**Teacher Notes for**

**Carbohydrate Consumption, Athletic Performance and Health**

**– Using Science Process Skills to Understand the Evidence**

Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, 2013[[1]](#footnote-1)

This discussion/worksheet activity is designed to develop students' understanding of the scientific process by having them

* design an experiment to test a hypothesis
* compare their experimental design with the design of a research study to test the same hypothesis
* evaluate research evidence concerning two hypothesized effects of carbohydrate consumption
* evaluate the pros and cons of experimental vs. observational research studies
* use what they have learned to revise a standard diagram of the scientific method to make it more accurate, complete and realistic.

This activity is designed for use near the beginning of a typical introductory biology course, e.g. at the end of a unit on biological molecules. Depending on your learning goals, you can use either part I or part II of the Student Handout, parts I and II together, or all three parts together.

**Learning Goals**

Students Engage in Scientific Practices[[2]](#footnote-2)

"Planning… Investigations" – Students should be able to:

* "Decide what data are to be gathered …"
* "Plan experimental… procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls."
* "Consider possible confounding variables or effects and ensure that the investigation’s design has controlled for them."

"Analyzing and Interpreting Data" – Students should be able to:

* "Analyze data systematically… to test whether data are consistent with an initial hypothesis."
* "Evaluate the strength of the conclusion that can be inferred from any data set…"

"Obtaining, Evaluating and Communicating Information" – Students should be able to:

* "Read scientific… text… commensurate with their scientific knowledge and explain the key ideas being communicated."
* "Engage in critical reading of… media reports of science and discuss the validity and reliability of the data, hypotheses and conclusions."

Additional Learning Goals

– Consuming carbohydrates can improve athletic performance and may also affect health.

– The process of science is more complex than the typical textbook diagram of the scientific method.

**Background Information and Suggestions for Implementation and Discussion**

To maximize student learning and participation, I suggest that, for each section, you have your students work individually and/or in pairs to answer the questions and then have a class discussion (discussions recommended after page 1 of the Student Handout, after page 2, after

part II, and after part III).

Before beginning, your students should have at least a basic understanding of what carbohydrates are, and for part II they should also know what proteins are. If your students are not thoroughly familiar with independent and dependent variables, you will want to provide an explanation of independent variables as hypothesized causes (e.g. variables that the experimenter controls) and dependent variables as hypothesized effects (e.g. variables that the experimenter measures). To help your students remember the distinction between independent and dependent variables, you may want to point out that an independent variable is what it sounds like – a variable that stands on its own and is independent of the other variables, and a dependent variable is what it sounds like – something that depends on another variable or variables. So, a typical hypothesis postulates that a change in an independent variable causes a change in a dependent variable.

This activity deals with only two of the multiple hypothesized effects of consuming carbohydrates. These effects have been chosen for analysis because of the accessibility of relevant research evidence and because this research evidence can be used to reinforce and develop student understanding of important aspects of the scientific process. To learn about a broader range of effects of carbohydrate consumption and how these effects vary depending on the amount and type of carbohydrate, see the sources cited below.

I. Can athletic performance be improved by consuming carbohydrates during sports events?

How do we know?

Questions 2, 3, 6 and 7 provide the opportunity to reinforce student understanding of independent and dependent variables. Question 2 also provides the opportunity to make sure that your students know what types of foods contain carbohydrates.

In discussing questions 1-5, I suggest that you highlight the strengths of the various experimental designs proposed by the students and encourage your students to think about any problems and how they might be resolved, without trying to push them to the sophisticated experimental design they will learn about on the second page of the Student Handout.

A full description of the research study that is summarized at the top of page 2 was published by Welch et al. in *Medicine and Science in Sports and Exercise* 34:723, 2002. Advantages of the experimental design for this research study include:

* having the same subjects perform the same activities in two different trials (one with sports drink and one with placebo) on two different days
* having practice sessions before the first experimental trial
* having half of the subjects receive sports drink in the first experimental trial and half receive placebo in the first experimental trial
* double-blind design so that neither the participants nor the researchers who assessed athletic performance knew whether a trial was a sports drink or placebo trial

Each of these features of the experimental design contributed to making the conditions in the sports drink and placebo trials as close as possible to identical, so differences in performance can be attributed to the effects of the sports drink. Another advantage of the experimental design was that athletic performance was tested during each 15-minute interval, so the researchers could evaluate whether carbohydrate consumption improved performance during the early stages of athletic activity. The use of multiple measures of athletic performance provided a more comprehensive assessment of the varied possible effects of carbohydrate consumption.

It is of interest that, in the first 45 minutes of the hour of vigorous physical activity, there were no differences in athletic performance between the sports drink and placebo groups. This research finding supports sports nutritionists' advice that carbohydrate intake is not needed during short-duration athletic competitions. In contrast, sports nutritionists advise athletes to consume small quantities of carbohydrate during long-duration, high-intensity sports events; this advice is supported by the study findings that athletic performance was better in the sports drink trials both during the last 15 minutes of the hour of vigorous physical activity and during the run after the hour of vigorous physical activity. This improved athletic performance was probably related to the finding that (from the end of the second quarter onward) blood glucose levels were higher in the group that drank sports drink.

It should be pointed out that one disadvantage of the experimental design of this study is that subjects fasted for 12 hours before the experimental sessions. It seems likely that most athletes would not fast for such a long time before an athletic event, and some evidence suggests that, if carbohydrate consumption has been high prior to an athletic event or research experiment, carbohydrate consumption during an athletic event may not have a significant effect. The benefit of carbohydrate consumption before athletic competitions is supported by research evidence. Carbohydrate consumption helps to maintain blood glucose levels and prevent depletion of glycogen stores in muscles. In addition, recent evidence suggests that rinsing the mouth with carbohydrate solutions (without swallowing) enhances performance in fasting athletes engaged in long-duration, high-intensity physical activities, apparently by effects on the central nervous system.

You will probably want to caution your students about the risks of drawing firm conclusions from a single study and mention that, although there are multiple supporting studies, there are also conflicting results and controversy in this field. You will also want to caution your students about extrapolating from a study with well-trained athletes engaged in high-intensity, long-duration physical activity to a sedentary person, for whom increased carbohydrate consumption is likely to have harmful effects, including increased risk of obesity and cavities. For example, one recent observational study found that sports drink consumption was associated with significantly increased weight gain in 9-15-year-olds (<http://www.theheart.org/article/1450295.do> ).

If you would like to read more, an informative review of "Nutrition and Athletic Performance", including recommendations from the American Dietetic Association, Dietitians of Canada, and American College of Sports Medicine, is available at <http://www.eatright.org/about/content.aspx?id=8365>. A useful, non-technical summary is available at <http://www.nlm.nih.gov/medlineplus/ency/article/002458.htm>. A brief description of recent controversy is available at <http://www.nutritionhorizon.com/news/Lack-of-Evidence-Sports-Nutrition-Products-Work-Says-BMJ-GSK-Responds.html>.

Depending on your learning goals and your students' background, you might want to add the following questions to the Student Handout and/or your discussion:

* How could carbohydrate consumption contribute to improved athletic performance for high-intensity, long-duration physical activities?
* What research question would you want to investigate next? What type of study would you suggest to investigate this research question?

II. Do low-carbohydrate, high-protein diets have harmful effects on health? What is the evidence?

There are a number of methodological points that you will want to be aware of as you discuss questions 10-14.

The researchers were interested in the hypothesis that low-carbohydrate, high-protein diets *cause* an increased risk of cardiovascular disease. Their observational study provides indirect evidence concerning that hypothesis, but the study actually tested the hypothesis that low-carbohydrate, high-protein diets *are associated with* higher subsequent risk of cardiovascular disease.

The article on page 5 of the Student Handout provides results for a dietary variable that reflects both low carbohydrate and high protein intake. The original article (Lagiou et al., *British Medical Journal* 344:e4026, 2012) provides results for two additional dietary variables – separate measures of carbohydrate intake and protein intake. All three of these dietary variables are based on a questionnaire completed at the beginning of the study; the participants reported their diets over the past six months by estimating how often they consumed each of about 80 food items and beverages and the average serving size for each. Obviously, the questionnaire does not provide a precise estimate of carbohydrate intake or protein intake, but it provides a reasonable basis for comparing women with low versus high intake of carbohydrates and proteins. A significant problem with the dietary variables is that they were based on a single questionnaire at the beginning of the study and many women may have made changes in their diet during the long follow-up period.

The article on page 5 of the Student Handout refers to heart disease in the title, but describes the results in terms of the findings for cardiovascular disease, a broader category which includes heart disease (55% of total diagnoses of cardiovascular disease for the women in this study), stroke (29%), and a few smaller categories. The original article provides more detailed evidence which shows that each of the three measures of dietary intake (low carbohydrate consumption, high protein consumption, or the combination of low carbohydrate and high protein consumption) is associated with higher rates for each of three measures of cardiovascular disease (all cardiovascular disease, heart disease, or stroke).

In discussing question 12, you may want to point out that the increase in risk seems larger when evaluated as a proportionate increase in risk (62% higher incidence of cardiovascular disease) and seems smaller when evaluated as an absolute increase in risk ("an additional four to five women out of 10,000 developed cardiovascular disease each year"). This illustrates the general principle that, if a health problem is rare, a high proportionate increase in risk corresponds to only a small absolute increase in risk. Note that both of these estimates compare the women in the lowest carbohydrate, highest protein intake category with the women in the highest carbohydrate, lowest protein intake category. In contrast, the 5% increase in risk with "20 fewer grams of carbohydrates and 5 more grams of protein a day" compares adjacent categories of carbohydrate and protein intake.

For question 13, students may come up with a variety of creative (although not necessarily practical) designs for an experiment to test the effects of low-carbohydrate, high-protein diets on the risk of heart disease. The student proposals can be used to discuss the requirements for a valid experiment and the advantages and practical difficulties of experiments to test nutritional hypotheses with human subjects. It may be helpful for you to know that researchers who test nutritional hypotheses with human subjects typically use a clinical trial. Clinical trials are a type of experiment in which participants are randomly assigned to either a group that receives the treatment (e.g. a vitamin supplement) or another group that receives a placebo (a pill that does not contain the vitamin but tastes, smells and looks like the vitamin supplement, so the participants in both groups have an equal expectation of benefit). Since the participants are assigned at random to either the treatment group or the placebo group, none of the participants' characteristics can influence who gets the treatment and who gets placebo; therefore, all of the participants' characteristics will be the same for the treatment and placebo groups. Thus, the design of a clinical trial eliminates the effects of all possible confounding factors, so any difference between the treatment and placebo groups can be interpreted as a causal effect of the treatment. For clinical trials of low-carbohydrate, high-protein diets, the comparison group receives a different diet (e.g. a low-fat diet) rather than a placebo.

A major advantage of experimental studies is that experimental studies can provide evidence of causal effects, whereas observational studies generally can only evaluate associations, not cause-and-effect.[[3]](#footnote-3) Nevertheless, much of our evidence concerning nutrition and health comes from observational studies because experimental studies are very difficult to carry out for the following combination of reasons:

* Health problems like cardiovascular disease are relatively rare and develop slowly over time so a research study needs to follow a large sample of people over a long period of time.
* It is extremely difficult or impossible to get large numbers of people to follow a specific diet over a long period of time.

With regard to question 14, the major reasons why this study does not support definite conclusions concerning the effects of low-carbohydrate, high-protein diets on heart disease or cardiovascular disease are:

* This is an observational study, so any observed association could be due to the effects of confounding factors.
* This is only a single study, and evidence from other studies is inconsistent. A few long-term observational studies have found similar associations between low-carbohydrate, high-protein diets and risk of cardiovascular disease, but a few other studies did not find significant associations. Furthermore, experiments (which lasted a year or less) have shown that low-carbohydrate diets can have beneficial effects on some risk factors such as weight, systolic blood pressure, and HDL cholesterol ("good cholesterol"). However, these experimental results cannot be extrapolated to long-term beneficial effects on risk of cardiovascular disease for several reasons, including:
* The same experiments have shown harmful effects on LDL cholesterol ("bad cholesterol”), and there may be harmful effects on other risk factors for cardiovascular disease that were not measured in these experiments.
* The short-term and long-term effects of low-carbohydrate diets appear to differ (e.g. the weight-loss advantage observed at six months is much reduced by one year).

The comments by the Atkins spokesperson are correct that "the women in the study ate more carbohydrates and less protein than prescribed in the Atkins diet", but this observation is not reassuring for people on the Atkins diet since the study results suggest that people who consume the more extreme Atkins diet probably have an even higher risk of cardiovascular disease than the low-carbohydrate, high-protein group in the study. The studies of the relationship between the Atkins diet and heart health that "have shown diminished risk" are the relatively short-term clinical trials that assessed effects on risk factors (see above paragraph for cautions concerning interpretation of these studies).

Useful relevant sources include:

* a commentary on the target article and some newspaper accounts of this article, available at <http://www.nhs.uk/news/2012/06june/Pages/low-carb-Atkins-diet-high-protein-heart-risk.aspx>
* "Atkins diet: what's behind the claims?", available at <http://www.mayoclinic.com/health/atkins-diet/my00648>
* "Carbohydrates: how carbs fit into a healthy diet ", available at <http://www.mayoclinic.com/health/carbohydrates/my01458>

The following questions can be used as an extension activity.

* What else would you like to know?
* How could you search for reliable information on this question?
* Search for sources and evaluate the evidence. What conclusions does this evidence support? What are the limitations of this evidence?

If you would like your students to develop a more sophisticated understanding of clinical trials, observational studies, and other nutritional research, I recommend the follow-up activity "Vitamins and Health – Why Experts Disagree" (available at <http://serendipstudio.org/exchange/bioactivities/vitamins>). This discussion/worksheet activity engages students in analyzing the seemingly contradictory research results concerning the health effects of vitamin E and helps students learn how to evaluate evidence, with a major focus on understanding the strengths and weaknesses of different types of studies.

III. Understanding the Scientific Method

Useful additions and modifications for the model of the scientific method shown in question 15 include:

* review the scientific literature to see what previous researchers have found
* conduct an experiment or observational study
* analyze data
* interpret results, considering various possible alternative hypotheses that could account for the observed results
* usually cannot accept or reject a hypothesis based on a single study; instead:
* may find evidence in support of accepting or rejecting a hypothesis, and other researchers may try to replicate
* *or* researchers may identify limitations in their study and design an improved study
* *or* researchers may refine their hypothesis based on research findings and then test this refined hypothesis (e.g. of refined hypothesis: some researchers have suggested that diets that are low in carbohydrates and high in animal proteins have harmful health effects, but diets high in plant proteins may not have harmful health effects).

If you want your students to learn about the scientific method by designing, carrying out, and interpreting the results of experiments, I recommend "Starch and Protein Investigation", available at <http://serendipstudio.org/sci_edu/waldron/#starch>. The Teacher Notes for that activity provide links to other similar activities.

The website <http://serendipstudio.org/exchange/bioactivities> provides discussion/worksheet activities that engage students in a variety of scientific practices such as interpreting evidence, using scientific understanding to construct explanations of observed phenomena, and applying scientific knowledge to policy questions. For example, see:

* Barley and Oat’s Brewing Backfire
* Where does a Plant's Mass Come from?
* Plant Growth Puzzle
* Should states repeal their laws banning first cousin marriage? – Effects of first cousin marriage on health risks for their children
* Vitamins and Health – Why Experts Disagree
* Understanding the Biology of Cancer

A wealth of resources for teaching and understanding the scientific process are provided in

"Understanding Science – How science really works", available at <http://undsci.berkeley.edu/>

A discussion of the diversity and dynamism of the scientific process is provided in "Problems with 'the scientific method' ", available at <http://www.sciencenewsforkids.org/2012/07/problems-with-the-scientific-method/>

1. These Teacher Notes, the related Student Handout, and other activities for teaching biology are available at <http://serendipstudio.org/exchange/bioactivities/sciproc> . [↑](#footnote-ref-1)
2. Quotations and recommendations for students to engage in scientific practices are from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (available at <http://www.nap.edu/catalog.php?record_id=13165> ). [↑](#footnote-ref-2)
3. One exception to this generalization occurs when observational studies find an extremely strong association (such as the roughly 10-fold greater risk of lung cancer among cigarette smokers). This association is too strong to be due to any plausible confounding factors. Reverse causation (i.e. effects of lung cancer on smoking) can be ruled out because cigarette smoking begins decades before lung cancer develops. Thus, this observational evidence provides strong support for a causal effect of cigarette smoking on lung cancer. [↑](#footnote-ref-3)