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Rest and Recovery in Interval-Based Exercise

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Whenever the Workout of the Day on CrossFit.com requires rest periods of unspecified duration between exercise bouts, there are always many questions about it on the comments page. This is understandable, as rest and recovery within a workout can be quite a complex issue, and the rest period should depend on the activity you are doing and the goal of the workout.

As many of you are aware, there are three systems that a human can draw on to produce the energy required to do physical work. These are the phosphagen, glycolytic, and oxidative systems (these are discussed in terms of sustaining maximum efforts in issue 10 of the *CrossFit Journal*).

A muscle must produce a chemical compound called ATP to fuel contraction. There is a very small amount of ATP already in the muscle, but the rest must be synthesized from other fuels in the body—creatine phosphate (CP) stores, glucose, fat, or protein. The chemical processes that produce the ATP from these different fuels are different, and some also require oxygen to be available while others don't.

The first of the three energy pathways—the phosphagen system—fuels the highest power output (rate of ATP production) but has only limited fuel available (small stores of ATP and CP in the muscle). The table below is quite technical, using moles of ATP per minute as the measure of power and moles of ATP as the capacity. But "moles of ATP" is simply a unit measure of the amount of energy available to do work. How much of this energy you can use per minute is one way to measure power (mathematically, power is the amount work done divided by the time it takes to do it). The important thing to see in this table is that the phosphagen system can produce nearly four times the power output of the oxidative system. Also note that the capacity of the phosphagen system is very limited, in that it can provide peak power for only approximately 11.5 seconds. Similarly, if you work at peak glycolytic power output rates, you'll be able to sustain that power level for only 45 seconds to a minute.

It all seems very neat and progressive as described here, but, in actuality, we do not use up one system and then switch to another. During exercise we tend to use all

	Power	Capacity
Energy system	**Moles of ATP per minute**	**Total moles of ATP available**
ATP-PC (phosphagen)	3.6	0.7
Lactic acid (glycolitic)	1.6	1.2
Aerobic	1.0	90.0

Table 1. Estimated maximal power output and capacity of the three energy systems. (Data from Foss and Keteyian 1998, p. 35.)

three (except during low-power-output efforts that can be sustained for 60 minutes or more, which use the oxidative system pretty much exclusively). The table below shows the approximate percentage contribution of each of the systems for maximal power outputs of different time durations. For example, if I work at a power output that I can sustain for only 30 seconds before reaching fatigue (and hence a reduction in power output), approximately 65 percent of the energy would be supplied by the glycolytic system over those 30 seconds.

Duration of power output	% Phosphagen	% Glycolitic	% Oxidative
5 seconds	85	10	5
10 seconds	50	35	15
30 seconds	15	65	20
60 seconds	8	62	30
2 minutes	4	46	50
4 minutes	2	28	70
10 minutes	1	9	90
30 minutes	negligible	5	95
60 minutes	negligible	2	98
120 minutes	negligible	1	99

Table 2. Approximate percentage contribution of the three energy systems during maximal power outputs of varying durations.

Table adapted from McArdle, Katch, & Katch 1996; Williams & Wilkins 1996, p. 129; and National Coaching Certificate Program 1990.

I will often ask my students on an exam, "If you got up and walked across the room for 10 seconds, what energy system would you predominantly use?" The answer is the oxidative system, because the power output is so low when I walk that I could sustain that power output for hours and hours. But if I asked "If you sprinted all-out for 10 seconds, what energy system would you predominantly use?" the answer would be the phosphagen system. So although time is shown on the left side of the table above, you must realize that it is really power output that determines the energy systems used (and high power output—aka intensity—cannot be sustained over long periods).

Before we discuss rest periods I should also mention muscle fiber types. Numerous books have been written on this topic and there is some disagreement on the right way to classify muscle fibers. So I am going to simplify things considerably here. There are three types of fibers:

- Type 2b fast-twitch fibers are recruited for very short duration high intensity bursts of power such as maximal and near-maximal lifts and sprints. These fibers produce high force levels quickly but they fatigue quickly also.
- Type 2a fast-twitch fibers are more fatigue-resistant than type 2b fibers but cannot produce force quite as rapidly. They are used more in sustained power activities like sprinting 400m or doing repeated lifts with a weight below your maximum (but not very light weights).
- Type 1 slow-twitch fibers are used in lower intensity exercises like light resistance work aimed at muscular endurance and long duration aerobic activities like running 5K and 10K.

So now you have a sense of what energy system and muscle fibers you are using, how long you should recover between exercise bouts? The answer depends on which energy system you are stressing and the purpose of your training that day. This is why rest periods are not always specified in exact terms in the WOD.

Let us start by looking at the WOD that requires three 800-meter sprints. Let us assume each 800-meter effort will take the athlete three minutes. We can estimate (from the data in Table 2, above) that around 40 percent of the energy required for each 800 meters will come from the anaerobic systems (mostly the glycolytic system and a small amount from the phosphagen system). Because of this reliance on the glycolytic system, an 800-meter run produces a considerable amount of lactic acid accumulation in the primary muscles involved in the run, and if you attempt to run again too soon, not enough of this lactic acid will have been cleared from the muscles. If the accumulation of lactic acid gets too high, the increased acidity in the muscle is going to result in local muscle fatigue and the muscles affected will start to lose power (i.e. contractile force) and coordination, which will directly affect your performance. Remember that lactic acid can be used

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as a fuel only if sufficient oxygen is available. If enough oxygen is available, as it will be when you are resting between efforts, the lactic acid will be either used for energy in the recovery process or resynthesized back into glycogen.

So how long should you wait before the next sprint? Table 3 shows that the rest could be as little as three minutes (a 1:1 work to rest ratio) or as long six minutes (a 1:2 ratio). If you are a really fast 800-meter runner (around two minutes), you may even use a 3:1 work to rest ratio and rest six minutes. Why such a range? Well, if you really want to develop a sense of a fast 800-meter pace and want to get to your best times for each exercise interval, then you need a longer rest. If you just want to run reasonably fast (but not close to your best possible 800-meter effort) and want to increase your ability to tolerate high levels of lactic acid, then you could rest closer to the 1:1 ratio.

Approximate % of maximum power	Primary energy system stressed	Typical exercise duration	Range of exercise-to-rest period ratios
90-100	Phosphagen	5-10 seconds	1:12 to 1:20
75-90	Glycolytic	15-30 seconds	1:3 to 1:5
30-75	Glycolytic and oxidative	1-3 minutes	1:2 to 1:4
20-35	Oxidative	>3 minutes	1:1 to 1:3

Table 3. Work-to-rest ratios for various exercise durations.

Adapted from Baechle and Earle 2000, p. 88.

What happens if you shorten the rest interval below the 1:1 ratio? Well, to help explain, let us take things to an illogical extreme. If we ran all three exercise bouts together and did a single 2.4-km distance, let's say it would take approximately 10 minutes. But what is the workout about now? It becomes an aerobic workout, with approximately 90 percent of the energy being supplied by the oxidative system (table 2), involving mostly slow-twitch muscle fibers.

Now, that was illogical (the zero rest period), but hopefully the example made it clear that you change the nature of the workout when you change the rest interval. What if I rested only one minute between 800-meter sprints? It wouldn't be enough time to remove the lactic acid and allow the muscles to restore enough fuel for the next run. If you ran 800 meters in 2:30 and then rested only one minute before going again, you wouldn't be able to maintain that time on your second effort (assuming that the initial 2:30 pace was fast for you). The second and third efforts would be slower and therefore rely more and more on the oxidative system. The muscle fibers used would also be affected as the muscles your body would prefer to be active during a fast 800m are fatigued and cannot contribute as much in the second and third runs. So you really do change the effect of the exercise bout by not having an appropriate rest interval.

As an additional point, I should explain that the best type of recovery from exercise bouts that produce lots of lactic acid is light work or "active" rest. By this I mean that if you sprint a distance of 400 to 1,000 meters and finish with high levels of lactic acid accumulation in your leg muscles, you should jog slowly during the recovery time. (This is what is termed a work-relief cycle.) The easy jogging will help maintain good blood flow to and from the muscles and therefore contribute to the removal of lactic acid. When recovering from work that predominantly uses the phosphagen or oxidative system (and hence does not produce much, if any, lactic acid), you can just rest.

Now let us think about a recent WOD that required ten100-meter sprints. One of the first posts to the CrossFit comments page asked if 30 seconds between sprints was adequate. This is far too short. If you rested only 30 seconds, your performance would drop off and you would be running at a 400-meter pace or slower by the end of the workout. So instead of sprinting 100 meters and predominantly stressing the phosphagen system and type 2b muscle fibers, you would be running at a pace that stresses the glycolytic system and probably more type 2a muscle fibers. So you would have changed the nature of the workout completely.

Table 3 shows that if you are taking 12 seconds to sprint that 100 meters, you should rest anywhere from 140 to 240 seconds (work/rest ratios 1:12 to 1:20). If you are really producing maximal efforts, I would suggest extending the rest period to the higher end of this range and beyond. Elite sprinters may wait five minutes or more between attempts at really fast 100-meter times. This seems like a long time. However, you cannot rush this process, as local muscle fatigue is related to factors that limit the ability to perform muscular work. These include the energy systems I've discussed, the accumulation of metabolic byproducts (such as lactic acid); and the failure of the muscle fiber's contractile mechanisms. For example, the replenishment of muscle phosphagen stores takes two to three minutes, depending on the duration of the high-intensity interval. And the many chemicals and structures that are involved in the contractile process also have to recover. Simply put, you cannot rush the chemistry involved. (While, over time, training does increase your physiological capacity for both work and recovery, there are limits on the speed of the chemical reactions involved in recovery. At any given fitness level, the biological processes can't be overcome merely by force of will.)

There is also the issue of central nervous system (CNS) fatigue. Neurotransmitters are involved in communication within the brain and between the brain and the rest of the body. During intense repeated bouts of strenuous exercise, these neurotransmitters get depleted, which results in reduced physical and cognitive performance. In the past, research has focused primarily, if not exclusively, on fatigue at the muscular level, in part because it is not easy to study the brain and CNS. However, research using new brain imaging technologies is starting to give us a better understanding of the relationship between voluntary effort from the brain and force output from the muscle. All voluntary muscle activities are controlled by the CNS through the nerve connections. Hence CNS fatigue is an integral part of rest/recovery cycles during exercise bouts. Unfortunately, much more research is needed, but we do know neurotransmitter depletion can cause CNS fatigue, reduced motivation, loss of motor control, and can even affect memory. And in true CrossFit fashion, regardless of academic research, we can look at specialist sprinting and weightlifting coaches and copy the recovery times they have come to recommend based on trial and error with thousands of athletes.

To summarize, if you do not get enough rest after periods of high-intensity exercise, you will not have the right fuel available to power your efforts, your muscle fibers and CNS will be fatigued, and you will have to shift to a slower energy system and type 2a or even slow-twitch muscle fibers to get the job done. But the job will have to be done with less weight or slower sprint times—in other words, at lower power outputs. There is also evidence that your coordination will be affected, which will further reduce your effective application of power.

If you are still wary of waiting three to five minutes between 100-meter sprints, think about how long you wait between attempting a set of lifts working up to a personal best attempt? For example, on Saturday, March 10, 2007, the WOD was: Split Jerk 3-2-2-2-1-1-1-1-1 reps. How long would an athlete wait before attempting these lifts for a one-repetition maximum or near-maximum? How long do you wait between the final attempts of one-repetition maximums when doing the CrossFit Total? Research suggests a minimum of three minutes rest between loads in the one- to three-rep maximum range. This probably wouldn't surprise those used to attempting one-rep maxes in their weight training. In the benchmark workout "Lynne" (five rounds for max reps of bodyweight bench press and pull-ups), each round is repeated every five minutes. However, many of these same athletes do not seem to view maximal-effort short-distance sprints in the same category as maximal lifts. They should though (and next month I plan to further discuss this and peak power efforts).

As coincidence would have it, I had already submitted this article when I saw that the WOD for Monday, March 19, 2007, was to run 400 meters four times with two minutes of rest rounds. Is this a long enough rest? It depends on the purpose of the workout. If you are sprinting maximally—and really trying to get your best time on each round—it isn't, as the rest to work ratio is only between 1:1 and 1:2 for those fast sprinters. Some of the results posts for that day that show fast times (65 to 80 seconds) show considerable drop-off between the first sprint and the fourth. (Keep in mind that 70 seconds dropping to 77 seconds is a 10 percent decline. Quite significant.) This shows that those athletes hadn't cleared enough lactic acid, had fatigued muscle fibers, and probably had some CNS fatigue. However, some of those who posted less fast times were able to repeat all four runs in the same time. This is simply because those with slower times were not truly pushing 100 percent and thus were leaving "something in the tank" (intentionally or not). This is why interval training is quite complex. You can run 400 meters at a slightly faster pace than your 5k pace and use it to work on pacing and your running endurance. In this case, you will not finish with high levels of accumulated lactic acid and you can run again relatively quickly (possibly with less than a two-minute rest interval). On the other hand, you can run the 400 meters as fast as possible and attempt to run each of the next three in the same time, but you would have to rest for periods in the 1:2 to 1:4 range (see table 3). As stated at the beginning it does depend on the goals of that workout for that day and, in true CrossFit fashion, you can do this kind of workout in either way and reap varied gains from it.

One of the most common errors for many specialized athletes, both distance runners and lifters, both beginners and advanced, is overtraining. Lured by the "more is better" mantra, many seem to think that if we train longer, harder, and more often, we'll get the best possible results. I have seen posts on the CrossFit website on rest day in which people say they don't want to rest and so they did another workout. This is an error. I think people sometimes make similar errors within the WOD. Can less be better? Well, fewer repetitions per work set and longer rest periods might mean a reduced average power output over the duration of the workout. But the peak power you attain and the number of exercise periods where you can reach this peak power will be higher. And that is a good thing.

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