How does the body respond to changing energy needs?

‘I’ve got the power’ is a group of experiments all about what limits our performance during exercise and how we release the energy that we require to move our bodies during different types of exercise.

My name is Dr Valerie Gladwell and I am a Senior Lecturer in Physiology at the University of Essex. I teach undergraduates who are taking a Sport and Exercise degree all about how the body works at rest, during exercise, and following training. My research involves exploring how the cardiovascular system responds following exercise. I am also passionate about the effect physical activity can have on health. The concepts that your students will be investigating are questions that I ask during my research studies in order to gain an understanding of how the body responds to different types of exercise, the recovery from exercise, and how this can relate to improvements in performance and health.

In these experiments, your students will collect and consider data relating to VO₂max, blood pressure, pulse rate during and in recovery from exercise, and also carbon dioxide production. They will relate these measurements to how the whole body responds to movement before looking at how the same principles are applied by sports scientists and trainers to help athletes improve their performance.

How can we improve performance?

Performance is dependent on providing the energy required to contract our muscles to move our bodies. Apart from very short-duration exercise (less than 10 seconds), this is dependent on: getting air into the lungs; the blood collecting oxygen from the lungs; the heart pumping blood around the body; the blood capillary network around muscles taking oxygen to and removing carbon dioxide from the muscles; and the uptake of oxygen from the blood into muscle tissue and the mitochondria. Training can improve most of these things. All athletes want to know how fit they are and how to improve their training.

Fitness: VO₂max

The volume of oxygen that you use while exercising at your highest level can be used as a measure of fitness. This is known as VO₂max. VO₂max is the maximum amount of oxygen you can use in 1 minute and usually takes into account your body mass. The higher the VO₂max value, the fitter a person is. Measuring VO₂max requires specialised equipment to measure the oxygen uptake. However, it can be predicted in other ways, without even pushing your body to the max! One way is to measure heart rate during exercise or in recovery from exercise and to use equations or tables to estimate your VO₂max and your fitness level based on the results.

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Heart rate during exercise and in recovery from exercise

Heart rate is a really important but very easy measurement to take during exercise and can be used to determine VO₂max and fitness. Furthermore, heart rate recovery from exercise can be used as a marker of fitness and health. The faster it falls after a certain intensity of exercise is performed, the fitter you are.1

Athletes such as runners, triathletes, cyclists, and cross-country skiers monitor their heart rate during competition to check that they are not racing too hard. It is also used in training to determine how hard to train and also during recovery from exercise. Athletes and their coaches also monitor resting heart rate (before they get out of bed in the morning) to ensure that they are not overtraining.

During exercise, the heart not only contracts quicker (i.e. the increased heart rate you can measure) but it also contracts more forcefully and pushes out more blood on each contraction (increasing stroke volume). Both the increase in heart rate and the increase in stroke volume cause the cardiac output (measured in litres of blood per minute) to increase. This enables more oxygen to get to the muscles and more carbon dioxide and lactate to be removed to try to meet the demands of the muscles during exercise.

Blood pressure during exercise and in recovery from exercise

The heart cannot work alone and requires changes to occur in the blood vessels. The resistance in the blood vessels can be reduced, allowing more blood to reach the muscles that are active. If there are enough muscles that are active during exercise, the diastolic blood pressure (minimum blood pressure during a heart beat) may decrease. On the other hand, if contraction of the muscle is sustained or particularly forceful, diastolic blood pressure may increase. The increase in systolic blood pressure (maximum blood pressure during a heart beat) during exercise occurs as a result of the increased force of contraction of the left ventricle, which pushes out more blood with each beat (increased stroke volume).

So all in all, the increase in stroke volume and heart rate and the potential decrease in resistance in the blood vessels allow more oxygen to get to the muscles that require it. However, during very high-intensity activity the muscles work more anaerobically, as the oxygen demands of the muscles cannot be met.

How do we provide the energy needed for movement?

You may think that muscle cells are respiring either aerobically or anaerobically at any one time, but in fact both types of respiration can be going on simultaneously. Different types of movement generally use both ways of releasing energy, rather than purely one or the other. Most types of exercise use different proportions of the immediate, short-term or long-term energy systems:

- **Immediate energy system** – **Aerobic respiration**. Explosive, strength and power events such as sprints use this system. It uses stored energy supplies but there is a limited amount available in muscle cells.

- **Short-term energy system** – **Lactic anaerobic respiration**. Lactic acid is produced as a by-product of this system. At one time lactic acid was thought of as a waste product but in fact it can be used itself as fuel for aerobic respiration.

- **Long-term energy system** – **Aerobic respiration**. Endurance events such as marathons use mainly aerobic respiration. It requires oxygen to get to the muscles for the energy to be released.
Carbon dioxide concentration during exercise

More carbon dioxide is produced during exercise than at rest, irrespective of whether the exercise is aerobic or anaerobic. In aerobic exercise glucose is combined with oxygen to produce carbon dioxide and water:

\[
\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} \\
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O
\]

In anaerobic respiration, lactate in the blood is buffered by sodium hydrogen carbonate, which makes sodium lactate and carbonic acid. This in turn produces carbon dioxide and water.

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\text{lactate} + \text{sodium hydrogen carbonate} \rightarrow \text{sodium lactate} + \text{carbonic acid} \\
\text{carbonic acid} \rightarrow \text{water} + \text{carbon dioxide}
\]

In the laboratory, scientists can measure oxygen uptake and carbon dioxide production. Usually when carbon dioxide production is greater than oxygen consumption it suggests that the athlete is mainly producing energy anaerobically. Scientists can use this information to design training programmes that have the right balance of aerobic and anaerobic exercise, depending upon the event they are training for.

Energy systems and respiration

The graph shows the role of the three different energy systems and types of respiration that provide the energy needed for exercise over time.

Lactate levels in the blood only increase if lactate production is greater than lactate removal. This is called OBLA, which stands for onset of blood lactate accumulation². The exercise intensity at which the lactate begins to build up is important to athletes in designing their training programmes.
In the training zone

Many athletes and coaches have devised complicated training plans to encompass all parts of fitness, from stamina and endurance to speed, strength, and power. The type of training sportspeople do will depend upon the event they are training for. Sprinters need to focus on power and strength but need a good aerobic base.

For long-duration endurance athletes the main training is stamina and endurance so their bodies are able to produce their energy aerobically and can deal with lactate more efficiently (increasing the exercise intensity at which lactate accumulates – OBLA). They also incorporate strength training to help improve their performance. Many sports, however, are not one or the other and require high levels of fitness mixed with speed and strength (e.g. rugby).

I hope that you and your students find the ‘I’ve got the power’ resources inspiring and that they help your investigation into how the body responds to movement and exercise. The 16–19 Knowledge Card will help your students understand the role of respiration in exercise. You can use the ‘Live Data Zone’ on the In the Zone website (www.getinthezone.org.uk) to upload some of your results, compare them to results from students across the UK, and contribute to capturing national data. I look forward to seeing your results.
