How does the body respond to changing energy needs and what are the implications for sports training programmes?

These experiments have given you the chance to explore how your body reacts to different sports and physical challenges. Complete the analysis and evaluation below to find out just how much you know about how the body responds to changing energy needs and how this has implications for training programmes for sportspeople.

**Experiment A: I've got the power**

Use the values you have already calculated from your results from the stepping exercises to complete Table 3 below. The instructions below the table will help you with your calculations.

The quantity of work done per step will always stay the same if the height of the step stays the same and the person doing the task is the same. What happens if you alter the rate of stepping?

Table 3 – Calculating total work done and power

<table>
<thead>
<tr>
<th>Total number of steps in 60 s (S)</th>
<th>Total work done (S × work for one step) (J)</th>
<th>Power (total work/60) (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculation 3</td>
<td>Calculation 4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculation 3: Total work done**

Calculate the total work done for the steps completed in 1 minute (S). This can be done using the results from your experiments and the calculations you have already done.

Total work done = number of steps in 1 minute × work for one step (in Joules, J)

**Calculation 4: Power**

Power in watts (W) = \( \frac{\text{total work done in J (from calculation 3)}}{\text{time you spent exercising in seconds}} \)

= \( \frac{\text{total work (J)}}{60s} \) W

1. Compare your power values and total work done values with those of your partner.
2. Find the mean power and the mean work done for the whole class at the different intensity levels. How do your values compare to the mean values?
3. How does the power and total work done vary within the class? Suggest what factors affect the power generated and the total work done.
4. Which factors may affect the values you got in the final exercise, at the highest intensity?
5 Who was able to generate the greatest power? Suggest why.

6 What other changes did you notice in your body while you did this experiment? For example, did you feel warmer, did your face look red, did you breathe faster, did your legs begin to ache? Suggest why these changes happened. Was it the same for all three intensity levels of exercise? Did the all-out effort feel different from the other tasks? Why might this be?

7 How was your body able to provide the energy it needed to move your muscles during the stepping task? Do you think the energy in all stages of the stepping task was obtained in the same way, or do you think different energy systems were used?

**Experiment B: What does being fit mean?**

1 Fitness levels can be compared by using your heart rate at 1 minute after aerobic exercise. In Experiment B, what was your heart rate at 1 minute after exercise? Look up this value in this table to compare your fitness rating with the ratings for 18–25 year olds.

<table>
<thead>
<tr>
<th>Male (beats per min)</th>
<th>Female (beats per min)</th>
<th>Fitness rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;79</td>
<td>&lt;85</td>
<td>Excellent</td>
</tr>
<tr>
<td>79–89</td>
<td>85–98</td>
<td>Good</td>
</tr>
<tr>
<td>90–99</td>
<td>99–108</td>
<td>Above average</td>
</tr>
<tr>
<td>100–105</td>
<td>109–117</td>
<td>Average</td>
</tr>
<tr>
<td>&gt;106</td>
<td>&gt;118</td>
<td>Below average</td>
</tr>
</tbody>
</table>

2 A better estimation of your fitness level can be calculated by taking into account the recovery of your heart rate over the 3 minutes following exercise by using the following formula. Work out your score using the data you collected from Experiment B and compare it with the ratings below*.

Fitness score = \( \frac{30000}{HR1 + HR2 + HR3} \)

<table>
<thead>
<tr>
<th>Fitness score</th>
<th>Excellent</th>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>&gt;90</td>
<td>80–90</td>
<td>65–79</td>
<td>55–64</td>
<td>&lt;55</td>
</tr>
<tr>
<td>Female</td>
<td>&gt;86</td>
<td>76–86</td>
<td>61–75</td>
<td>50–60</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

*These values are for 16-year-olds.

3 Another common way that athletes talk about fitness levels is by calculating the maximum rate at which their bodies absorb and use oxygen. This is known as their VO2max. This can then be compared against tables for people of the same age and gender as yourself. The test you did within this experiment is a sub-maximal test (i.e. you are unlikely to have exercised as hard as you could) but you can calculate the rate at which you used oxygen during the stepping task. From this you can calculate an approximation of your maximum rate of oxygen uptake (i.e. the maximum amount of oxygen you could use in your body to do an activity).
Background information for VO₂ max calculation

During your stepping task there are two components that need to be taken into account to calculate the rate at which you used oxygen. You have backwards/forwards (horizontal) movement and you also have an upward/downward (vertical) movement. These both need to be taken into account when calculating the rate at which oxygen is consumed. The full equation is:

\[ \text{VO}_2 \ (\text{ml kg}^{-1} \ \text{min}^{-1}) = [f \times 0.2] + [f \times h \ (\text{m}) \times 1.8 \times 1.33] + 3.5 \text{ml kg}^{-1} \ \text{min}^{-1} \]

where \( f \) = steps per minute (30 steps per minute in Experiment B)
\( h \) = height of the step

0.2 ml kg\(^{-1}\) min\(^{-1}\) = work done for the horizontal movement
1.8 ml kg\(^{-1}\) min\(^{-1}\) = work done for upward movement

A factor of 1.33 is used for the vertical movement because you need to include oxygen used when stepping down, which takes 0.33 of the energy of stepping up \((1 + 0.33 = 1.33)\).

3.5 ml kg\(^{-1}\) min\(^{-1}\) is the rate at which we consume oxygen at rest, so this is added too.

Worked example

For example, for stepping using a bench height of 0.3 m at a rate of 30 steps per minute:

\[ \text{VO}_2 = (30 \times 0.4) + (30 \times 0.4 \times 1.8 \times 1.33) + 3.5 \]
\[ = 34 \text{ml kg}^{-1} \ \text{min}^{-1} \]

\( a \) Use the formula to work out your rate of oxygen consumption during exercise in Experiment B.

\( b \) Next, you need to find out how hard you worked. This is calculated by knowing your heart rate at the end of the task. Then calculate this as a percentage of your maximum heart rate. An approximation for maximum heart rate is 220 – age.

\[ \% \text{ of maximum heart rate} = \frac{\text{heart rate at end of task}}{\text{maximum heart rate}} \times 100 \]

\( c \) Finally, calculate the rate at which you would have consumed oxygen if you had been working at maximum heart rate:

\[ \text{maximum rate of O}_2 \text{ consumption} = \frac{\text{rate of O}_2 \text{ consumption during exercise}}{\% \text{ of maximum heart rate}} \]

and compare it with the values of VO₂ max below*.

Normative data for VO₂ max (ml kg\(^{-1}\) min\(^{-1}\))

<table>
<thead>
<tr>
<th>Gender</th>
<th>Excellent</th>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>&gt;60</td>
<td>47–60</td>
<td>42–46</td>
<td>37–41</td>
<td>&lt;37</td>
</tr>
<tr>
<td>Female</td>
<td>&gt;56</td>
<td>42–56</td>
<td>38–41</td>
<td>33–37</td>
<td>&lt;32</td>
</tr>
</tbody>
</table>

*These values are for 18–25-year-olds.
4 What happens to your heart rate and arterial oxygen saturation level following exercise?

5 Compare the different ways you have calculated aerobic fitness. What do you think are good ways of assessing aerobic fitness? Explain your answer.

6 Do you feel that you exercised as hard as you could in the stepping task? How would this affect the VO\(_2\)\sub{max} that you calculated?

7 Look at the class data for VO\(_2\)\sub{max} and standing or sitting height, for students of the same gender and perceived fitness. Do you think standing or sitting height affects the calculation for VO\(_2\)\sub{max}?

8 What other ways can you think of that could be used to assess your fitness levels?

9 Why is measuring fitness levels important for athletes and for health?

10 Why does training improve fitness levels? What does it alter inside your body?

**Experiment C: Does carbon dioxide increase in my breath after exercise?**

Fill in the table below using your results from Experiment C and draw a graph of your data. Think about which type of graph is most appropriate and which data you need to plot. Think about which exercise was aerobic and which was anaerobic.

<table>
<thead>
<tr>
<th>Level of activity and type of exercise</th>
<th>At rest</th>
<th>Exercise 1</th>
<th>Exercise 2 (if time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of breaths (N) needed to neutralise indicator / sodium hydroxide solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for number of breaths in seconds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breathing rate (calculation 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of carbon dioxide in each breath = 5.6/N (cm(^3)) (calculation 2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of carbon dioxide breathed out in 1 minute = (5.6/N) (\times) BR (cm(^3)) (calculation 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculation 1: Breathing rate**

\[
\text{Breaths per minute} = \frac{\text{total number of breaths (N)}}{\text{time to neutralise solution in seconds}} \times 60
\]

**Calculation 2: Volume of carbon dioxide in one breath**

To neutralise the solution it takes 5.6 cm\(^3\) of carbon dioxide.

\[
\text{Volume of carbon dioxide in one breath} = \frac{5.6}{\text{total number of breaths}} \text{ cm}^3
\]
Calculation 3: Volume of carbon dioxide in 1 minute

Volume of carbon dioxide in 1 minute = number of breaths per minute × volume of carbon dioxide in each breath

1. Discuss the change in the volume of carbon dioxide breathed out per minute after exercise compared to being at rest. Is this what you expected?

2. Explain why the volume of carbon dioxide in the breath changes.

3. Does the type of exercise alter the change in volume of carbon dioxide breathed out? What happens if it is really intense exercise, e.g. anaerobic exercise where energy is released in respiration without using oxygen? What happens if it is more gentle exercise, e.g. aerobic exercise where energy is released in respiration using oxygen? Do we produce the same volume of carbon dioxide in each breath?

4. What are the possible sources of error in this investigation and how could they be reduced? How else could carbon dioxide production be measured?

5. Why might it be important for physiologists working with top athletes to measure oxygen consumption as well as carbon dioxide production?

Experiment D: What happens to my heart rate and blood pressure when I exercise?

1. How long did it take in each case for your heart rate and blood pressure to return to normal after exercise? Suggest reasons for any differences.

2. Estimate how long it took in each case for your blood pressure to return to normal. What are the limitations of this method in terms of finding exactly how long blood pressure takes to return to normal?

3. Why does it take a while for your heart rate and blood pressure to return to normal?

4. Plot your data on a graph.

5. Suggest why an athlete who has been pedalling hard on an exercise bike feels dizzy and faint if she suddenly stops pedalling, rather than slowly doing a ‘cool-down’ before getting off the bike.

6. All athletes and sportspeople need to be in good health. Why do you think a resting blood pressure of around 110–120/70–80 mmHg is an indicator of good cardiovascular health?

7. When we stop exercising, heart rate and blood pressure do not immediately return to their resting levels. What may alter how quickly heart rate returns to baseline?

How does the body respond to changing energy needs?

1. What were the differences in the body’s response to aerobic and anaerobic exercise?

2. Which sporting events use a) aerobic and b) anaerobic respiration systems?

3. How would you train for a) aerobic and b) anaerobic events?

4. Look at the data on the ‘Live Data Zone’ on the In the Zone website. How do your results compare to students’ results across the UK? How do you think that the results of athletes such as those Dr Valerie Gladwell works with would compare to your results?

5. What exercise did you find hardest out of all the ones you took part in? Suggest why.