Activity: Unknown Bones

DAMIÁN A. CONCEPCIÓN PÉREZ[1], RAISA HERNÁNDEZ-PACHECO[2]
[1]The School of San Juan, San Juan, Puerto Rico, [2]Caribbean Primate Research Center, University of Puerto Rico, Puerto Rico

Theoretical Framework

Patterns in nature can be described and modeled through statistical processes.

Focus

Application of data analysis and statistics to understand and illustrate sexual dimorphism in rhesus macaque skeletal specimens.

Grade Level

Secondary School 9-12 (Biology/Mathematics)

Inquiry Questions

- Do you expect to see differences in skeletal traits between male and female rhesus macaques?
- Do you expect to see differences in skeletal traits across ages?
- If there are differences, how can they be illustrated statistically and graphically?
- How can this information be used to make predictions about the sex and age of unknown rhesus macaque skeletons?
- How can this information be used to make inferences on sexual selection in rhesus macaque populations?

Learning Objectives

- Collect and manage rhesus macaque skeletal data.
- Describe the distribution of male and female bone lengths (mean and standard deviation) to predict the sex of unidentified skeletons.
- Model the relationship between bone length and age to predict the age of unidentified skeletons.
- Formulate hypotheses on sexual selection in rhesus macaques based on the statistics applied.

Materials

- Six male and six female rhesus monkey skeletal specimens of known age. Recommended specimens in Appendix 1. If specimens are unavailable, skeletal data is presented in Appendix 2.
- Calipers
- Nitrile/latex gloves
- Computers with Microsoft Excel (or alternative)

Teaching Time

Two to three 50-minute periods.

Seating Arrangement

Groups of two

Key words

- Rhesus macaques
- Sexual Selection
- Sexual dimorphism
- Linear Model
- Mean
- Standard Deviation

Supplementary Resources

Appendix 1 - Recommended specimens
Appendix 2 - Skeletal data
Appendix 3 - Morphological data sheet
Appendix 4 - Excel sheet for sexing (Only canine data analysis is presented)
Appendix 5 - Excel sheet for ageing (Only femur data analysis is presented)

Background Information

Male mammals often present more accentuated features, compared to those of females. Specially in primates, exaggerated traits such as extravagant colors, great body size, and large canines can be commonly observed in males. Such sexual dimorphism is a product of sexual selection, a natural process that occurs when certain traits increase mating success. Thus,

sexual selection is an important process that contributes to the evolution of populations.

Sexual selection can be observed in two different ways; intra-sexual selection (e.g., male-male competition) and inter-sexual selection (e.g., female choice). Primate species living in multi-male multi-female groups, such as rhesus macaques, may present examples of both types of sexual selection. For instance, males fight other males to establish dominance, which results in more access to females and higher mating success (intra-sexual selection). These hostile encounters might explain why adult male rhesus have evolved canines twice as large as those of adult females. On the other hand, females might prefer to mate with males with large canines as they represent a better protection for their offspring (inter-sexual selection). Besides canine length, many other traits could be studied to identify and describe sexual selection and consequent sexual dimorphism within primate populations. No matter which trait is being studied, all biological hypotheses should be tested and supported by statistics.

Unknown Bones is an inquiry-based educational activity for high school students in which they apply data analysis and statistics to understand sexual selection and illustrate sexual dimorphism in Cayo Santiago rhesus macaques. We decided to integrate biology and mathematics in this activity to increase future college students' awareness of the relevance of mathematics to fields of biology, while developing quantitative skills necessary in modern biology. The activity follows the Next Generation Science Standards. Its completion leads to a better understanding of pivotal concepts in biology (i.e., sexual selection) and statistics (i.e., statistical dispersion, linear regression), and allows students to grasp an idea on how scientists build and test hypotheses.

Primate Skeletal Resources

Cayo Santiago is one of the oldest colony of nonhuman primates in the world. It is located in Humacao, Puerto Rico, and is administered by the Caribbean Primate Research Center (CPRC) of the University of Puerto Rico-Medical Sciences Campus. The Laboratory of Primate Morphology (LPM) of the CPRC houses a collection of over 2,500 rhesus monkey skeletons from Cayo Santiago with known life history. CPRC resources are available for scientist and educators. The LPM encourages school trips to visit and study the skeletal collection on site. Short-term skeletal specimen loans can also be arranged for local school teachers and educators. For more info visit cprc.rcm.upr.edu. If a loan is not possible, we present the skeletal measures in Appendix 2.

Learning Procedure

Engage

1. Bring the skeletons to the classroom. Prepare a demonstration table with two unidentified rhesus macaque skeletal specimens; one adult male and one adult female of same age.

   a. Ask students to identify differences among samples. Focus them on striking features such as canines and femurs (Fig. 1).

Fig 1. Craniums of adult male (left) and female (right) rhesus macaques.

2. Discuss with students the fact that these two specimens are monkeys of the same species, same population, and same age.

a. Ask students to explain why they think such differences are present. Focus them to think about the life history of rhesus macaques (e.g., are they vegetarians or carnivores; solitary or do they live in social groups?).

b. Are these male or female specimens? Could these differences be generated by sexual selection? Explain.

At this point, you may start the three-part activity by asking students to make predictions on the sex of unknown samples and how such differences can be measured and illustrated in order to test their predictions.

Part I: From bones to data

Before starting the activity, review with the students the terms “sexual selection” and “sexual dimorphism”. Discuss these concepts with them and tell them that now they will generate data from skeletons to make inferences on sexual selection and consequent sexual dimorphism in rhesus macaques.

1. Set up six different data collection stations in the class room. In each station, provide students with a fully identified pair of specimens (1 male and 1 female of same age). Complete specimens can be provided for exploration but make sure to emphasize the use of canines and femurs.

a. Tell students to look at all specimens and analyze further their previous prediction on the sex of unknown samples.

b. What is the most striking feature differentiating males from females (i.e., canines)?

c. What measure could they carry out to illustrate such difference graphically (i.e., canine length)?

d. Challenge them to think further; is sexual dimorphism maintained across ages? How could they illustrate this graphically?

e. Besides canines, which bones might be used to describe sexual dimorphism across ages (i.e., femur)? Ask students to explain.

2. Provide a caliper (or an appropriate ruler) and nitrile gloves to each group. Ask them to rotate through all stations, measure and record canine and femur lengths on the Morphological Data Sheet (Appendix 3). Demonstrate in front of the class how to use the caliper. For each specimen ask students to:

a. Measure the length of both left and right upper canines.

b. Measure the length of both left and right femur bones.

Part II: Male or Female?

Now that the students have generated the skeletal data, ask them to establish the best way to manage it and get useful information from it. Discuss why is important to carry out quantitative analyses when making biological inferences. Review key statistical concepts such as “mean” and “standard deviation”.

1. Ask the students to organize the data in a table using a spreadsheet (e.g., Microsoft Excel or an alternative). You may refer to Appendix 4 for guidance.

a. To explore differences between male and female canine and femur lengths, how such data should be organized?

2. Ask students to calculate the mean and standard deviation of male and female data. Why are these useful when comparing two groups?

a. Highlight the importance of understanding variability and statistical dispersion. What does the standard deviation (SD) tell us about the variability within groups. You may want to review the “68-95-99.7” rule at this point.

b. Based on 1SD, do the data suggest male canine length is different from females’? Explain.

c. Based on 2SD, does this sustain? Which of these two estimates of dispersion is more appropriate to compare between groups?

d. Do they get similar results when comparing femur lengths?

3. Ask students to graph their results.

a. Using the spreadsheet, tell students to explore which graph would be appropriate to illustrate the difference between male and female bone lengths (i.e., bar graph, Fig. 2).

b. Ask them to add error bars (i.e., SD) to the figure. Why is this helpful for presenting their data?

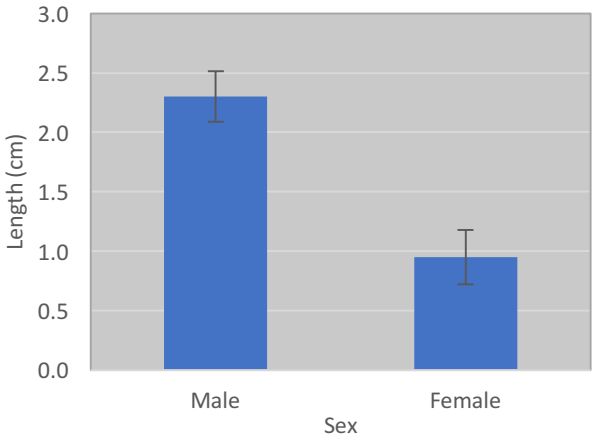

Fig 2. Mean canine length of male and female rhesus macaques. Error bars represent standard deviation.

4. Based on their statistics, which of the two skeletal features measured, canine and femur length, appears to be a better predictor of sex in rhesus macaques?

5. Ask students what can they infer about sexual selection in this monkey population? Do their predictions on the sex of unknown samples is sustained?

Part III: How Old?

Once the students have established that there is sexual dimorphism in rhesus macaques, have them investigate the previous question on the maintenance of sexual dimorphism across ages. You may refer to Appendix 5 for guidance.

1. Ask students to compare the pair of younger skeletons (4 year olds).

a. Do they expect these differences to increase or decrease with age? Explain.

b. Are the differences in skeletal traits as pronounced as in adults?

c. How can this be explored statistically with the data they have collected?

2. Ask students to calculate the age-specific mean canine and femur length of male and females. At this point you may discuss with students the limitations of their data and the importance of sample replication.

a. Theoretically, how could they improve the analysis?

3. Ask students to graph their results. Using the spreadsheet, have them explore which graph would be appropriate to illustrate the change in bone length across ages (i.e., scatter plot, Fig. 3).

a. Which variable should be presented in the *x*-axis and *y*-axis?

b. Graph both male and female data in the same figure. Are younger ages similar in bone length? What happens as age increases? (Appendix 5; Average and Figure sheet).

c. Discuss with students the term “asymptote”. Can they observe an asymptote? Why is this expected when analyzing bone length across ages?

4. Based on their knowledge on regression models, how could they develop a model describing the change in canine and femur length as age increases?

a. Using the spreadsheet, ask students to add a trendline to the figure. Have them explore which trendline is more appropriate (e.g., linear, polynomial) (Appendix 5; Regression Model sheet).

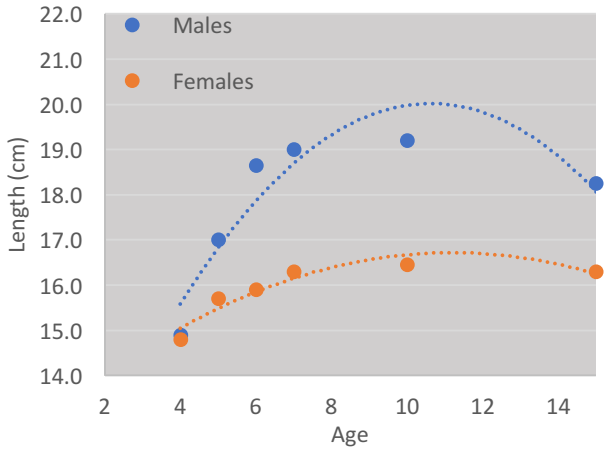

Fig 3. Change in femur length across ages of male and female rhesus macaques.

5. Discuss with students how could they use the information of the trendline to predict the expected average bone length of each age.

a. Ask students to extract the values of the equation describing the trendline.

b. Ask students to evaluate the equation for each age value. This would allow them to estimate the predicted average bone length for each age (Appendix 5; Prediction sheet).

6. Now that the students have completed the three-part activity, ask them to explore all figures. Discuss with them whether the bones studied suggest to be good predictors of sex and age.

a. Is canine length a better predictor of sex than femur length? Explain.

b. Is femur length a better predictor of age than canine length? Explain.

c. How can this information be used to make inferences on sexual dimorphism in rhesus macaques?

d. How can this information be used to make predictions about the sex and age of unknown rhesus macaque skeletons?

Evaluate:

Unknown Bones

1. Tell students to imagine they are scientists monitoring the Cayo Santiago rhesus macaque population and they find three dead monkeys in the field. As Cayo Santiago has a tropical weather, decomposition is rapid, which makes identification of individuals difficult once they are found dead. Thus, they need to use their statistical models on skeletal morphology to estimate both sex and age of the unknown skeleton in order to identify the dead individuals.

a. Provide students with the three unidentified skeletal specimens and ask them to take the appropriate measurements in order to make predictions on sex and age.

b. Provide students with a hypothetical list of "missing" monkeys from the last visual census in Cayo Santiago. Give them information on ID, date of birth, sex, and last date sighted. We recommend a list of four to five "missing" monkeys, three of them matching unknown dead individuals from step a.

c. Ask students to compare the data from the three unknown skeletons with the list of missing monkeys. Can you identify the dead monkeys on the missing list? Explain. Are any of the missing monkeys the ones found dead?

2. As scientists in charge, they should update the Cayo Santiago database with approximate dates of death for these individuals.

a. Using your estimates on Part c, how would you determine an approximate date of death? Explain.

Resources

Caribbean Primate Research Center: http://cprc.rcm.upr.edu/

Center for Technology and Teacher Education: http://www.teacherlink.org/content/math/interactive/interactiveexcel.html

Colon-Berlingeri M, Burrowes PA (2011) Teaching biology through statistics: application of statistical methods in genetics and zoology courses. CBE-Life Science Education 10:259-267. scholars.opb.msu.edu/en/publications/teaching-biology-through-statistics-application-of-statistical-me

McPherson FJ (2013) Sexual Dimorphism in Primates. J Primatol 2:e121. doi:10.4172/2167-6801.1000e121

Next Generation Science Standards www.nextgenscience.org/topic-arrangement/hsnatural-selection-and-evolution

Next Generation Science Standards

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

Acknowledgements

This work was possible thanks to the support of Terry Kensler at the Laboratory of Primate Morphology of the Caribbean Primate Research Center (CPRC)-University of Puerto Rico. The CPRC is partially funded by the Office of Research Infrastructure Programs of the National Institute of Health, Grant Number 2 P40 OD012217. We also thank The School of San Juan for their support implementing this activity.

About the authors

Damián A. Concepción Pérez is a Math teacher at The School of San Juan, San Juan, PR. He is formally trained in Secondary Education holding certifications in Physical Science and Mathematics.

Dam.concepcion@gmail.com

Raisa Hernández Pacheco is a biologist with expertise in population ecology. She works as Scientific Staff at the Caribbean Primate Research Center.

raisa.hernandezpacheco@upr.edu