Why Do We Fatigue?

A Dynamic Model of Fatigue

Why do we fatigue?

In my opinion this is the single most important unanswered question in all of endurance physiology. Really. What prevents us from running faster for a particular distance? Or asked another way, why can't we hold a set pace for a longer period of time? At its essence these questions boil down to this – why do we fatigue?

What is Fatigue

The term f*atigue* is used by physiologists to describe a decrease in power output. At some point while running at a particular pace you will be unable to maintain that pace. Your power output drops, your pace drops, and physiologists say you have fatigued. Even though you can continue running at a slower pace, fatigue prevents you from maintaining the higher pace at which you were originally running.

Models of Fatigue

Exercise physiologists have been working for more than 100 years to answer the question "What causes fatigue?" Hundreds, perhaps thousands, of researchers have conducted untold numbers of research studies in an effort to unravel the mysteries of the body and definitively answer the question. Yet, despite all the effort and the multitude of studies the question remains unanswered.

This is not to say that no progress has been made. We have gotten closer to answering the question. Science has identified things now known to contribute to fatigue; things like glycogen depletion, muscle damage, dehydration, and muscle acidity amongst others. Exercise physiologists have taken all the various things believed to cause or contribute to fatigue and have proposed no less than 8 models to explain fatigue.(1) These 8 models are:

- Cardiovascular/anaerobic model
- Energy supply / energy depletion model
- Neuromuscular fatigue model
- Muscle trauma model
- Biomechanical model
- Thermoregulatory model
- Psychological / motivational model
- Central governor model

Challenges with the current Models of Fatigue

The challenge with the competing models of fatigue is that they are inconsistent with each other. If one of the models is accurate, then some or all of the other models must be inaccurate. For example, the cardiovascular/anaerobic model proposes that a limited supply of oxygen to working muscles ultimately causes fatigue. If this is true and limited oxygen is truly the root cause of fatigue during endurance events then all 7 of the other models are inaccurate since all of them propose that fatigue occurs elsewhere in the body before a limited oxygen supply causes fatigue.

Each of the 8 models of fatigue has supporting research evidence. However, each also has either evidence that contradicts it or things that are unexplained by the model. For example, research has shown that 70% of tested athletes do not exhibit a true VO2max. If the cardiovascular/anaerobic model is correct then virtually 100% of athletes should exhibit a true VO2max, not just 30%. Consider the energy supply / energy depletion model, which states that depleted levels of muscle glycogen (energy) causes fatigue. If this theory were correct then exhausted athletes should not be able to increase their pace near the end of a race, yet athletes routinely sprint near the end of a race, a feat that would be impossible if fatigue were caused by a depleted supply of glycogen.

My goal here is not to explain all 8 models of fatigue and the research evidence for and against them; I'm only pointing out that each of the 8 models has both evidence supporting it and evidence that either contradicts it or things that are unexplained by the model.

How do we properly deal with a model that has valid, reliable evidence that contradicts it? Stephen Hawking, in his book A Brief History of Time, explained it this way

> "…you can disprove a theory by finding even a single observation that disagrees with the predictions of the theory…Each time new experiments are observed to agree with the predictions (of the theory) the theory survives, and our confidence in it is increased; but if ever a new observation is found to disagree, we have to abandon or modify the theory." (2)

Why have I taken such pains to point out all this? The answer is that when multiple models are known to be inconsistent with each other, then we know the models are incorrect. There can only be 1 accurate model that explains fatigue – not 2 or more models that are inconsistent with each other. This means that either only 1 of the 8 models is the correct one or all 8 models are inaccurate.

Any time a theory is contradicted we know the theory is inaccurate and either must be dismissed or modified. In the case of our 8 models of fatigue for each that has contradictory evidence we know that model is inaccurate.

A Dynamic Model of Fatigue

While pondering the nature of fatigue I asked myself the same basic question that led to the creation of The Running Theory of Everything. The question I asked was, "What model of fatigue would account for all the various things known to cause fatigue?" After much thought I finally came to the realization that fatigue is not caused by any single thing, but is, in fact, dynamic. Many things cause fatigue, at different times and under different circumstances. Additional thought and review of the available research led me to conclude that the dynamic model of fatigue was simply an extension of Noakes' Central Governor model. Basically, I added my dynamic theory of fatigue to the Central Governor model to explain those elements of fatigue not fully addressed by the Central Governor. Let's review the Central Governor model and then cover the subtle extension I've proposed for it.

The Central Governor Model, formulated by preeminent physiologist and researcher Prof. Tim Noakes, proposes that fatigue is ultimately a function of your brain. Essentially the Central Governor model suggests that the subconscious brain continually monitors all the various systems of the body and anytime one or more parts of the body approaches dangerous levels, the brain reduces motor output (and therefore pace) and sends the signals of fatigue and distress to the conscious brain that all runners are familiar with. For example, during a run in hot weather if your body's core temperature reaches a critical level the brain reduces muscle activation in order to prevent you from becoming overheated and suffering a heat injury. In this way all the body's systems are protected from catastrophic failure, injury and/or death from excess heat. Or, for example, if during a race or workout you become dehydrated, the central governor in your brain forces a slowing of the pace so that the rate of fluid loss can be decreased. The central governor also sends strong thirst and distress signals to your conscious brain so that your conscious desire to continue running is decreased.

In this way your brain is the source of fatigue. Fatigue is a result of the process of the central governor working to keep the body working within safe parameters. Physiological factors are at the root of fatigue but do not directly cause fatigue. The central governor is the source of fatigue, governing power output in order to protect the body.

The Dynamic Nature of Fatigue

The area that did not seem to be fully addressed by the central governor is the dynamic and changing nature of the root of fatigue. While the central governor model clearly recognizes that different physiological factors at different times can be the activating force in fatigue, it seemed to not fully account for the dynamic and changing roots of fatigue.

I suggest that the physiological factors that activate the central governor are not consistent over time; they vary with fitness, environment, and performance conditions. There is no one universal physiological factor that causes fatigue; instead, many different factors can activate the central governor, at different times and under different circumstances, causing fatigue.

The dynamic nature of fatigue theory extends Noakes' Central Governor and accounts for all known contributors to fatigue. This extension means that the physiological factors that activate the central governor:

change with changes in fitness and training
are different in different environments
are different under different performance conditions

Let's look at all 3 in turn.

Changes in fitness and training status = varying roots of fatigue

I propose that as a person's fitness level changes, the underlying physiological factors that activate the central governor change. For example, the root of fatigue in a beginner runner may be weak muscle fibers that posses poor resistance to fatigue. With training the beginner's muscles become stronger, more powerful, and more resistance to fatigue, thus enabling the beginner to run faster. At this point, muscle is no longer the root of fatigue for this beginner runner. Instead another physiological factor, say muscle acidity or an insufficient aerobic system, become the new root of fatigue. This process continues indefinitely; as one system or physiological factor at the root of fatigue adapts to training it is no longer the root of fatigue and some another system or physiological factor becomes the new root of fatigue.

Similarly, a runner trained at running on flat terrain and untrained at running up and down hills will encounter a different root of fatigue while running hills than another runner trained at running hills. A runner trained at short distances will experience a different root cause of fatigue while running long distances than a runner trained at running long distances. A runner who trains exclusively at slow to moderate paces will experience a different root of fatigue while running a fast pace than will one trained at running fast paces.

The body adapts to the training stimulus and as it adapts to a particular training stimulus the root of fatigue changes too.

Different environments = different roots of fatigue

The dynamic theory of fatigue suggests that different environments cause different systems and physiological factors to be the root of fatigue. For example, running during hot weather causes core body temperature to be the root of fatigue. Hot weather causes the body's core temperature to reach a critical level sooner and at a slower pace than when running in cooler weather, causing the central governor to limit further power output. Similarly, running at altitude causes decreased oxygen in the blood, resulting in a slower pace for the same level of oxygen consumption. At a critical low level of oxygen saturation the central governor kicks in to limit further power output, protecting the body from harm due to insufficient oxygen to working muscles.

Different performance conditions = different roots of fatigue

Finally, the dynamic fatigue model proposes that events conducted at different paces and distances have different roots of fatigue. The root of fatigue during

a 100 meter sprint will be different than the root of fatigue during a 10k race because running at different paces places different stresses on the body. During a 100 meter sprint fatigue in the fast twitch muscle fibers may be the root of fatigue while during a 10k race fatigue of the slow twitch muscle fibers may be the root of fatigue. Similarly, the slower pace held during a marathon means that root of fatigue will be different than during other, shorter races.

Supporting Research

If the dynamic theory of fatigue is accurate then it must be true that there is no single, consistent root of fatigue. This means the evidence must show that not only is there is no one, universal cause of fatigue but it must also show that there is no single, consistent root of fatigue under any circumstance. Let's take a look at the research.

No single, universal root of fatigue

This particular point is perhaps the easiest to prove. Simply logic tells us that if there were a single, universal root of fatigue that physiologists wouldn't have come up with at least 8 competing models of fatigue, especially 8 models that are inconsistent with each other. However, this logic isn't quite enough. Instead we need to show at least a single case where fatigue cannot be attributed to a single, global root. In this particular case, we will use the cardiovascular / anaerobic model to show there is no single root cause of fatigue.

As noted earlier, the cardiovascular/anaerobic model proposes that a limited oxygen supply to working muscles is ultimately the cause of fatigue. This model further proposes that exhaustive exercise terminates shortly after an athlete reaches VO2max. Is this the case? Do all athletes reaching exhaustion during an exhaustive exercise test exhibit a VO2max? The answer is no. In fact, research has shown that only about 30% of elite athletes reach VO2max during exhaustive exercise.(3) The other 70% of elites clearly reached exhaustion during the test but did not reach VO2max. This study shows that there is no one, universal root of fatigue. If there were one universal root of fatigue, VO2max in this case, all 100% of the tested elites would reach VO2max during the test. Since some did and some did not, this shows that other factors are causing fatigue in the 70% who did not reach VO2max. If another, single factor was the root of fatigue, then none of the athletes would have reach VO2max. Since 30% did reach VO2max, this shows that some other single factor is not the root of fatigue.

No single, consistent root of fatigue during any event

The other possibility is that events of different distances or durations have different but consistent roots of fatigue. For example, the root of fatigue during a 5k race might *consistently* be too high muscle acidity while fatigue during a marathon might *consistently* be glycogen depletion. So, while each individual event has a different root of fatigue than other events, each individual event would have its own consistent, unique root of fatigue.

Physiologists associate various physiological factors with fatigue. For example,

VO2max, lactate levels, muscle acidity, and glycogen levels have all been correlated with fatigue. If a particular event has a consistent root of fatigue, then the physiological measures for athletes competing in that event will all be the same. For example if muscle acidity is the sole cause of fatigue during a 5k race, then we should see similar levels of muscle acidity in all competitors running a 5k at their best effort. Or if lactate causes fatigue during all out exercise, then at the end of an all out exhaustive test all competitors should exhibit similar lactate levels. Or if glycogen levels are the root of fatigue during a marathon we should see similar low levels of glycogen in all competitors finishing a marathon. On the other hand, if competitors during a specific event exhibit a broad range of one or more of these physiological measures then it indicates that there is no one consistent root of fatigue during these events.

Research clearly shows that competitors exhibit a broad range of physiological factors upon completion of competition. For example, one study gave an exhaustive test to members of a University cycling team and found a very broad range of blood lactate of 5.9 – 18.2 mM immediately postexercise.(4) If lactate or some other single factor were the root of fatigue then blood lactate levels would have been similar for all the trained subjects in this study. Similarly, the amount of glycogen utilized during this test ranged from 17.4 – 82.6 mmol/kg, quite a large range. Another study observed a wide range in muscle acidity at exhaustion in tested subjects.(5) The wide variation measured in these physiological factors support the idea that no single cause of fatigue exists. If there were a single cause of fatigue during any particular event we would see a similar level in all or most subjects in at least one of physiological measure correlated with fatigue.

Combining the Dynamic Model of Fatigue and the Central Governor

I do not believe that the dynamic model of fatigue is a complete and unique model of fatigue. Instead, I suggest it as an extension of the Central Governor model; that it be added to the Central Governor (the Central Governor v2.0 if you will). What this means is that the Central Governor remains the cause of fatigue but notes that the roots of fatigue are dynamic and ever changing.

Reference:

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