How many calories used to run a 5K?

This simple question can lead to some in depth discussion of physiology and biomechanics. Let’s start with some definitions. What is a calorie? A calorie is a unit for heat. What is heat? Heat is a transfer of energy from one object to another by means of thermic interactions. What is energy? Energy is the capacity to do work. What is work? Work is the application of a force over some distance. What is force? A force is a push or a pull that tends to cause movement.

Wow … there is a lot of information there. Let’s break it down a bit. Let’s start with the basics: 1 calorie is the amount of heat needed to increase 1 gram of water 1 degree Celsius. For the human body, that is not a lot of energy ... so we often talk in terms of kilocalories which is the amount of heat needed to increase 1000 grams of water 1 degree Celsius. Instead of ‘kilocalories’ it is common to use ‘Calorie’ (capital ‘C’). So, a Calorie tells us how much heat has transferred from one object to another. When the body breaks down food substrate, we talk about the amount of Energy in the food in terms of Calorie. The transfer of energy from the chemical state (i.e., food) to the mechanical state (i.e., force applied) can be expressed in Calories.

Thinking back to your Exercise Physiology class, you should remember that food substrate (carbohydrate, fats, protein) are broken down to yield Adenosine Triphosphate (ATP) which is critical in muscle contraction (and therefore creating muscle force). The energy systems are ‘aerobic’ (using oxygen) and ‘anaerobic’ (without oxygen). You should also remember that relying on anaerobic production of ATP will last about 2 minutes at maximal effort whereas endurance performance is largely a function of producing ATP aerobically (later on, we’ll talk about the importance of anaerobic production of ATP during endurance events).

The chemical equation for producing ATP from a carbohydrate is basically something like this: Carbohydrate + Oxygen yields ATP and Carbon Dioxide (which is exhaled). So, in essence, what is happening is that the stored chemical energy in carbohydrate is being transformed to ATP which is then transformed to mechanical energy (via cross bridge formation) as muscle contracts. The amount of energy in a carbohydrate is commonly described in units of Calories. This is important ... because now we can see that the amount of Calories used (i.e., via production of ATP) is related to the amount of oxygen consumed. The faster that oxygen is consumed, the faster food substrate is being broken down to yield ATP.

When we talk about oxygen consumption, we talk about the ‘volume of oxygen consumption’ (i.e., VO2). It is very common to express this volume as a rate ... for example, Liters of oxygen per minute (L/min). When we do that, technically we should put a dot over the ‘V’ in VO2 because that is the notation for ‘rate’. However, many times we get lazy and leave it off (it is not always easy to add this using word processors). That being said, when we discuss VO2, it is important to stipulate the units that are being used.

Sometimes, we want to measure the total volume of oxygen used (vs. how fast it is being used). In this case, we would simply use units of ‘Liters of oxygen’ (vs. L/min). That is no longer a rate and simply tells how much oxygen was consumed. Ok ... now some numbers. For every Liter of oxygen consumed, 5
Calories have been used. This varies a bit depending on the substrate used (carbohydrate: 5.05 Calories for each L of O₂; fat: 4.74 Calories for each L of O₂). When we express VO₂ as a rate (e.g., L/min), that tells us the rate of Calories (e.g., Cal/min) being used. It is really important to distinguish between volume and rate ... pay attention to the units as you are reading research papers ... it can make a huge difference in understanding what is being presented.

Now let’s switch gears to Energy ... which is the capacity to do work. Energy has units of ‘joules’ ... a Calorie is just another unit for energy and is specific to heat (sort of like kilometers and miles are both units for distance). There are 4.2 kilojoules of Energy for 1 Calorie (this will be important to remember when we talk about measuring power during cycling).

So, when we talk about how many Calories are needed to run a 5 K (or any other distance), we are talking about the amount of energy needed to complete the distance. Furthermore, we are talking about how much oxygen needs to be consumed in order to transform the chemical energy in food substrate to mechanical energy (i.e., force applied).

Ok ... back to exercise physiology. Let’s look at the relationship between VO₂ (as a rate) and running speed. The figure below illustrates VO₂ (I’ll use units of L/min for now) on the y-axis and running speed (we’ll use m/min) on the x-axis. By looking at this figure, we can see that faster a person runs, the faster we consume oxygen.

![Figure](image.jpg)

Time for a bit of math ... let’s look at the slope of this plot. Remember that slope is calculated as ‘rise over run’ or, in other words, change in ‘y’ over change in ‘x’. You might already recognize that the slope is constant for a straight line ... that’s great if you already figured that out! In formula, slope looks like this:

\[ \text{Slope} = \frac{\Delta y}{\Delta x} \]

Or... slope = ΔVO₂/ΔRunning speed

In a unit analysis, it looks like this:

\[ \text{Slope} = \text{L/min}/\text{m/min} \]

...rearranging we have:
Slope = \((L/\text{min}) \cdot (\text{min/m}) = L/m\)

This is a new set of units and represents the ‘Energetic Cost of Locomotion’. This parameter represents the total amount of oxygen consumed per distance (not per time). Very cool ... if we know how much oxygen was consumed, we know how many Calories were used (vs. how fast they were used).

Now, let’s look at the graph of Energetic Cost of Locomotion. As mentioned above, the slope of a straight line is a constant ... so our figure now looks like the one below.

On the ‘y-axis’ is still \(\text{VO}_2\) but now the units are \(L/m\) (vs. \(L/min\)) and represents the total amount of oxygen consumed for a given distance measured in ‘meters.’ What this graph tells us is that the total amount of oxygen consumed for a distance is the same for any speed! That means, the same number of Calories are used to cover 5 K regardless of how fast you run!

That sounds really odd ... but let’s think about this a bit. If I run a 5 K in 10 mins per mile, that is a 31 minute 5 K. If I run a 5 K in 5 mins per mile, that is a 16.5 min 5 K ... that’s really good. In both cases, I covered 5 K and used the same number of total calories. When I ran faster, I needed to transform chemical energy to mechanical energy at a faster rate ... so my \(\text{VO}_2\) (L/min) would be higher but I would have run for a shorter period of time. This would end up yielding the same volume of oxygen consumed to cover a 5 K and therefore the same number of Calories.

This concept is really important when planning endurance events. By knowing the distance covered, you can calculate the amount of Calories needed to cover the distance ... and that is the same regardless of what speed is used.

Ahhh ... but let’s think back to what was said about the amount of Calories per type of food substrate. Remember, for a liter of Oxygen, we get 5.05 Calories when carbohydrate is used but 4.75 when fats are used. What does this mean? If we factor in the exact substrate used, we get a clearer picture of the number of Calories used. In a simple sense, as exercise intensity increases, there is a tendency to use carbohydrates as the primary fuel whereas during lower intensity fats can be the primary fuel. Manufacturer of heart rate monitors may take this into account when calculating calories used ... but this takes us down the path of explaining anaerobic threshold and we need to save that for another day!

What does all this have to do with biomechanics? Now we know that the energy expended to cover a distance is constant (or nearly constant). The next step is to figure out how to decrease the energy...
expenditure and be more economical. For example, if you run 5 K in work boots vs. running shoes, the total volume of oxygen consumed (and therefore Calories) will be greater while wearing boots. Likewise, running on softer surfaces, while you are fatigued, wearing different clothes, and taking longer or shorter strides can all influence energy cost of locomotion. Biomechanics works into this discussion in that it makes sense to determine the best running style that will cost the least amount. This takes us down the path of discussion Running Economy. Be sure to look that up and check out a couple of references on running economy ... knowledge about this parameter will be very helpful to our discussions.

Also, our next set of questions to look at includes 'What stride frequency should I use when running?' The answer to this question is centered around running economy.