The Chemistry of Running Interactive Lab

Introduction

The Chemistry of Running simulation allows students to explore the chemistry and physiology of exercise—a field that attracts a lot of interest from coaches, scientists, anthropologists, and even the military. There are three parts to this exercise:

1) Learners will choose an avatar and run a series of timed races in an initial exploration of the software and how it works.
2) Set a running goal, applying the chemistry of running principles to successfully complete a full 42.195 km marathon and improve their time in subsequent runs.
3) Perform an energy calculation to see how many kilocalories were burned during the race.

Background

In the simulation, learners will control several parameters: choice of avatar, level of effort during different phases of the race, and rest time between races. During trial races, they vary the level of intensity for training purposes. When they are ready to run, they strategize during the race to set the level of intensity to achieve the best outcome.

While running, the most important parameter that can be changed is the level of effort, which is closely tied to the runner's speed and heart rate. In the simulation, the intensity of exercise (Effort) is measured on a scale of 1 to 9, with 0 being at rest and 9 corresponding to the maximum effort that the runner is capable of exerting. When the runner is close to his/her max—not necessarily effort 9—effort increases by 0.5 increments in the effort and then an automatic decline to the last whole number. If the user keeps pushing the avatar to the max, the avatar will collapse from overexertion.

Effort Scale

1	Very Weak
2	Weak
3	Moderate
4	Somewhat Strong
5	Strong
6	Stronger
7	Very Strong
8	Very Strong +
9	Maximal-all out

(with 0.5 increments as runner nears fatigue)

Scale is modified from Dr. Gunnar Borg's "Scale of Perceived Exertion" (Borg, 1982).

Measurements of human subjects in a variety of exercise experiments demonstrate a correspondence between effort and metabolic power required, measured in watts (Nobel, et al., 1983). The power required is linked to the speed of the run and heart rate, with higher levels of effort corresponding to higher heart rates and running speeds.

Exercise can be broken down into two regimes: aerobic and anaerobic. In the aerobic regime, people can generally sustain their current level of intensity for a long time, because the energy needed is provided by oxidation of food stores, with the oxygen delivered as needed from the cardiorespiratory system. As the runner increases his or her effort, more and more oxygen will be consumed until, ultimately, the runner will not be able to increase their rate of oxygen uptake. This level of uptake is called maximal aerobic power or VO2max, the maximum rate of oxygen uptake (measured in milliliters of oxygen per minute per kilogram of body mass). At this point, no matter how hard the runner pushes, their rate of oxygen intake does not increase. (Hill and Lupton, 1923; Bassett and Howley, 2000).

VO2max is an important measurement for runners and their trainers because, while it varies from runner to runner (Morton, et al., 1990), the speed that can be supported by a runner's maximal aerobic power is the best predictor of endurance over long races. It can be improved over time through training.

It is possible for runners to temporarily exceed the effort that they can sustain at VO2max. Exercises such as sprints, rapidly climbing stairs, or riding a stationary bike at full speed, will temporarily produce power outputs that are 2.5 to 3 times higher than the maximum sustained values (Carey and Richardson, 2003). When this happens, the extra energy is provided by the anaerobic pathway, glycolysis, which can deliver a limited amount of energy stored in the muscles immediately, without waiting for the supply of oxygen from the lungs.

Anaerobic exercise cannot be sustained very long before fatigue occurs. The mechanism of muscle fatigue is not known, but regardless of the specific cause, the accumulation of blood lactate is a good indicator of the intensity of the exercise intensity (i.e. running speed) that will become unsustainable. If blood lactate accumulates slowly, fatigue will eventually occur. If blood lactate accumulates quickly, fatigue will typically occur rapidly. When blood lactate levels reach very high concentrations (around 12.5mM/L) exercise generally cannot be continued.

The concentration of lactic acid in the blood is determined by two factors:

1) An immediate factor – rising levels of lactic acid during strenuous aerobic exercise and rapid accumulation during anaerobic exercise.
2) A slowly changing factor – the diffusion and metabolic removal of lactic acid. Even after the runner stops exercising, it takes approximately 15 minutes for lactate to drop to half its former level (Margaria, 1972).

Many researchers have measured lactate at various levels of exercise. In general, some lactate is generated at any level of exercise, but often it can be removed as fast as it is made and does not accumulate. However, if the intensity of effort increases, the lactate level will eventually start to rise, and will do so more rapidly when effort reaches a level of intensity called the "Onset of Blood Lactate Accumulation (OBLA)." OBLA is another important measurement in the chemistry of running, because if runners continuously push themselves beyond OBLA, they will eventually reach exhaustion. OBLA can be improved by training, especially by interjecting short bursts of intense effort into longer runs (Gass, et al. 1981; Weltman, 1995).

Exercise stimulates physiological/chemical adaptations that raise performance over time with training. Exercise increases the blood supply by increasing the volume of blood pumped by the heart. In addition, exercise causes muscle cells to form extra mitochondria. Called the "powerhouse of the cells," mitochondria are the cellular structures that package chemical energy in an easily available form called ATP (adenosine triphosphate), which is then available for contraction of the muscle fibers. In both cases, the stress of exercise causes changes in the expression of genes, which, in turn, changes which cellular proteins are built or broken down. The beneficial effects of training are maximized when the exercise has bouts of high intensity alternating with lower effort periods—while avoiding dangerous levels of lactate. The chemical changes from training take time—up to several weeks. During this time, the benefits of additional training are not immediately available. In fact, the opposite is true: after each training session, fitness decreases, and it is only after some time that the runner has fully recovered and is able to run again at the same level or above. (Booth and Thomason, 1991).

Connections to Chemistry Course

Some of the places where interactive content is directly linked to the content in Chemistry, Challenges and Solutions are:

Unit 6, Section 7 – Stochiometry
Unit 7, Section 3 – Energy Changes in Chemistry
Unit 7, Section 7 – Calorimetry (Sidebar: Food Energy)
Unit 10, Section 3 – The pH Scale
Unit 10, Section 10 – Buffers
Unit 12, Section 5 – Catalysts

Learning Objectives

• Understand the different energy pathways in exercise.
• Understand the importance of regulating pH in the blood
• Obtain an overview of how muscles change during training
• Practice calculations using the Ideal Gas Law and chemical energy

Procedure

Part A: Experimentation and Goal Setting

1. Have the learners choose an avatar and run several races with different levels of effort, to see how the levels of exercise affect speed, heart rate, and levels of lactic acid. They should record the results of three different trials to see how far and fast their avatar can run without collapsing. They can stop early and run again to see the effects. Learners are able to flip between the results and training course without disrupting the overall marathon training for that avatar.

2. After initial experimentation, tell learners that their goal is to train their avatar to successfully complete the marathon within a time goal that they set that is reasonable, given the age, sex, and fitness condition of their avatar. The following table indicates a reasonable minimum goal to be chosen for the avatars, who are all runners, ages 18-34 (BAA, 2013).

Avatar	Runner Profile	Time to Complete
1. Alice (yellow)	Female (elite, trained athlete)	3hrs, 30min
2. Bill (blue)	Male (elite, trained athlete)	3hrs, 15min
3. Cindy (pink)	Female (moderately fit)	5hrs, 10min
4. Doug (red)	Male (moderately fit)	4hrs, 30min

3. Learners should pick their avatar and write down the training goal for the avatar. Next, they should test their avatar in a run at the highest level of effort possible without collapsing. If the runner fails to reach the goal, collapses, or if he/she cannot complete the run within the 8 hour limit, then they need to do training to improve their fitness.

Part B: Training and Testing

4. In Part 2, learners will train their avatar so they can reach their goal. During training, there are two factors that accumulate during each minute of running: an arbitrary unit of training called a “TRIMP” (for “Training Impulse”), and a fatigue factor, which tends to slow the runner’s performance. (For this reason, there is a button called “Rest Day.” Pressing this button allows 24 hours for recovery; students should be encouraged to give at least one rest day between runs.) The simulation is designed to mirror the familiar effect that exercise is difficult at first, especially if there is no rest between sessions, but as fitness increases, the same level of effort becomes easier.

5. Learners should run at least five simulated training sessions before attempting another marathon race. The Student Worksheet guides learners to record the effect of training; in addition, their “Results” page records all their runs.

6. Learners should keep running their avatar until they come as close as they can to reach the goal they set in Step 2. They should compare not only their times, but also their runner’s VO_2max and OBLA from before and after the training, to see if these numbers have improved.

Part C: Applying Kinetics Calculations to Running

7. In this section, learners will calculate how many kilocalories are burned during the race by converting the total volume of oxygen consumed during the race to kilocalories. A general rule is 4.8 kcal per liter, but this amount can vary slightly, depending on the runner and race conditions. To give practice with the Ideal Gas Law, learners first convert the volume of O_2 consumed to moles, then to kcal at 117 kcal per mole of oxygen consumed. Extensions could be made to incorporate bond enthalpies for the different energy sources (carbohydrates, fats, and proteins).

8. Finally, learners compare the energy expenditure in running a marathon to that of driving a car the same distance (42.195 km or 26.216 miles).

9. Learners are asked to print out a record of their runs from the main Results page (which shows each run) and hand it in with the worksheet. Another assessment tool is a box on the worksheet for written reflection.

References

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