CHAPTER 7 CELLULAR RESPIRATION AND FERMENTATION

Scientific Skills Exercise

Teaching objective: Students will practice making a bar graph with categorical data in this exercise. The students are then encouraged to think of a biological explanation for the data pattern.

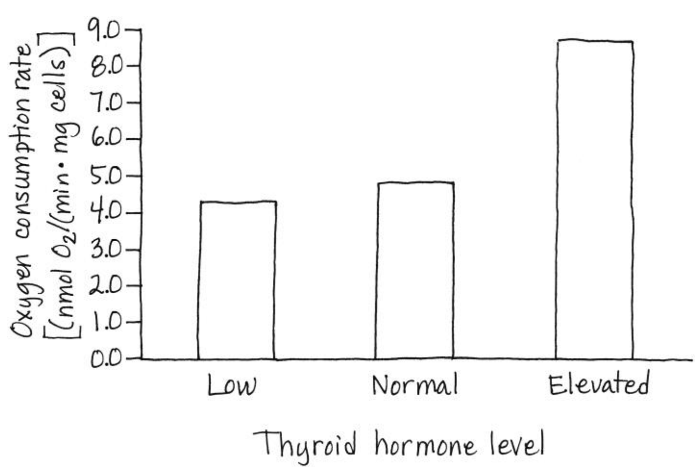
Teaching tips: A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

When faced with data that fall into categories instead of along a continuum, many students will "connect the dots" of data points instead of keeping them separate in bar graph format. Having students make the graph several times, changing the order that the categories align on the *x*-axis, will demonstrate that the pattern will change if points are connected but not if left separate. Some astute students may argue that in this example, the cells with low, normal, and elevated thyroid hormone levels represent a continuum of thyroid hormone levels and can be treated as continuous data. In this case, challenge them to assign numerical values to the hormone levels and they will see that in the absence of actual hormone data, the cell types must be treated as non-continuous categories. However, it is logical to put the categories in order from low to high hormone levels.

Answers:

1. (a) The researchers intentionally varied the thyroid hormone level, which is therefore the independent variable and should be put on the *x*-axis. The data should be shown in the categories Low, Normal, and Elevated. Putting the categories in the order Low, Normal, and Elevated is logical, but the categories could go in a different order. (b) The researchers measured the oxygen consumption rate, which is therefore the dependent variable and should be put on the *y*-axis. (c) The units on the *y*-axis are nanomoles of oxygen gas (O_2) per minute per milligram of cells (abbreviated as "nmol O_2/min · mg cells"). The largest value on the *y*-axis is 8.7, so numbers from 0.0 to 9.0 should be used as tick mark labels on the *y*-axis.

2.



A bar graph is more appropriate than a scatter plot or line graph because the thyroid hormone levels are categories, not continuous values. (As mentioned in the “Teaching Tips” section, above, numerical values for “low,” “normal,” and “elevated” are not given.)

3. (a) The cells with elevated thyroid hormone levels had the highest rate of oxygen consumption, and the cells with low thyroid hormone levels had the lowest rate of oxygen consumption. (b) Thyroid hormone may stimulate the rate of mitochondrial electron transport in these cells. This hypothesis is supported because the state of thyroid hormone of each cell type (low, normal, or elevated) is correlated with the rate of mitochondrial oxygen consumption. Note that the experiment does not give us any information about the mechanism of action of thyroid hormone. You might also want to discuss the fact that correlative evidence is not as strong as some other types of evidence, such as those referred to as “loss-of-function” or “gain-of-function” evidence. For example, if an agent was used that blocked the action of thyroid hormone in mice and O_2 consumption decreased, or a different agent was used that increased the activity of thyroid hormone and O_2 consumption increased, then both of these would provide stronger evidence. (c) Because the rate of oxygen consumption is a measure of the rate of mitochondrial electron transport, and electron transport rate is related to how much heat is produced by the mitochondria, one can predict that the rats with low thyroid levels will have the lowest body temperature and the rats with elevated thyroid levels will have the highest body temperature. (This does turn out to be the case.)

Interpret the Data

9. Under both conditions, the phosphofructokinase enzyme increases in activity as the concentration of the substrate increases, up until a point at which the rate remains the same. Under conditions of low ATP concentration, however, phosphofructokinase enzyme activity increases faster and reaches maximum rate sooner. At higher concentrations of ATP the enzyme is less active, which makes sense because if ATP is abundant, there is less need for ATP to be made by the processes of cellular respiration, beginning with glycolysis. At low ATP concentrations in the cell, the concentrations of AMP and ADP are higher, and it makes sense that more ATP would be needed, thus phosphofructokinase would be more active, moving sugar along in the breakdown pathway. Therefore, phosphofructokinase activity is higher when the concentration of ATP is low.

Suggested Answers for End-of-Chapter Essay Questions

See the general information on grading short-answer essays and a suggested rubric at the beginning of this document.

10. Scientific Inquiry

In a person treated with uncoupling agents like DNP, the proton gradient established during respiratory electron transport is no longer tied to ATP synthesis. As a result, oxidation of glucose during the citric acid cycle yields very little ATP, since ATP is normally produced as protons flow back through the ATP synthase sites in the inner mitochondrial membrane, while still generating heat. Without large amounts of ATP available, biosynthesis cannot take place and new organic molecules cannot be synthesized. Low ATP levels would signal the body to continue breaking down its own molecules and feeding them into the cellular respiration pathway, leading to excessive weight loss and severe overheating and dehydration. One or a combination of these factors can cause death.

11. Focus on Evolution

(a) The presence of ATP synthases in all of these places suggests the likelihood of common ancestry. As described in Chapter 4, the endosymbiont theory says that mitochondria evolved from a free-living, aerobically respiring, nonphotosynthetic prokaryote that was engulfed by an ancestral eukaryotic cell. It further holds that chloroplasts evolved from a free-living, photosynthetic prokaryote engulfed in the same way. (b) One would expect to observe a high degree of similarity when comparing the amino acid sequences for the ATP synthases of mitochondria, chloroplasts, and prokaryotes living today. Observation of this similarity would support the hypothesis that these eukaryotic organelles and prokaryotes share common ancestry. Observation of a relatively low degree of similarity between the amino acid sequences of these ATP synthases would fail to support the stated hypothesis.

12. Focus on Organization

Sample key points:

- An electron transport chain consists of complexes of membrane proteins that transfer electrons from carrier to carrier in a series of redox reactions.
- Redox reactions release energy as electrons move to lower energy levels, while the protein complexes shuttle protons across the membrane.
- Thousands of electron transport chains embedded in the inner mitochondrial membrane establish a concentration gradient of protons.
- Through the energy-coupling process of chemiosmosis, the resulting proton-motive force drives diffusion of H^+ through ATP synthase.
- The organization of proteins in the electron transport chain and of ATP synthase in the inner mitochondrial membrane are key to this process.
- The arrangement of proteins in the ATP synthase complex allow them to function.

Sample top-scoring answer:

Novel properties emerge from the arrangement and interaction of parts at each level of the biological hierarchy. An electron transport chain consists of a sequence of electron carrier molecules embedded in the inner mitochondrial membrane that transfer electrons through a series of redox reactions, while shuttling protons across the membrane. The thousands of electron transfer chains create a concentration gradient of H^+. This proton-motive force drives ATP formation by ATP synthase via chemiosmosis. It is the organization of the electron carrier proteins in the electron transport chain and the location of ATP synthase that allows ATP synthesis to occur. The function of the ATP synthase complex is also due to the specific, ordered arrangement of the proteins that make up the complex. Thus, oxidative phosphorylation is an emergent property resulting from the structural and functional organization of component parts, none of which would be able to synthesize ATP on its own.

13. Synthesize Your Knowledge

Coenzyme Q ("Q" in Figure 7.14) is a small hydrophobic molecule that is part of the electron transport chain in mitochondria, involved in shuttling electrons during oxidative phosphorylation. This process occurs at the end of cellular respiration and helps produce ATPs for use by the cell. As you might imagine, cells that are particularly active—such as heart muscle cells—require additional coenzyme Q. The product shown in the photo therefore functions as a nutritional supplement by providing extra molecules for the electron transport chain. (Although the body can synthesize coenzyme Q, various disorders, including heart disease, are correlated with a deficiency of this molecule.) However, coenzyme Q is not a fuel because it is not consumed by cells; instead, it is used over and over again as an electron shuttle.