Exercise 1B

Scientific Investigation: Experimental Design Applied

Adapted from Investigating Biology, Morgan & Carter, 6th ed.

The shape of an organism depends in part on the relative growth rates of different body parts during development. The terms **allometry** and **allometric growth** are used when describing the changing relative rates of growth. Specifically, allometry is the phenomenon whereby parts of an organism grow at different rates, or the disproportionate growth of a part in relation to the entire organism. This can be observed in humans as seen in Figure 1.2, an illustration of differential growth rates. Notice in this figure, in which the newborn and adult are scaled to the same height, that the head is larger in proportion to the body length in a newborn than in an adult.

Allometric growth contrasts with **isometric growth** when two parts grow at the same rate. This takes place when proportions between body parts remain constant as the organism grows. You can imagine this type of growth by taking a photo of the baby in Figure 1.2 and simply enlarging it as it grows to an adult. For example, if the arms and legs of a human grow isometrically, then their lengths will be the same relative to the body in a newborn as in an adult.

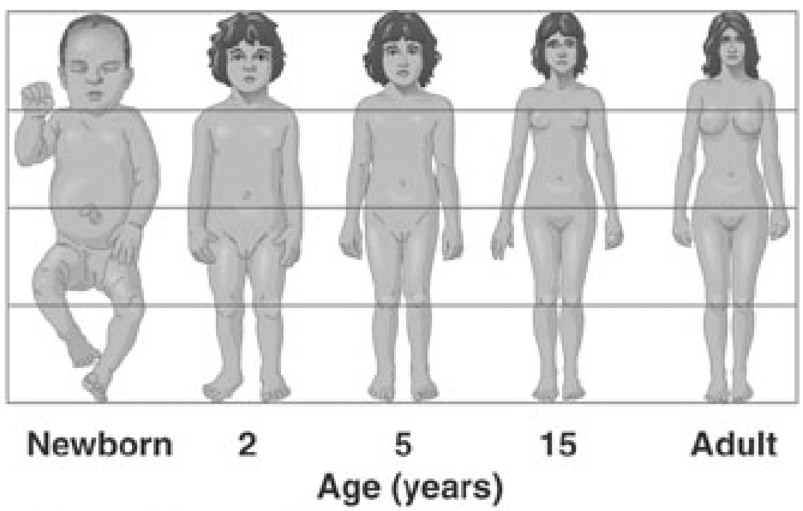

Fig. 1.2 ifferential growth rates in a human

In the following exercise you will collect data to compare ratios of height to selected body parts for newborns with the same ratios in students (yourselves). This should provide information to determine if selected body parts grow allometrically or isometrically in humans. In the process you will practice designing experiments, collecting data, and processing that data. The data for newborns are given in Table 1.1. These data are taken from Hall *et al.* (2007), a handbook of physical measurements for health professionals.

For this exercise, the two body parts we will be measuring are head circumference and arm length. Take a few minutes to discuss *specific* questions that you can ask about growth rates (allometric, isometric) of head circumference and arm length in relation to height in humans.

Record your two questions below:

Hypothesis
Record a hypothesis for each of your questions:

Table 1.1 Average Body Part Sizes for Newborn North Americans, Both Sexes

Body Part	Description of Measurement	Size (cm)
Length/Height	From sole of foot to top of head	48
Head circumference	Head at largest diameter	33
Upper limb (total arm)	From shoulder joint to tip of middle finger	20
Hand length	From wrist to tip of middle finger	6
Span	Between fingertips of middle finger with arms outstretched	51
Lower limb (total leg)	From sole of foot to joint where leg meets hip laterally	18
Crown-rump length	In seated position, from top of head to surface of a flat-bottom chair or bench	33
Foot length	Measure from heel to toe standing on a tape measure	7.5

The Experiment
In this experiment you will compare the ratios of height to head circumference and arm length in newborns and yourselves. Work in your group to discuss experimental design and complete the questions below.

What is the dependent variable in your experiments?

What is the independent variable?

What are some controlled variables?

Prediction
Predict the results of each experiment based on your hypotheses (if/then). Write one prediction for head circumference and one for arm length.

Performing the Experiment
To measure head circumference, use a piece of string to wrap around the head of the person being measured at the forehead level. Measure the string using a meter stick. To measure arm length, you may also use a piece of string to measure from the shoulder joint to the tip of the middle finger. You may self-report your height.

Results

1. Record measurement results of height (H), head circumference (HC), and arm length (AL) for each member of your team for the first body part in Table 1.2.
   (Remember, to convert inches to cm, multiply by 2.54.)
2. Calculate height:head circumference ratio (H:HC) for each member of your team.
   (Just divide H/HC)
3. Record data for newborns from Table 1.1 for the first body part.
4. Calculate the (H:HC) ratio for newborns.
5. Follow the same procedure for arm length (H:AL), and record all data in Table 1.2.
6. **Enter all data into the class database.**
7. Record average ratios using class data in Table 1.4.

Table 1.2 Height, Head Circumference and Arm length Measurements for Group _____ and for Newborns.

Name of Student	Sex (M/F)	Height (cm)	Head Circumference (cm)	Arm Length (cm)	Height:Head Circumference Ratio	Height:Arm Length Ratio
Newborn Data						

Please enter your data in the class spreadsheet. Spreadsheet will be posted on-line for use in the next lab.

Presenting and Analyzing Results

Once the data are collected, they must be organized and summarized so that scientists can determine if the hypothesis has been supported or falsified. In this exercise, you will design tables and graphs; the latter are also called figures. Tables and figures have two primary functions. They are used (1) to help you analyze and interpret your results and (2) to enhance the clarity with which you present the work to a reader or viewer.

Tables

You have collected data from your experiment in the form of a list of numbers that may appear at first glance to have little meaning. Look at your data. How could you organize the data set to make it easier to interpret? You could *average* the data set for each treatment, but even averages can be rather uninformative. Could you use a summary table to convey the data (in this case, averages)?

Table 1.3 is an example of a table from the experiment described in the pre-lab using data averages of the number of seeds per pod and number of pods per plant as the dependent variables and exposure to sulfur dioxide as the independent variable. Note that the number of replicates and the units of measure are provided in the table and in the legend.

Table 1.3 Effects of 4-Hour Exposure to 0.6 ppm Sulfur Dioxide on Average Seed and Pod Production in Soybeans

Treatment	Number	Seeds per Pod	Pods per Plant
Control	24	3.26	16
S02	24	1.96	13

Tables are used to present results that have a few too many data points. They are also useful for displaying several dependent variables. For example, average number of bean pods, average number of seeds per pod, and average weight of pods per plant for treated and untreated plants could all be presented in one table.

The following guidelines will help you construct a table:

- All values of the same kind should read down the column, not across a row. Include only data that are important in presenting the results and for further discussion.
- Information and results that are not essential (for example: test-tube number, simple calculations, or data with no differences) should be omitted.
- The headings of each column should include units of measurement, if appropriate.
- Tables are numbered consecutively throughout a lab report or scientific paper. For example: Table 1.3 would be the third table in your report.
- The title, which is located at the top of the table, should be clear and concise, with enough information to allow the table to be understandable apart from the text. Capitalize the first and important words in the title. Do not capitalize articles (a, an, the), short prepositions, and conjunctions. The title does not need a period at the end.

- Refer to each table in the written text. Summarize the data and refer to the table; for example, "The plants treated with sulfur dioxide produced an average of 1.96 seeds per pod (Table 4)." Do not write, "See the results in Table 4."
- If you are using a database program, such as Excel, you should still sketch your table on paper before constructing it on the computer.

Application

Complete Table 1.4 below using group data from the spreadsheet. Your table should present average ratios for height:head circumference and height:arm length for the class and for newborns. Don't forget the title.

Table 1.4

Graphs

The results of an experiment usually are presented graphically, showing the relationships among the independent and dependent variable(s). A graph provides a summary of the results and allows you to see relationships in the data that may not have been apparent in a table. Your graph should be accurately and clearly constructed, easily interpreted, and well annotated.

The following guidelines will help you to construct such a graph.

- Use graph paper and a ruler to plot the values accurately. If using a database program, you should first sketch your axes and data points before constructing the figure on the computer.
- The independent variable is graphed on the x axis (horizontal axis, or abscissa), and the dependent variable, on the *y* axis (vertical axis, or ordinate).
- The numerical range for each axis should be appropriate for the data being plotted. Generally, begin both axes of the graph at zero (the extreme left corner). Then choose your intervals and range to maximize the use of the graph space. Choose intervals that are logically spaced and therefore will allow easy interpretation of the graph, for example, intervals of 5s or 10s. To avoid generating graphs with wasted space, you may signify unused graph space by two perpendicular tic marks between the zero and your lowest number on one or both axes.
- Label the axes to indicate the variable and the units of measurement. Include a legend if colors or shading is used to indicate different aspects of the experiment.
- Choose the type of graph that best presents your data. Line graphs and bar graphs are most frequently used. The choice of graph type depends on the nature of the variable being graphed.

- Compose a title for your figure, and write it below your graph. Graphs, diagrams, drawings, and photographs are all called **figures** and should be numbered consecutively throughout a lab report or scientific paper. Each figure is given a caption or title that describes its contents, giving enough information to allow the figure to be self-contained. Capitalize only the first word in a figure title and place a period at the end.

The Line Graph

Line graphs show changes in the quantity of the chosen variable and emphasize the rise and fall of the values over their range. Use a line graph to present continuous data. For example, changes in the dependent variable, soybean weight, measured over time would be depicted best in a line graph.

- Plot data as separate points.
- Whether to connect the dots or draw a best fit curve depends on the type of data and how they were collected. To show trends, draw smooth curves or straight lines to fit the values plotted for anyone data set. Connect the points dot to dot when emphasizing meaningful changes in values on the x axis.
- If more than one set of data is presented on a graph, use different colors or symbols and provide a key or legend to indicate which set is which.
- A boxed graph, instead of one with only two sides, makes it easier to see the values on the right side of the graph.

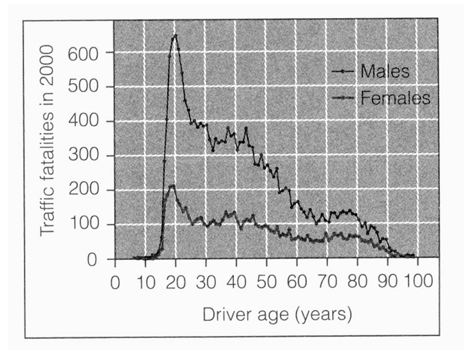

Figure 1.4 Differences in traffic fatalities in 2000 for male and female drivers by age.

Note the features of a line graph in Figure 1.4, which shows that young males are the most likely victims of car crashes based on data from 2000.

The Bar Graph

Bar graphs are constructed following the same principles as for line graphs, except that vertical bars, in a series, are drawn down to the horizontal axis. Bar graphs are often used for data that represent separate or discontinuous groups or non-numerical categories, thus emphasizing the discrete differ-ences between the groups. For example, a bar graph might be used to depict differences in number of seeds per pod for treated and untreated soybeans. Bar graphs are also used when the values on the x axis are numerical but grouped together. These graphs are called histograms.

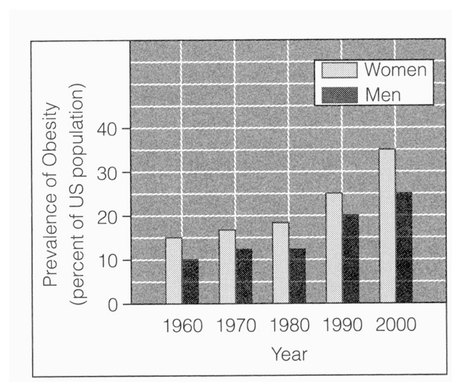

Figure 1.5 Prevelence of obesity among adults in US from 1960 to 2000.

Note the features of a bar graph in Figure 1.5, which depicts the prevalence of obesity in US women and men from 1960 to 2000.

Application

1. Using data from your experiments and the grid provided, design a bar graph that shows the relationship between the dependent and independent variable for both body parts. Discuss with your teammates how to design one figure so that it includes the data for the independent variable for each experiment.
   a. What was the independent variable for each experiment? On which axis would you graph this?
   b. What was the dependent variable? Write it on the appropriate axis.
2. Add a legend to your figure to distinguish newborn and student ratios.
3. Draw, label, and compose a title for your figure.
4. Imagine an experiment similar to the one you have performed where it would be appropriate to use a line graph.

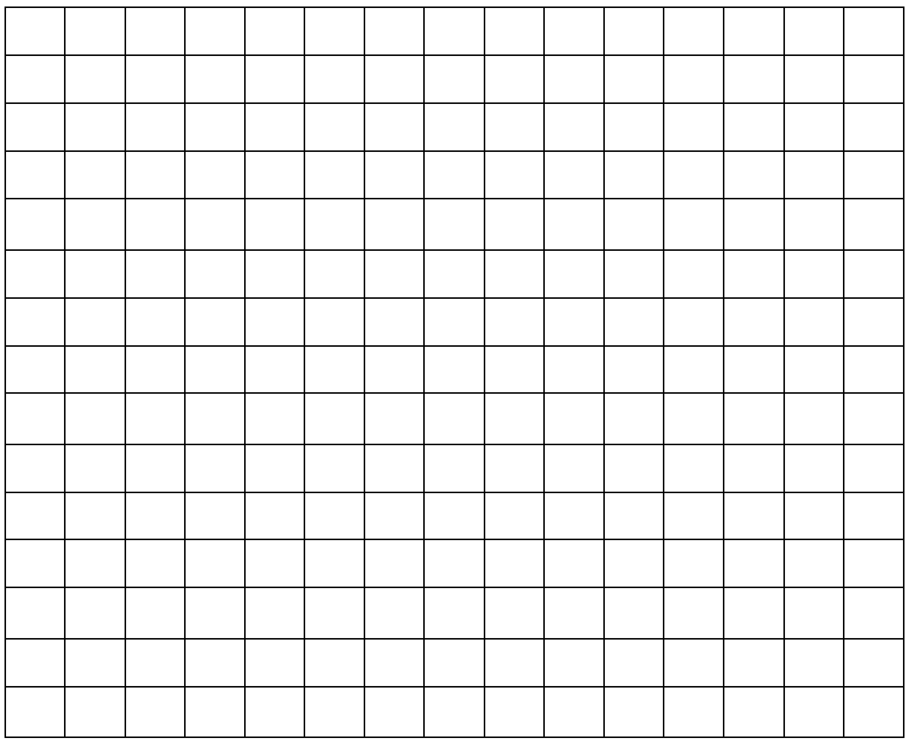

Figure 1.6

Interpreting and Communicating Results

The last component of a scientific investigation is to interpret the results and discuss their implications in light of the hypothesis and its supporting literature. The investigator studies the tables and graphs and determines if the hypothesis has been supported or falsified. If the hypothesis has been falsified, the investigator must suggest alternate hypotheses for testing. If the hypothesis has been supported, the investigator suggests additional experiments to strengthen the hypothesis, using the same or alternate methods.

Scientists will thoroughly investigate a scientific question, testing hypotheses, collecting data, and analyzing results, until they are satisfied that they can explain the phenomenon of interest. The final phase of a scientific investigation is the communication of the results to other scientists. Preliminary results may be presented within a laboratory research group and at scientific meetings where the findings can be discussed. Ultimately, the completed project is presented in the form of a scientific paper that is reviewed by scientists within the field and published in a scientific journal.

The ideas, procedures, results, analyses, and conclusions of all scientific investigations are critically scrutinized by other scientists. Because of this, science is sometimes described as *self-correcting,* meaning that errors that may occur are usually discovered within the scientific community.

Scientific communication, whether spoken or written, is essential to science. During this laboratory course, you often will be asked to present and interpret your results at the end of the laboratory period. Additionally, you will write components of a scientific paper for many lab topics. In Appendix A at the end of the lab manual, you will find a full description of a scientific paper and instructions for writing each section.

Application

Using your tables and figures, analyze your results and draw your conclusions.

1. Did your data suggest allometric growth or isometric growth for head circumference? For arm length?

2. Write a summary statement for the experiment using your results to support or falsify your hypotheses.

3. Critique your experiment. What weaknesses do you see in the experiment? Suggest improvements.

4. Suggest additional and modified hypotheses that might be tested. Briefly describe your next experiment.

Questions for Review

1. Review the major components of an experiment by matching the following terms to the correct definition: control, controlled variables, level of treatment, dependent variable, replication, procedure, prediction, hypothesis, independent variable.

   a) Variables that are kept constant during the experiment (variables not being manipulated)

   b) Tentative explanation for an observation

   c) What the investigator varies in the experiment (for example, time, pH, temperature, concentration)

   d) Process used to measure the dependent variable

   e) Appropriate values to use for the independent variable

   f) Treatment that eliminates the independent variable or sets it at a standard value

   g) What the investigator measures, counts, or records; what is being affected in the experiment

   h) Number of times the experiment is repeated

   i) Statement of the expected results of an experiment based on the hypothesis

2. Identify the dependent and independent variables in the following investigations. (Circle the dependent variable and underline the independent variable.)

   a) The number of aborted foals are counted for mares grazing in fields with and without black cherry trees on Kentucky horse farms.

   b) Scientists observed and recorded pecking patterns and underwing color markings of an unknown woodpecker to determine the species: common pileated woodpecker or, rarest-of-rare, ivorybilled woodpecker.

   c) Number and size of cubs born to polar bears in 1990 and 2000.

3. Suggest a control treatment for each of the following experiments.

   a) Frogs are captured from ponds where the parasitic worm *Robeiroia* is abundant. The number of limb deformities is recorded.
   Control treatment:

   b) Patients with the eating disorder anorexia nervosa are given Prozac to alleviate symptoms. Control treatment:

   c) Children with autism are given a diet free of gluten.
   Control treatment:

4. In a recent study of 10,000 women scientists reported that women who had breast cancer had a history of heavier antibiotic use than women who did not have breast cancer. What possible explanations for this correlation can you suggest?

5. What is the essential feature of science that makes it different from other ways of understanding the natural world?