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Concussion Leaves Clues in the Blood

SOCIETY FOR SCIENCE & THE PUBLIC

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About this Guide

This Guide, based on the *Science News* article "Concussion leaves clues in the blood," asks students to explore research into concussions and draw on their own experiences to think about the various signs and symptoms of injury or disease. After testing various materials, students will develop designs for protective headgear.

This Guide includes:

Article-based Comprehension Q&A — These questions, based on the *Science News* article "Concussion leaves clues in the blood," Readability: 12.4, ask students to explore the search for a better way to diagnose concussions. Related standards include NGSS-DCI: HS-LS1; HS-ETS1.

> **Student Comprehension Worksheet** — These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular Discussion Q&A — Students will explore how symptoms and other biological information — including protein biomarkers in particular — can help doctors identify a problem and recommend a treatment. Related standards include NGSS-DCI: HS-LS1; HS-ETS1.

> **Student Discussion Worksheet** — These questions are formatted so it's easy to print them out as a worksheet.

Activity: Protective Headgear Design Challenge

> **Summary:** Concussions are a common sports injury. After reviewing Newton's laws of motion, force diagrams, momentum, and elastic and inelastic collisions, students will test various materials that might protect the head from sports collisions and use those materials to design protective headgear.
>
> **Approximate class time:** 2 class periods.

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Article-based Comprehension, Q&A

Directions for teachers: After your students read "Concussion leaves clues in the blood," ask them to answer the following questions.

1. What is a concussion and how is it typically diagnosed?

A concussion is a brain injury that results from a knock to the head. That knock can come from a fall, a car accident or while playing sports, for example. Concussions are diagnosed by assessing physical symptoms including headache, nausea, dizziness, confusion and loss of consciousness.

2. Why is the current method for diagnosing concussions not always reliable?

Diagnosing concussions can be tricky because some physical symptoms, such as a headache, may not always be a sign of brain injury.

3. How many sports-related concussions are reported by college athletes in the United States each year?

Estimates suggest 10,560 sports-related concussions are reported annually.

4. What are biomarkers and how do scientists hope to use them in concussion diagnoses? Could biomarkers replace current concussion diagnostic methods?

Biomarkers are chemical signals that may indicate a medical state, such as a concussion. Scientists hope to find biomarkers for concussion in the blood and use them alongside symptoms to improve diagnosis.

5. What did the research study described in the article find? What data supported that result?

The study found that athletes had higher blood levels of three proteins after a concussion than before the injury — a clue that those proteins may be linked to concussion. Scientists compared blood samples taken from nearly 300 college athletes before and after the athletes sustained a concussion. The study also looked at protein levels of athletes who didn't have concussions and athletes who didn't play contact sports.

6. Why did scientists measure blood protein levels of athletes that didn't have concussions?

Non-concussed athletes served as the control groups in the study. If the protein levels for this group had shown a large variability, it would have called into question the association between proteins and concussion.

7. What potential concussion biomarkers did the scientists find? What do the biomarkers have in common?

Scientists found three biomarker candidates: Glial fibrillary acidic protein, Ubiquitin C-terminal hydrolase-L1 and tau. All three proteins are related to injury or damage in certain types of brain cells.

8. Were there any issues, limitations or gaps in the study? Are the biomarkers ready to be used to diagnose concussions? Explain.

The biomarker candidates are not yet ready for use by doctors. Scientists still need to figure out how consistently the proteins are linked to concussions, and to see how the proteins vary in different groups of people. Most of the athletes in the study were male, for example.

9. Can you think of a next step for scientists?

As a next step, scientists could replicate the study with female college athletes, who have a higher rate of concussion than male athletes and can experience more severe symptoms, to see if the candidate biomarkers consistently show up in women too.

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Student Comprehension Worksheet

Directions: After reading "Concussion leaves clues in the blood," answer the following questions.

1. What is a concussion and how is it typically diagnosed?

2. Why is the current method for diagnosing concussions not always reliable?

3. How many sports-related concussions are reported by college athletes in the United States each year?

4. What are biomarkers and how do scientists hope to use them in concussion diagnoses? Could biomarkers replace current concussion diagnostic methods?

5. What did the research study described in the article find? What data supported that result?

6. Why did scientists measure blood protein levels of athletes that didn't have concussions?

7. What potential concussion biomarkers did the scientists find? What do the biomarkers have in common?

8. Were there any issues, limitations or gaps in the study? Are the biomarkers ready to be used to diagnose concussions? Explain.

9. Can you think of a next step for scientists?

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Cross-curricular Discussion, Q&A

Directions for teachers:
After students have read "Concussion leaves clues in the blood," lead a class discussion based on the first set of questions below. The prompts encourage students to use their own experience as a starting point to think about the various signs and symptoms of injury or disease.

After the class discussion, ask students to break out into partners or small groups to explore biomarkers in particular. Once students have covered the last question, bring the class together to share any final thoughts.

Class discussion questions

1. Think about the last time you or someone you know was injured. What did people (parents, athletic trainers, nurses, doctors, for example) do to try to diagnose the problem or its extent? What questions did they ask? What types of tests and procedures, if any, were run and what kind of information did those tests provide?

2. Now broaden your thinking. What techniques or tools do doctors or other medical professionals have available to identify injuries more generally? What about diseases and other health problems? Be sure to consider low-tech approaches and more high-tech tools.

3. Why are some health problems harder to diagnose than others? What characteristics of the injury or disease might influence the ease of identifying the problem? How might differences among individuals affect the ability to make a diagnosis? Why do you think doctors often rely on multiple lines of evidence for a diagnosis?

Partner discussion questions

4. What are biomarkers? How might biomarkers be useful in diagnosing concussions? Can you think of other diseases or injuries where biomarkers might be useful? Do a quick search at www.sciencenews.org to find examples of potential biomarkers that researchers are currently exploring.

Biomarkers are chemical signals that may indicate a medical state, such as a concussion. Scientists hope to find biomarkers that can be paired with other signs and symptoms, such as physical assessments and memory tests, to help diagnose concussions. Researchers are currently exploring biomarkers that might someday help diagnose autism, pancreatic cancer and Alzheimer's disease, as just a few examples.

5. How do biomarkers compare with other types of tests? What are the benefits and limitations of biomarkers? For the concussion study described in the article, did the researchers show that a knock to the head *caused* an increase in the biomarkers? Did the increase in the biomarkers *cause* the loss of normal brain function? Explain. Are there other cases when biomarkers can play a *causative* role?

Biomarkers offer a window into what is happening within the body. They may be less subjective than tests that rely on recall or reported symptoms and less invasive than tests that need to study tissue directly. Still, biomarkers are just one source of evidence and often can't be used to make a diagnosis on their own. They require preexisting knowledge of baseline levels and in some cases may be misinterpreted.

In the case of the concussion research described in the article, the researchers did not prove that a knock to the head caused the biomarker levels to increase. The researchers instead reported an association between a concussed state and biomarker levels. Factors other than the knock on the head could have affected the protein levels, which might make them a red herring for researchers. Likewise, it's unclear whether the presence of the biomarkers contributes to the loss of normal brain function; it's likely that they are an indirect sign that the damage has happened. In some cases, biomarkers might be a causal step in the path to a disease, their presence initiating or confounding the damage. In other cases, they might be a sign that the body is recovering. It can take a lot of research to figure all of this out.

6. Neurologist Juliana VanderPluym says "it is important to consider [biomarkers] as an aide, and not necessarily as the final determinant" of a diagnosis. There could be a case where an athlete reports symptoms that suggest a concussion but doesn't show elevated levels of the biomarkers. What would you do if you were a coach or trainer faced with that situation, and why? How could scientific research help to address such cases in the future? What additional research should be completed?

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Student Discussion Worksheet

Directions: After reading "Concussion leaves clues in the blood," discuss questions No. 1–3 as a class. Then, find a partner and answer the rest of the questions together.

Class discussion questions

1. Think about the last time you or someone you know was injured. What did people (parents, athletic trainers, nurses, doctors, for example) do to try to diagnose the problem or its extent? What questions did they ask? What types of tests and procedures, if any, were run and what kind of information did those tests provide?

2. Now broaden your thinking. What techniques or tools do doctors or other medical professionals have available to identify injuries more generally? What about diseases and other health problems? Be sure to consider low-tech approaches and more high-tech tools.

3. Why are some health problems harder to diagnose than others? What characteristics of the injury or disease might influence the ease of identifying the problem? How might differences among individuals affect the ability to make a diagnosis? Why do you think doctors often rely on multiple lines of evidence for a diagnosis?

Partner discussion questions

4. What are biomarkers? How might biomarkers be useful in diagnosing concussions? Can you think of other diseases or injuries where biomarkers might be useful? Do a quick search at www.sciencenews.org to find examples of potential biomarkers that researchers are currently exploring.

5. How do biomarkers compare with other types of tests? What are the benefits and limitations of biomarkers? For the concussion study described in the article, did the researchers show that a knock to the head *caused* an increase in the biomarkers? Did the increase in the biomarkers *cause* the loss of normal brain function? Explain. Are there other cases when biomarkers can play a *causative* role?

6. Neurologist Juliana VanderPluym says "it is important to consider [biomarkers] as an aide, and not necessarily as the final determinant" of a diagnosis, noting that there could be a case where an athlete reports symptoms that suggest a concussion but doesn't show elevated levels of the biomarkers. What would you do if you were a coach or trainer faced with that situation, and why? How could scientific research help to address such cases in the future? What additional research should be completed?

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Activity Guide for Teachers: Protective Headgear Design Challenge

Purpose: Concussions are a common sports injury. In this activity, students will review the concepts of Newton's second and third laws of motion, force diagrams, conservation of momentum, and elastic and inelastic collisions and apply that knowledge to sports collisions. Students will draw a force diagram and use critical thinking skills and experimental design to propose ways to reduce force in a collision.

Procedural overview: After comparing impacts in an elastic and inelastic collision and answering associated questions, student groups will develop and carry out a protocol for testing materials that can reduce the force of an impact. Students will analyze the data to identify the best materials for use in protective headgear and then apply their knowledge to design headgear that might reduce the likelihood of concussions in a particular sport.

Approximate class time: 2 class periods.

Supplies:

Protective Headgear Design Challenge student activity guide (see below)

Materials for demonstration 1
Two eggs
One flat bedsheet
Safety pins
Paper towels and spray cleaner

Materials for demonstration 2
One bouncy ball
One meterstick
Hard and soft surfaces to bounce the ball off of

Materials per student group
One bouncy ball
One meterstick
A shallow box to hold materials to be tested
A variety of soft materials that can absorb impact in a collision (cloth, packing peanuts, bubble wrap, crumpled paper)
Video recording device, such as a smartphone or tablet (optional)

Directions for teachers:
Introduce students to the issue of concussion in college sports by having them read "Concussion leaves clues in the blood." The story notes that an estimated 10,500 sports-related concussions are reported by NCAA college athletes in the United States each year. You may wish to discuss concussions in high school athletics, the potential for underreporting, and any personal experience students have had with concussions.

Explain that such a high number of concussions suggests that athletes could benefit from more or better protective headgear. After a review of Newton's second and third laws of motion and related concepts, students will test materials to use in protective headgear. They will then use the test results to draw a design for headgear for a particular sport.

Review

Explain that the force that leads to a concussion is a force from a collision. Remind students of any prior activities the class has done on force and collisions and present a review of related concepts as necessary. You may wish to have students develop their own review and then discuss their ideas before creating a final class review. Here are some possible points to cover in a review:

1. An object's acceleration is directly proportional to and in the same direction as the net force exerted on it and inversely proportional to its mass (Newton's second law). This relationship is expressed mathematically as $F = ma$.

2. When two objects exert forces on each other, those forces are equal in amount and opposite in direction (Newton's third law).

3. Momentum is the product of an object's velocity and mass. This relationship is expressed mathematically as $p = mv$.

4. If there is no external force on two colliding objects (labeled 1 and 2), the total amount of momentum in the system is conserved. This relationship is expressed mathematically as $\sum p_1 = \sum p_2$.

5. A force diagram shows all the forces acting on an object. The forces are shown with arrows that indicate direction and relative strength (or magnitude) of the forces.

6. The velocity an object is related to its kinetic energy. This relationship is expressed mathematically as $KE = (1/2)mv^2$.

After the review, have students answer Questions 1–3 to check their basic understanding of the physics concepts.

Next, review the derivation of the impulse-momentum theorem. Explain that for each object the relationship between force applied, the time over which the collision occurs (change in time) and the change in momentum can be shown by writing out Newton's second law, substituting $\Delta v/\Delta t$ for a and multiplying both sides by Δt, as follows.

$F = ma$
$F = m\Delta v/\Delta t$
$F\Delta t = m\Delta v$
$F\Delta t = \Delta p$

Explain that the final equation is called the impulse-momentum theorem. In this equation F is the average force applied to an object and Δt is the time over which the collision occurs.

After the derivation of the equation, have students answer Questions 4–5 and discuss.

Next, show students how to use the impulse-momentum theorem to analyze collisions by conducting or discussing two demonstrations, both related to the scenarios posed in Questions 4–5.

Demonstration 1

In the first demonstration, toss an egg at approximately the same velocity over the same distance, first against a wall and then against a loosely held sheet. If demonstrating in class, have students hold the sheet at the four corners and create a pocket with pins at the bottom of the sheet so the egg will roll into the pocket. Demonstrate or discuss what will happen. Have students draw force diagrams for an egg's collision with the wall and the sheet. Remind students that all vectors should include direction and relative strength to one another.

After determining that the egg does not break in the second collision, have students answer Questions 6–9. Then facilitate a class discussion on the answers. Students will consider the differences between the two collisions in terms of change in velocity and the difference in time, Δt, over which the collision occurs. When comparing the two collisions, the change in velocity is the same but the change in time is different. Use this discussion to ensure that students understand that the longer it take a collision to occur, the less force is exerted by the colliding objects on each other.

Demonstration 2

In the second demonstration, drop a bouncy ball on different types of surfaces. When colliding with a hard surface, the ball will bounce almost to the height it was dropped from. When colliding with a soft surface, the ball will not bounce as high. Explain that the ball loses only a small amount of kinetic energy when bounced off a hard surface (a more elastic collision), but loses more kinetic energy when bounced off a soft surface (a more inelastic collision).

In which collision does the ball experience less force, and why that is the case? Have students draw force diagrams for the ball's collision with each surface. Remind them that all vectors should include direction and relative strength.

After determining that the ball hitting the soft surface experiences less force, have students answer Questions 10–13. Then facilitate a class discussion on the answers. Students should realize that in this set of collisions there are two factors to look at, the time over which the collision takes place and the change in velocity, Δv, since the ball does not come to rest.

Testing materials

Next, group students and have each group consider how concussions occur in different sports, such as football, cycling, basketball, hockey, lacrosse or soccer. Each student group should choose a sport to focus on and answer Questions 14–15, including drawing a force diagram to represent a collision in their sport. Have students share their ideas with the class. Organize student responses by sport and have students add any final comments or possible changes to their force diagrams. Use this discussion to ensure students were able to analyze and diagram the forces on a head that occur in their sport.

Tell students that they will now develop a standard protocol for testing how well various materials or combinations of materials can protect the head from the force of an impact. Explain that the ability of a material to decrease the force will be tested by dropping a bouncy ball on it.

Lead a class discussion for ideas on how to test materials. You may wish to have groups come up with different ideas first to ensure student engagement. With the help of student volunteers, test different possible protocols to determine a standard height from which to drop the bouncy ball and a standard material thickness. (It may be easiest to set the standard thickness based on the material that is thickest, such as bubble wrap.)

Explain that student groups will measure how high the ball bounces up with each material after being dropped from a standard height. You may wish to have students use a recording device (smartphone, tablet, etc.) to capture the bounces with a meterstick in the frame and then play the video back in slow motion to better measure the bounce height. Post the testing protocol in the classroom and have students record the protocol in answer to Question 16.

Tell groups to inventory the materials in the classroom and then work in their groups to record additional materials they have at home that they would like to bring in to test in answer to Question 17.

At the start of the next class period, have students set up the equipment and carry out the testing of materials. Encourage students to vary material type and to try out combinations of materials, as long as they can maintain the standard thickness. Explain that students need to record each trial in the data table they create for Question 18.

Based on their data, have student groups identify the best materials to reduce force in a collision. Then, have the groups decide which materials they might want to use in designing protective headgear. The choice of materials should be recorded in answer to Question 19.

Design

Ask students to brainstorm designs of protective headgear in their groups for the sport they selected. Tell students to consider the shape of the headgear, type of materials, order of layering if multiple materials are used, thickness and weight. Once two or three design ideas have been proposed by the group, the group should discuss the pros and cons of each possible design and then choose the best design. The design ideas and their pros and cons are recorded in answer to Question 20.

Tell students that their final task, Question 21, is to develop a detailed sketch of their headgear design that incorporates their force diagram, their understanding of how to reduce force in a collision and the testing of materials. The choice of materials may include other factors in addition to reducing force of impact, such as relative weight. Encourage students to think of other considerations in designing protective headgear. The reasoning for materials selected should be included on the sketch. The sketch must include a title that makes clear the purpose of the headgear.

If time permits, have student groups share their design ideas and get feedback from the class.

Student directions:

Background questions
Answer the following questions to assess your knowledge of physics concepts related to collisions. Use your notes or classroom resources as needed.

1. During a collision, each object exerts a force on the other object. From Newton's third law, what must be true of the two forces?

The two forces are equal in magnitude and opposite in direction.

2. During a collision, each object exerts a force on the other object. From Newton's second law, what factors affect the amount of force?

The mass and acceleration of the object.

3. When two objects collide, they undergo changes in momentum. If no other forces act on the two objects, what happens to total momentum of the system before and after a collision?

The total momentum does not change.

Impulse-momentum theorem
Answer the following questions to assess your understanding of the impulse-momentum theorem, $F\Delta t = \Delta p$.

4. In the impulse-momentum theorem, F is the average force of the collision and Δt is the time over which the collision occurs. If the change in momentum and the mass of the object in two collisions is the same, how could you make one of the collisions occur with less force?

Increase the time over which the collision occurs.

5. Change in momentum, Δp, is equal to $m\Delta v$. If the change in time and the mass of the object in two collisions is the same, how could you make one of the collisions occur with less force?

Decrease the change in velocity.

Observing collisions 1
Discuss the differences in an egg colliding with a wall and an egg colliding with a sheet that is not taut. Then answer the following questions.

6. Which collision had less force? Explain your reasoning.

The collision with the sheet had less force because the egg did not break.

7. Assume both eggs have the same mass and are tossed the same way in both collisions. Is the change in momentum the same or different in the two collisions? Explain your reasoning.

It is the same. Since the mass of the egg remains the same, the change in momentum is due only to change in velocity. In both collisions, the velocity in the collision changes from the value of velocity right before the impact to zero.

8. Assume both eggs have the same mass and are tossed the same way in both collisions. Is the change in time the same or different in the two collisions? Explain your reasoning.

It is different. When the egg collides with the sheet, the sheet moves back and the collision takes place in a longer period of time. When the egg collides with the wall, the wall does not move and the collision takes place in a shorter period of time.

9. Do the observations from the demonstrations support your conclusion about how to reduce force in a collision?

Yes, one way to reduce force is to increase the time over which the collision occurs.

Observing collisions 2

Discuss the differences in a bouncy ball colliding with a hard surface and a soft surface. Then answer the following questions.

10. Which collision had less force? Explain your reasoning.

The collision with the soft surface had less force because the ball did not bounce as high.

11. In both cases, the ball's velocity before it collides with the floor is the same. However, the velocity of the ball after it collides is not the same. Is the change in momentum the same or different in the two collisions? Explain your reasoning using an equation.

It is different. Since the mass of the ball remains the same but the change in velocity is different, then the change in momentum must also be different because momentum is the product of velocity and mass, or p = mv*.*

12. Is the change in time over which the collision occurs the same or different in the two collisions? Explain your reasoning.

It is different. When the ball collides with the soft surface, the collision takes more time because the material becomes compressed or deformed as the ball makes contact with it.

13. Do the observations from the demonstrations support your conclusion about how to reduce force in a collision?

Yes, two ways to reduce force are to decrease the change in velocity or to increase the time over which the collision occurs.

Testing materials

Head injuries occur in different ways in different sports. Choose a sport, such as football, cycling, basketball, hockey, lacrosse or soccer. Working in a group, answer the following questions.

14. For the sport you have chosen, what are two common impacts on the head that can occur?

Answers will vary. For example, common impacts in soccer are 1) players heading the ball, which results in impacts on the front of the head, near the hairline, and 2) two players that are side by side both jump up to try to head the ball, which results in impacts on all sides of the top part of the head.

15. Draw force diagrams that show the common impacts you described.

Answers will vary, however the diagrams should show the direction of the force and relative strength of the force. For example, in soccer the force of collision between the heads of two players is often stronger than the force of heading the ball.

16. Your class will develop a standard testing protocol for materials that might protect the head during collisions. Summarize the protocol after your class discussion. Record the standard thickness and standard height the bouncy ball will be dropped from. Also determine how many times you will test each material or combination of materials.

Answers will vary depending on the protocol selected.

17. Examine the materials available for testing. Brainstorm any additional materials you have at home that you would like to test and record them here.

Answers will vary.

18. Using the protocol, test a variety of materials. Create a data table, and carefully record the materials and the height the ball bounces for each trial.

Answers will vary.

19. Share your testing data with the class. Analyze this data to determine which materials or combination of materials you would use in protective headgear and record your choices below.

Answers will vary.

Designing protective headgear

Working with your group, brainstorm two or three designs for protective headgear for the sport you selected. Consider the protection afforded and the extent to which the design will affect the ability to play the sport by taking into account shape of the headgear, type of materials, order of layering of materials, thickness and weight.

20. Record your group's ideas below and then discuss the pros and cons of each design.

Answers will vary.

21. Choose a final design. Create a detailed sketch of your final design and describe why your design will be effective according to the concepts discussed earlier. Label your sketch with the materials you would use in a prototype of your design. Write down your reasoning for your choice of materials that includes

the testing results and other factors such as relative weight of the materials. Title your design sketch in a way that makes clear which sport you are addressing.

Answers will vary.

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Activity Guide for Students: Protective Headgear Design Challenge

Directions for students:

Background questions
Answer the following questions to assess your knowledge of physics concepts related to collisions. Use your notes or classroom resources as needed.

1. During a collision, each object exerts a force on the other object. From Newton's third law, what must be true of the two forces?

2. During a collision, each object exerts a force on the other object. From Newton's second law, what factors affect the amount of force?

3. When two objects collide, they undergo changes in momentum. If no other forces act on the two objects, what happens to total momentum of the system before and after a collision?

Impulse-momentum theorem
Answer the following questions to assess your understanding of the impulse-momentum theorem, $F\Delta t = \Delta p$.

4. In the impulse-momentum theorem, F is the average force of the collision and Δt is the time over which the collision occurs. If the change in momentum and the mass of the object in two collisions is the same, how could you make one of the collisions occur with less force?

5. Change in momentum, Δp, is equal to $m\Delta v$. If the change in time and the mass of the object in two collisions is the same, how could you make one of the collisions occur with less force?

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Discuss the differences in an egg colliding with a wall and an egg colliding with a sheet that is not taut. Then answer the following questions.

6. Which collision had less force? Explain your reasoning.

7. Assume both eggs have the same mass and are tossed the same way in both collisions. Is the change in momentum the same or different in the two collisions? Explain your reasoning.

8. Assume both eggs have the same mass and are tossed the same way in both collisions. Is the change in time the same or different in the two collisions? Explain your reasoning.

9. Do the observations from the demonstrations support your conclusion about how to reduce force in a collision?

Observing collisions 2

Discuss the differences in a bouncy ball colliding with a hard surface and a soft surface. Then answer the following questions.

10. Which collision had less force? Explain your reasoning.

11. In both cases, the ball's velocity before it collides with the floor is the same. However, the velocity of the ball after it collides is not the same. Is the change in momentum the same or different in the two collisions? Explain your reasoning using an equation.

12. Is the change in time over which the collision occurs the same or different in the two collisions? Explain your reasoning.

13. Do the observations from the demonstrations support your conclusion about how to reduce force in a collision?

Testing materials

Head injuries occur in different ways in different sports. Choose a sport, such as football, cycling, basketball, hockey, lacrosse or soccer. Working in a group, answer the following questions.

14. For the sport you have chosen, what are two common impacts on the head that can occur?

15. Draw force diagrams that show the common impacts you described.

16. Your class will develop a standard testing protocol for materials that might protect the head during collisions. Summarize the protocol after your class discussion. Record the standard thickness and standard height the bouncy ball will be dropped from. Also determine how many times you will test each material or combination of materials.

17. Examine the materials available for testing. Brainstorm any additional materials you have at home that you would like to test and record them here.

18. Using the protocol, test a variety of materials. Create a data table, and carefully record the materials and the height the ball bounces for each trial.

19. Share your testing data with the class. Analyze this data to determine which materials or combination of materials you would use in protective headgear and record your choices below.

Designing protective headgear

Working with your group, brainstorm two or three designs for protective headgear for the sport you selected. Consider the protection afforded and the extent to which the design will affect the ability to play the sport by taking into account shape of the headgear, type of materials, order of layering of materials, thickness and weight.

20. Record your group's ideas below and then discuss the pros and cons of each design.

21. Choose a final design. Create a detailed sketch of your final design and describe why your design will be effective according to the concepts discussed earlier. Label your sketch with the materials you would use in a prototype of your design. Write down your reasoning for your choice of materials that includes the testing results and other factors such as relative weight of the materials. Title your design sketch in a way that makes clear which sport you are addressing.