitute body mass as allometric scaling in case the lack of body mass data. However, we use the skull-based method for age determination. Further research is needed to determine the maturity of brain growth in this species related to the adult age. Clinal found in T. auratus relative to brain size supporting statement of the previous study about cranial measurements on this species, also supporting the idea of T. auratus subspecies that found in Lombok Island.

ACKNOWLEDGEMENT
Thanks to Eko Sulistiyadi M.Si and Dr. Ulfah Mardhiah, for their assistance in statistical analysis, Alamsyah Elang N.H., S.Si for his assistance in using Rstudio as a statistic tool, Dr. Achmad Dinoto and Prof. Ibnu Maryanto for their guidance in writing KTI, also the colleagues of PNS Zoologi 2018 who support authors during the study.

AUTHORSHIP AND DECLARATION OF CONFLICTING INTERESTS
Endah Dwijayanti is the principal author of this paper. The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES


Franklin, M. S., Kraemer, G. W., Shelton, S. E., Baker, E., Kalin, N. H. & Uno, H.
Zoo Indonesia 2020 29(1): 19-28
Comparison Between Trachypithecus auratus and Trachypithecus cristatus Brain Size in Indonesia


