

What stride rate should I use during running?

What stroke frequency should I use during swimming?

What cadence should I use during cycling?

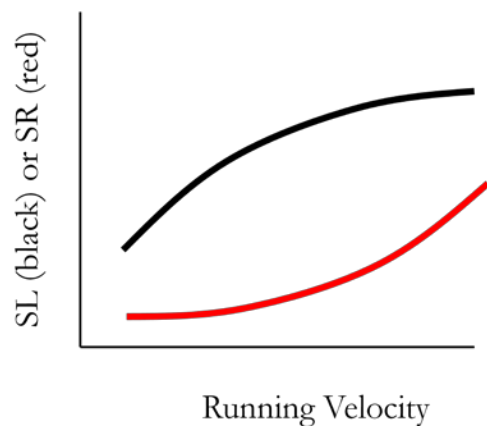
The common element of all these questions is that they are ‘rate’ questions. In this handout, the focus will be on running and what stride frequency a runner should use.

Running

During running, we talk about a stride as being the time between consecutive same-side foot strikes. For example, a stride can be defined as the time (and all the movements during that time) between one right foot contact and the next right foot contact. A step is the time between different side contacts (e.g., right-left). Stride rate describes how fast strides are taken and the units are strides per time. Generally, strides per second (aka, Hertz or Hz) or strides per minute are used for units. Stride length is the distance covered per stride ... units being distance per stride (e.g., meters per stride).

The product of stride rate and stride length is running velocity. You can see that by doing a unit analysis. Using ‘strides per second’ as units for stride rate and ‘meters per stride’ for stride length, the product will be ‘meters per second’. When someone goes out for a run, he/she naturally selects a stride rate and length combination – we call this the ‘self-selected’ or ‘preferred’ stride rate and stride length.

The basic kinematic descriptors of a running stride are stride rate and stride length. Let’s look first at how stride rate and length change as running velocity changes. A landmark study was done back in 1952 by Hogberg. What he noticed was that as a runner ran faster, he would take longer strides vs. taking faster strides except when trying to achieve the fastest speeds ... then the runner would take faster strides. The graph below illustrates this observation where Stride Rate is the red line and Stride Length is the black line.



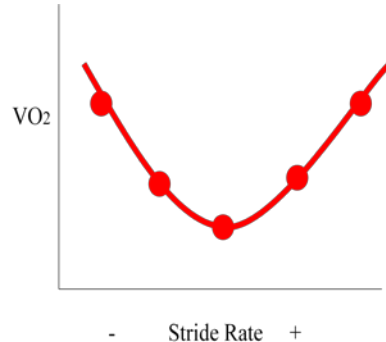
The take home point of this graph is that for submaximal increases in speed, the runner likely increases stride length while maintaining (or maybe slightly increasing) stride rate. Why would

this happen? There is something important about the stride rate that we select – and the exact reason why a runner selects a particular stride rate is not necessarily known.

A common belief is that runners select a stride rate that is the most economical. Remember, running economy is the steady-state rate of oxygen consumption for running a given speed. What happens to running economy when stride rate changes?

Some classic work by Cavanagh and Williams (1982) had runners run at a given speed at a self-selected stride rate. Then, they had the runners run using faster and slower stride rates (always running the same speed). All the while, they measured rate of oxygen consumption. What they noticed was that as stride rate increased or decreased, rate of oxygen consumption always seemed to increase. That seems to mean that the self-selected stride rate was the ‘most economical’ ... or, in other words, the runners had the lowest rate of oxygen consumption (and therefore the best running economy) while running at the self-selected stride rate.

However, not all runners chose the most economical stride rate. Sometimes, the runners would have been better to take a slightly faster or slower stride rate to run with the best economy (i.e., least rate of oxygen consumption). This is actually a great test to do in the lab with runners. That being said, a lot of times small changes in stride rate do not really influence rate of oxygen consumption that much. Sometimes, runners can take 10% faster or slower stride rates and not really negatively impact rate of oxygen consumption.

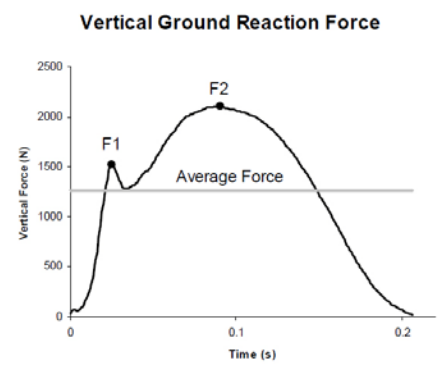


Many people have used data like these to hypothesize that runners need to find that optimal stride rate. However, if you look at studies that have done this type of work, there is often no statistical difference in the rate of oxygen consumption when running at stride rates that are 10% faster and 10% slower than the self-selected stride rate. Furthermore, stride rate will change based upon what type of surface you run on, whether you are running up hill or down, across speeds (subtly), and whether you are fatigued. It seems that there must be some other reason that is driving the choice of a particular stride rate for a given set of conditions.

Another key component of a running stride is how much force is exerted on the ground with each foot contact. This force can be measured using a force platform which measures the ground reaction force. As a runner pushes on the ground, the ground pushes back on the runner

(Newton's 3rd Law of Motion). A force platform is just like your bathroom scale. As you stand on the bathroom scale, the scale pushes up on you with the same force of gravity that is pulling down on you. When you stand still, the ground reaction force is equal to your body weight. If you do not stand still, but instead move up and down or swing your arms, the scale varies in the reading (that is because your center of mass is accelerating). In a laboratory setting, we can measure these fluctuations to get a better sense of forces applied to the body during running.

Below is an illustration of a typical ground reaction force during running. The ground reaction force is a three dimensional force applied to the foot. The force can be broken into the three orthogonal components ... for this handout (and in the illustration below), I will refer to the vertical component only (it is the greatest magnitude of the three components).



The ground reaction force rises above zero when the foot initially strikes the ground and then falls to zero as the toe leaves the ground. The time the foot is in contact with the ground is referred to as 'ground contact time' or 'stance time' and is typically around 0.200-0.280 seconds (the length of time is based upon a number of factors ... a key one being how fast you run .. the faster you run, the shorter the contact time).

There are some important ways that the ground reaction force is analyzed. Here are some typical parameters that are used to describe and analyze forces:

- Average force: The average force during contact.
- Impulse: The area under the curve.
- Impact force (aka, Impact Peak, F1, or passive peak): The first local maximum that usually occurs within 50 ms (0.050 s) of contact.
- Active force (aka, F2): The second maximum force that usually occurs around mid-stance.
- Loading rate: The rate of increase of the force during the initial impact phase (i.e., the time leading up to the impact force).

Sometimes, a ground reaction force will not have an impact peak ... this can occur if running on a soft surface or running in a way that the front part of the foot strikes the ground first (i.e., fore-

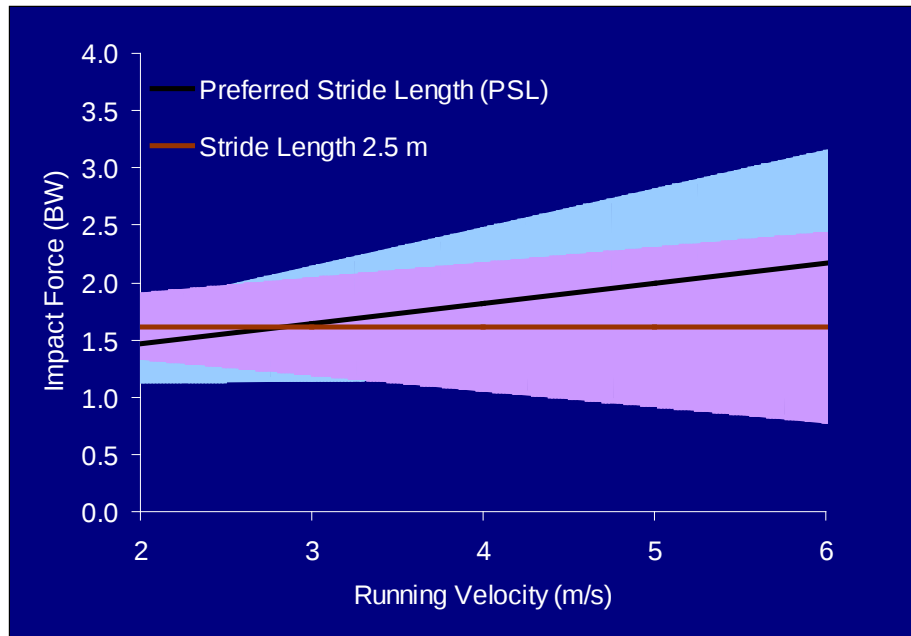
foot style). In cases like this, we would still refer to the Active force as F_2 even though there is no F_1 (impact force).

The impact force has received a lot of attention over the years as it has been thought to be a main contributing factor to running overuse injuries. This makes sense because a typical 30 minute run will involve 2400 impacts per side (using 80 strides per minute as a typical stride rate). Each foot strike is a collision between the foot and the ground ... impact forces can be in the range of 1.5 to 2.5 times body weight for a typical run. So, if you weigh 180 lbs, that is 270-450 lbs each foot strike! That's a lot when you combine it with the repetition. No wonder runners get injured.

In any case, there are a lot of factors that influence how large the impact force is ... running speed, running uphill/downhill, running on different surfaces, and so forth. For this handout, I want to focus on how the impact force changes when speed, stride rate, and stride length change. As runners go from a slow speed to a fast speed, the impact force increases. Part of this is because running speed is increasing, but part of this is because stride length increases (as noted before). We also know that as stride length increases for a given speed, the impact force is greater (Mercer et al., 2005). So we have a bit of a confusing issue ... as speed increases, so does impact force. At the same time that speed is increasing, stride length is increasing. We asked the question: What would happen to impact force if speed were increased but stride length was held constant?

We did this experiment in our lab by having subjects first run in the lab at a variety of speeds while we measured the impact force. As expected, impact force increased. Likewise, as expected, stride length increased as speed increased. We then had subjects run a variety of speeds but use the same stride length. We did this by putting markers on the floor that subjects had to hit with each foot strike. Interestingly, when we looked at impact force, it did not increase as much as when stride length was allowed to increase. The figure below illustrates the impact force when subjects were allowed to freely choose a stride length (Preferred Stride Length in black) and then when we fixed (in red) the stride length (in this experiment, we used 2.5 m).

From this experiment, we saw that the increase in impact force across speeds was largely due to an increase in stride length. What this means is that the stride length being chosen at the higher speeds was done so without regards to the impact force. That is, runners can select a shorter stride length (and higher stride frequency) at the faster speeds, but chose not to and therefore impact force increased.



The interesting aspect of this experiment is that it gives us a bit of insight into why people choose a stride length. It does not seem that they are choosing a stride length to minimize the impact force. When we are able to rule out answers, we are making progress!

So let's put this together. When running a given speed, runners tend to choose a stride rate and length combination that is close to optimal (i.e., lowest rate of oxygen consumption). This is not always the case ... but then again, there is probably a large range of stride rate/length combinations that can be used that do not negatively increase rate of oxygen consumption. Along with this, as stride rate increases, the impact force decreases. Taken together, it seems to make sense to err on the side of having too fast of a stride rate vs. too slow since impact force will be reduced and rate of oxygen consumption is likely still in the optimal range.

References

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- Hogberg, P. (1952) How do stride length and stride frequency influence the energy-output during running. *Arbeitsphysiologie*, 14, 437-441.
- Mercer, J.A., Bezodis, N.E., Russell, M., Purdy, A., & DeLion, D. (2005). Kinetic consequences of constraining running behaviour. *Journal of Sports Science and Medicine*, 4, 144-152.