DON’T RUN LIKE A HEADLESS CHICKEN: A SIMPLE GUIDE TO SPORTS PHYSIOLOGY

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Physiological Adaptations to Increased Physical Activity

A sedentary lifestyle is one of the most significant health risks in Western societies, including Australia. Physical inactivity not only contributes to the growing prevalence of obesity and cardiovascular diseases but also leads to negative changes in posture, joint cartilage health, and bone density due to insufficient muscle and joint activity. However, regular exercise plays a critical role in significantly reducing the risk of cardiovascular, metabolic (e.g., diabetes), and musculoskeletal diseases.

While some individuals find themselves restricted by the demands of long hours in sedentary office jobs, others may take physical activity to an extreme level. Both extremes can be equally detrimental to health if the body's signals for rest and gradual progression are ignored, especially during the initial stages of training.

Through a series of articles, I hope to provide insights into how your body responds to physical activity, why you should approach your fitness journey with patience and self-compassion, and why sustainable progress takes time. In today's article, we'll explore some of the remarkable physiological adaptations that occur in your body when you resume training after a period of inactivity—whether it's been three months of lockdown, recovery from an injury, or another extended break from exercise.

It's important to remember that these changes don't happen overnight, but with consistent effort, they will come.

1. Adaptations in the Cardiac System

One of the most remarkable changes in a well-trained body is the increase in heart volume, which directly enhances cardiac output. This adaptation results from a balanced combination of heart chamber dilation (allowing the heart to hold more blood) and hypertrophy of the heart muscle (increased muscle thickness). Together, these changes strengthen the heart, enabling it to pump a greater volume of blood with each beat.

As an interesting aside, the heart of the legendary racehorse *Secretariat* reportedly weighed an astounding 10 kilograms, illustrating the incredible adaptability and power of the cardiac system in response to sustained physical training.

2. Respiratory Adaptations

As your body becomes fitter, your respiratory system learns to work more efficiently, by decreasing respiratory frequency and increasing tidal volume (the amount of air inhaled or exhaled with each breath). In short, your breathing becomes more economical, requiring less effort for the same amount of oxygen intake.

3. Enhanced Vascularization of Muscles

Regular endurance training (at least three times per week) promotes the growth of new capillaries within your muscles, a phenomenon known as vascularization. Capillaries are the smallest blood vessels, responsible for the exchange of oxygen and carbon dioxide, as well as delivering nutrients like glucose and electrolytes to active muscles during exercise.

With training, the number of capillaries surrounding each muscle fiber can increase by as much as 20%. This enhanced capillary network improves oxygen delivery and nutrient supply to working muscles, supporting sustained physical activity and improving overall endurance.

4. Increased Muscle Power

Contrary to popular belief, muscle power does not increase solely with muscle size. In endurance sports, muscle power depends heavily on the muscle’s capacity to store and produce energy during exercise.

Glycogen, the stored form of glucose, is a key energy source for muscles during prolonged activity. It is stored in the liver and muscles and can sustain physical effort far longer than the glucose circulating in the bloodstream. The ability to store glycogen improves with regular training and is further supported by consuming an appropriate amount of carbohydrates during exercise preparation. Trained muscles have a significantly higher glycogen-storage capacity than untrained muscles.

However, glycogen or blood glucose is not directly usable as energy. The real "fuel" for muscle activity is **ATP** (Adenosine Triphosphate), which is generated by mitochondria—the energy "powerhouses" of muscle cells. Remarkably, well-trained muscles can have up to 40% higher mitochondrial density compared to untrained muscles, resulting in greater energy production and improved endurance capacity.

5. Improved Lactate Utilization

During intense physical activity, the buildup of lactate in muscles can lead to the familiar sensation of fatigue and muscle burn. However, with consistent training, the body adapts to this challenge. Specific enzymes, such as lactate dehydrogenases, become more efficient at metabolizing and utilizing lactate as an additional energy source through a process known as lactate oxidation. This improved lactate clearance helps to restore the muscle's pH levels more quickly, reducing fatigue and enabling athletes to sustain performance for longer periods.

Conclusion

As illustrated by these physiological adaptations, the body is remarkably capable of responding to increased physical activity and recovering from periods of rest or inactivity. These positive changes—improved cardiac function, enhanced respiratory efficiency, increased vascularization, greater muscle power, and better lactate management—are all evidence of the body's innate ability to adapt to healthy physical stress.

However, it is crucial to approach training with patience and consistency. Significant improvements take time and dedication, especially after a prolonged period of inactivity. Remember, these adaptations not only enhance your performance in physical activities, such as paddling, but also contribute to better overall health.

Motor Learning

Performance in sports is often explained by how well or fast we can perform a certain task or cover a certain distance. However we often don't fully acknowledge what the process involves when we seek performance. The first and most important process that we actually face when working on performance is a learning process, motoric learning, before training can be effective. This relates well to paddling a new boat, an elite ski or that beast of a K1.

Motoric learning is the first and most important step into achieving performance where we acquire and optimise central nervous functions to control skeletal muscles. Learned movements are spatial-temporal, dynamic-static and most typically unconscious. It's a central nervous process consisting of information intake, -processing, -storage, and –output and is closely connected to sensory inputs from the periphery. Therefore learned movements require mental training and observative training.

At the beginning of this learning process new movement patterns are uncoordinated. With continued learning the intra- and intermuscular coordination improves, fine coordination will be achieved, your technique develops. During that stage unnecessary associated movements will be eliminated and sensory feedbacks calculated faster. This is the stage when efficiency and performance increases significantly while paddling at same effort or paddling appears "easier" because for the same speed we require less physical and mental energy.

Training, as the second factor of performance, is gradually increasing during the process of learning but fully dependent on the learning progress (you can't train while constantly capsizing in that K1). Continued training of what is learned will "fix" your technique to an unconscious movement.

Therefore it is often recommended by many coaches to first learn the specific movement patterns correctly and then train an efficient stroke before thinking about speed. Ladies are often more patient with that!

In summary:

- Motoric learning will develop fine motoric, reduces unnecessary movements and processes sensory input faster leading to higher efficiency → your technique develops.
- Training is the repetition of the learned movement → your technique becomes fixed/unconscious.

Cyclical or rhythmic movements can be stored in the long-term memory for many years. Unfortunately if technique is not taken seriously enough at the beginning, bad technique is also a learned movement that will last you for years, keeps efficiency low and has to be compensated by an extreme effort of muscle strength.

Balancing Heat and Fluid Intake

Energy metabolism in the human body operates with an efficiency of only 20-40%, meaning that 60-80% of the energy produced in muscle cells is lost as heat—a process similar to the inefficiency of an automotive engine. During intense exercise, the body can generate up to 20 times more heat than it does at rest. This excess heat poses significant challenges, as it not only limits performance but can also lead to heat exhaustion if it is not effectively dissipated.

Heat Dissipation Mechanisms

To prevent overheating, the body relies on two primary mechanisms to dissipate heat:

1. Sweat Production
   Sweat evaporates from the skin, carrying heat away from the body in the process. However, sweat contains both water and salts (mainly sodium and chloride), and excessive sweating can lead to significant losses of both. For instance, one litre of sweat contains approximately 3 grams of sodium chloride. Athletes exercising intensively in the heat can lose up to 2.5 litres of sweat per hour. Over the course of a 2-hour marathon paddle, the average paddler may lose 5 litres of fluid and 15 grams of salt (equivalent to 2.5 teaspoons)—far exceeding typical daily intake levels.
2. Increased Blood Flow to the Skin
   The body redirects blood flow to the skin's surface, allowing heat from the body's inner core to dissipate through the skin and enabling sweat to evaporate.

Both of these mechanisms—sweating and increased blood flow to the skin—are highly dependent on maintaining adequate blood volume. When blood volume is reduced, the body's ability to transport blood to the skin and produce sweat is compromised.

Competing Demands for Blood Volume

During heavy exercise, working muscles require optimal blood flow to deliver oxygen and nutrients as well as to remove metabolic by-products. At the same time, the body needs to divert blood to the skin for heat dissipation. This creates a competing demand for blood volume between muscle activity and thermoregulation.

When blood volume is low, both heat regulation and muscle performance can be severely impaired. As a result, maintaining adequate blood volume becomes a critical factor in determining whether performance can be sustained during prolonged activities, such as a marathon paddle.

Hydration: Is Water Enough?

Given the demands placed on the body during exercise, water alone is insufficient for hydration. This is because exercise results in the loss not only of water, but also of electrolytes and blood sugar. A proper sports beverage should include all three components to support performance and recovery.

Key Points on Hydration:

- When to Drink:
  It is recommended to consume a high-quality sports drink for any exercise lasting longer than 30 minutes, and it should be consumed even before thirst occurs. Thirst is triggered by a dry mouth and throat, which occurs in direct relation to blood plasma concentration. Unfortunately, the sensation of thirst only arises after the body has already lost 2 litres of water, making it an unreliable indicator of hydration needs during high-performance activities. If you feel thirsty during a race or training session, it’s often too late, as your performance is likely already declining due to reduced blood volume.
- Drinking on Schedule: During exercise, fluid loss typically exceeds fluid intake, making full hydration during the activity impossible. To avoid dehydration, athletes must train themselves to drink on a fixed schedule, regardless of whether they feel thirsty. Drinking fluids that taste good can also encourage better hydration habits.

Fluid Absorption and Carbohydrate Balance

The speed at which consumed fluids are absorbed into the bloodstream is crucial for maintaining hydration during exercise. The carbohydrate concentration of a drink plays a key role in determining how quickly fluid is absorbed in the intestines.

- Optimal Carbohydrate Concentration:
  A 6-7% carbohydrate solution strikes the best balance for rapid absorption. Drinks that are too concentrated (such as highly sugary exercise gels) can temporarily cause fluid to shift from the bloodstream into the intestines, as the body works to dilute the gel. This fluid shift can negatively impact hydration levels, making it essential to consume gels with plenty of water to aid in dilution.

Summary

- Heat Dissipation: Exercise produces significant amounts of heat, and the body relies on sweating and increased blood flow to the skin to regulate temperature. Both mechanisms depend on maintaining adequate blood volume.
- Hydration Needs: Water alone is insufficient for hydration during exercise. Athletes lose water, electrolytes, and blood sugar, and a good-quality sports beverage containing all three is essential for sustained performance.
- Timing Matters: Thirst is a poor indicator of hydration needs during exercise. Athletes should drink on a schedule and aim to consume fluids with the correct balance of carbohydrates (6-7%) to ensure rapid absorption and avoid dehydration.
- Gels and Fluids: Exercise gels, while useful for energy, should always be consumed with sufficient water to prevent potential negative effects on hydration.

In essence, proper hydration during exercise is about more than just replacing lost water—it's about maintaining blood volume, regulating heat, and sustaining energy levels to ensure peak performance. By understanding the body's energy and hydration needs, athletes can optimize their endurance and reduce the risk of heat-related fatigue or exhaustion.

Fatigue, Exhaustion, Recovery and Overtraining

Nearly everyone who has participated in a race can relate to the experience of fatigue that sets in during the final few kilometres. Your coordination falters, and the precision of your paddling strokes and leg drive diminishes significantly. Your shoulders and core begin to collapse, and the paddle slaps awkwardly against the water's surface. You may feel as clumsy as a beginner, struggling to manage your seemingly unstable boat. After the time trial, even basic fine motor skills may desert you for several hours—opening a bottle, inserting car keys into the lock, or unwrapping a food package suddenly feel like monumental tasks. Thankfully, your shift as a dentist has already ended.

The causes of fatigue are multifaceted. Below are some:

- **Electrolyte depletion**: High-frequency muscle innervation depletes electrolytes, impairing muscle function.
- **pH drop due to lactate build-up**: Lactate accumulation lowers the pH within the muscle, creating an acidic environment that inhibits the activity of metabolic enzymes.
- **Muscle glycogen depletion**: Glycogen, the primary energy reserve in muscles, becomes exhausted during prolonged exertion.
- **Increased core and muscle temperature**: Excessive heat disrupts enzymatic activity, impairing metabolic processes.
- **Dehydration**: A drop in blood pressure caused by dehydration reduces blood volume, which in turn compromises the delivery of oxygen and nutrients to muscles and the brain.
- **Blood glucose depletion**: Glucose serves as the primary energy source for the nervous system. A significant reduction in blood glucose levels not only affects skeletal muscle performance but also hinders neural function and diminishes motivation, leading to mental fatigue caused by hypoglycemia.

Exhaustion

Exhaustion occurs when the state of fatigue is prolonged—either as acute exhaustion during a race or as chronic exhaustion caused by insufficient recovery between intense physical activities, such as at the end of a racing season. This state of extreme fatigue leads to a decline in performance and, in severe cases, can result in physical collapse.

Acute exhaustion is not uncommon in sports and presents minimal risk to healthy individuals, provided that adequate rest is taken afterward. In fact, a mild form of acute exhaustion can be beneficial, as it triggers physiological adaptations in the body that contribute to improved performance. However, it is crucial to note that acute or chronic exhaustion can pose serious risks to individuals with pre-existing medical conditions.

Recovery

Recovery begins when physical activity is reduced, discontinued, or replaced with alternative, less demanding activities. During this period, fatigue gradually subsides, and performance levels improve.

Recovery involves two key processes:

1. **Energy restoration**, which typically occurs within 24 hours.
2. **Structural repair**, a slower process that involves the healing of microlesions in muscles and tendons. This phase is often accompanied by inflammatory responses until full recovery is achieved.

Neglecting recovery can lead to overtraining, which might manifest in a range of unexpected symptoms, including sleep disturbances (e.g., insomnia) or even physical issues such as chest pain. The most significant consequence of overtraining, however, is a decline in physical performance. Chronic exhaustion occurs when recovery times are repeatedly insufficient, resulting in long-term physical impairment, persistent fatigue lasting weeks or months, and even structural damage to the musculoskeletal system.

The underlying causes of chronic exhaustion are complex, often involving dysregulation in the central nervous system (including hypothalamic-pituitary activity), adrenal gland dysfunction, and metabolic stress. Moreover, inadequate recovery prevents proper healing of micro-injuries, leading to cumulative damage. Over time, this can result in permanent injuries to tendons, ligaments, and joints. Common injuries—such as tendinitis, bursitis, and arthritis in the elbow or shoulder—are often the result of accumulated damage caused by poor technique and overtraining.

The Importance of Recovery

Discipline is required not only for training but also for recovery. Recovery is an essential component of any effective training regimen, ensuring that the body has adequate time to repair and adapt to the stresses of physical exertion. By prioritizing recovery, athletes can prevent long-term damage, enhance their performance, and sustain their physical and mental well-being over time.

Understanding Lactate Threshold

The term *"lactate threshold"* is frequently mentioned during training sessions, and while most of us recognize the sensation associated with it, do we fully understand the processes occurring in our bodies? To grasp the concept of lactate threshold, we must first understand the difference between aerobic and anaerobic energy production in the body.

The only usable form of energy for muscle activity is ATP (adenosine triphosphate). However, ATP cannot be stored in the muscle and must be constantly generated during physical activity from energy sources that *can* be stored in the muscle. There are four primary pathways through which ATP is produced within muscle cells, each varying in efficiency and their dependence on oxygen (aerobic or anaerobic processes):

1. **Hydrolysis of Creatine-Phosphate**

- Creatine, in the form of creatine-phosphate, acts as a carrier for the phosphate group used in ATP production.
- This pathway does not require oxygen (**anaerobic**) and is incredibly rapid. However, it is highly limited, as creatine-phosphate stores are depleted within approximately 20 seconds during maximal muscle activity.
- **Reaction**: CrP → Kr + ATP
- Despite its short-term benefits, the limited capacity of this pathway means that supplements like creatine are often unnecessary for most athletes.

2. **Aerobic Glucose Metabolism (Oxidation of Sugars)**

- This pathway is the most efficient method for ATP production, but it requires oxygen (**aerobic**).
- Simple sugars, such as glucose, are metabolized within the muscle cell to produce ATP. From one molecule of glucose, **38 molecules of ATP** can be synthesized, with water (H_2O) and carbon dioxide (CO_2) as by-products.
- **Reaction**: 1 $C_6H_{12}O_6$ (glucose) + 6 O_2 → 6 H_2O + 6 CO_2 + 38 ATP

3. **Anaerobic Glucose Metabolism**

- This pathway involves similar metabolic reactions as aerobic glucose metabolism, but due to a lack of oxygen, the final step is interrupted. Instead of CO_2 and H_2O, **lactate** is produced as a by-product.
- This anaerobic pathway is highly inefficient, producing only **2 ATP per molecule of glucose**, compared to the 38 ATP produced in aerobic metabolism.
- **Reaction**:
  1 $C_6H_{12}O_6$ (glucose) - O_2 → Lactate + **2 ATP**

4. **Oxidation of Fat (Triglycerides)**

- Triglycerides, stored within muscle cells, must first be broken down into free fatty acids (FFAs) and then metabolized through complex processes such as **β-oxidation**.
- The ATP yield from fat oxidation is significantly higher than from glucose oxidation—up to **100 ATP molecules per fat molecule**, depending on the type of fat. However, this process requires even more oxygen than glucose metabolism.
- For every molecule of oxygen, fat metabolism produces only **5 molecules of ATP**, compared to **6 molecules from glucose**. As a result, oxygen availability becomes the limiting factor, and the body prioritizes carbohydrates over fats for energy during high-intensity exercise.

Efficiency of Energy Pathways

To better understand the differences in efficiency among these pathways, we can compare how far an individual might paddle using energy derived from a single molecule of each energy source:

- **1 molecule of creatine-phosphate (anaerobic)**: ~100 meters
- **1 molecule of glycogen without oxygen (anaerobic)**: ~1,500 meters
- **1 molecule of glycogen with oxygen (aerobic)**: ~30 kilometers
- **1 molecule of fat with oxygen (aerobic)**: >100 kilometers

Although these figures are not exact, they proportionally illustrate the vast differences in energy efficiency between the pathways. Oxygen availability is the most critical factor for efficient ATP production. However, during high-intensity exercise, oxygen supply to the muscle cells becomes limited due to constraints in breathing, oxygen transport via the blood, and oxygen utilization within the muscles. When the demand for ATP surpasses the capacity of aerobic metabolism, the body must increasingly rely on anaerobic energy production—leading to the accumulation of lactate.

Lactate Accumulation and the Lactate Threshold

As anaerobic metabolism becomes more dominant with increasing exercise intensity, lactate begins to build up in the muscles. Fortunately, lactate is constantly broken down and removed from the muscles by specific enzymes called lactate dehydrogenases. The lactate threshold refers to the steady-state exercise intensity at which lactate begins to accumulate in the blood at the same rate that it can be removed by these enzymes. Beyond this threshold, lactate removal processes can no longer keep up, resulting in a rapid increase in lactate levels.

It is important to note that the lactate threshold varies significantly between individuals. Training can have a profound effect on the lactate threshold due to a variety of muscular and cardiovascular adaptations, such as:

- Increased efficiency of lactate-dehydrogenase enzymes.
- Improved oxygen delivery to muscles via higher cardiac output and enhanced vascularization.
- Enhanced muscular oxygen extraction and utilization.

These adaptations allow trained individuals to maintain higher intensities of exercise for longer periods before reaching their lactate threshold.

In conclusion, understanding the role of lactate threshold and the body's energy systems is key to optimizing athletic performance. By improving the efficiency of oxygen utilization and lactate clearance through training, athletes can push their limits, delay fatigue, and achieve greater endurance in their chosen sport. For a deeper dive into how training influences lactate threshold, refer to other articles in this series.

Muscle Pains

Acute Muscle Soreness

Muscle pain experienced during or immediately following physical activity typically manifests as stiffness, aching, or tenderness. In the absence of pre-existing injuries, acute muscle soreness is commonly attributed to the accumulation of lactate and the development of tissue oedema. During intense endurance training, oedema can result in noticeable muscle swelling. Fortunately, such discomfort generally subsides within a few hours of rest.

Delayed-Onset Muscle Soreness (DOMS)

Delayed-Onset Muscle Soreness (DOMS) typically emerges 24 to 48 hours after engaging in strenuous exercise and can range in severity from minor stiffness to intense, debilitating pain. The primary cause of DOMS is structural damage to muscle fibers (microtrauma) and the surrounding connective tissue. Significant muscle damage is often observed following a marathon, which highlights the extensive disruption of muscle filaments.

Injury to muscle cells triggers an acute inflammatory response, characterized by tissue swelling, the recruitment of inflammatory mediators, all of which contribute to the sensations of pain, tenderness, and oedema. This injury also results in a marked reduction in the force-producing capacity of affected muscles, stemming from anatomical disruptions in muscle filaments, the loss of contractile elements, and impairments in the excitation-contraction coupling process.

The extent of muscle damage, alongside the strain on surrounding connective tissues, necessitates sufficient recovery time for proper regeneration. Notably, the replenishment of muscle glycogen, which typically occurs within 24 hours, is significantly delayed as the muscles repair themselves.

While DOMS are difficult to entirely avoid, even with low-intensity training, it is worth noting that the physiological processes associated with DOMS play a key role in promoting training adaptations, such as muscle hypertrophy. However, when pain and muscle damage are excessive, they may impair performance and increase the risk of chronic injuries, particularly in connective tissue (e.g., fascia), which has a limited capacity for rapid and complete regeneration.

Exercise-Associated Muscle Cramps (EAMCs)

Exercise-Associated Muscle Cramps (EAMCs) are characterized by painful, involuntary, and spasmodic contractions of skeletal muscles, often arising during periods of fatigue or physical exhaustion. Factors such as inadequate conditioning, improper training practices, dehydration, depletion of muscle energy stores, and electrolyte imbalances are strongly associated with muscle fatigue and the onset of EAMCs.

Two primary theories explain the occurrence of EAMCs:

1. **Neuromuscular Control Theory**: This theory proposes that EAMCs result from abnormalities in muscle innervation, specifically the hyperactivity of alpha motor neurons and reduced inhibitory feedback mechanisms within fatigued muscles.
2. **Electrolyte Depletion Theory**: According to this theory, EAMCs are caused by the loss of electrolytes (particularly sodium and chloride) and dehydration, often due to excessive sweating, which can lead to "heat cramps."

Management and Prevention of EAMCs

Both types of cramps can be alleviated through specific interventions. Stretching the affected muscles helps by increasing muscle tension, which activates the Golgi tendon organs and inhibits the excessive activity of alpha motor neurons. In cases of heat cramps, consuming a high-sodium solution (e.g., 3 grams of sodium dissolved in 500 ml of fluid every 10 minutes, followed by smaller amounts throughout the day) is particularly effective.

To prevent EAMCs, the following strategies are recommended:

- Ensure proper physical conditioning that aligns with the intensity of the exercise.
- Regularly engage in stretching exercises to maintain muscle flexibility.
- Maintain adequate hydration and electrolyte balance.
- Sustain carbohydrate stores in muscles by consuming a balanced meal at least 1.5 hours before exercise, allowing for proper digestion and energy storage.

High Performance Diet

The science behind sports nutrition is very much explained by sports physiology which describes the complex chemical and mechanical body functions during exercise. Therefore scientific knowledge/evidence around sports nutrition is changing little compared to the input coming from "trends" in sports nutrition driven by the "weight loss" industry. I won't dare to put out another opinion on sports nutrition instead I want to provide some basic facts that are only explained on physiological mechanisms within our body. Many of these mechanisms and reactions were presented in my previous articles (read "Aerobic and anaerobic energy supply" or "General trainings effects") and I recommend to read them again to answer potential questions that come up when reading this article.

In this article I want to suggest a well-balanced and healthy diet that is adjusted towards your high energy requirements in times of intense training. This article is to provide you with some key principles to support your body to work towards your highest potential based on metabolic requirements. The facts presented here only apply for high intensity exercise (TTs, marathon racing) as energy metabolism is very different for low intensity exercise (touring).

A healthy and "well-balanced" diet

A healthy diet includes all essential macro (carbohydrates, fat and protein) and micro (vitamins, minerals and trace elements) nutrients to restore and renew our body tissues and to function. However no single food contains all nutrients. Some foods are packed with fats, others are rich in protein or carbs. When I talk about a "well-balanced" diet I mean "eat everything very little and nothing too much" (Paracelsus: "Res omnes venena sunt dosis sola facit venenum"). All foods contain goodies and baddies, to get all the goodies we will also get all the baddies. Key to a balanced diet is to eat it all in healthy amounts, change your foods often and consume nothing too much.

Macronutrients

1. **Proteins:** Proteins in our diet provide essential building blocks, the amino acids, to build and renew our body tissues and to provide many other carriers and metabolically and osmotically active compounds. Half of the protein content of a human body is found in skeletal muscle mass. An 80 kg person should be eating at least 65 g of protein a day when not in training to provide enough amino acids to renew and restore the daily body turnover but this needs to be increased significantly (100-140g/day) when training heavily and muscle building is the goal. There is a whole industry around sports protein supplements but proteins of high quality are present in natural foods such as eggs, milk products, meat and fish. There is no benefit in taking supplements over normal food proteins unless you end up having to eat 5 steaks a day to achieve your protein intake.

2. **Fat:** Fat is often considered as the baddie, but this is not the case. Fats are essential! Here the type of fat is important and you definitely want to have a basic understanding of saturated and non-saturated fats to get your fat intake right. Particularly plant fats (Linolenic and Linoleic acids) are absolutely necessary as structural lipids and cannot be generated by the body. Many vitamins (ADEK) are fat-soluble and can only be absorbed with fat. Oil and fish are an important part of your diet. Proteins and also fats can be metabolised into carbohydrates but this is a highly energy dependent (least efficient) process and releases acidic ketone bodies as by-products into the system (see "keto diet").

3. **Carbohydrates:** Carbohydrates are the main energy source for high intensity sports (etc in racing). They come in various complexity and are more or less easy to digest which means are more or less quickly available as a source of energy. Glucose, a simple carbohydrate, is the end product of all carbohydrate digestion, the only energy source for cells during high intensity sports and the only fuel source for the brain. All other simple sugars are converted to glucose in the liver which then is used for ATP production and glycogen storage. The amount consumed daily is completely dependent on the physical activity but is normally around 50% of your diet. To make this energy source

useful for you particularly during training and for performance in competition you want to understand the basic chemistry below.

Simple and complex carbs

Depending on its chemical composition, carbohydrates can be "fast-releasing" which means easily digestible and readily absorbable. "Slow-releasing" carbohydrates are only slowly digestible and provide smaller amounts of energy over a long time. This equates to the blood sugar levels.

***Fast-releasing carbohydrates* are "simple" carbs such as monosaccharide**s (glucose, fructose, and galactose-**one** carbon ring structure) and **di**saccharides (lactose, maltose, and sucrose- **two** carbon ring structures hooked together). Monosaccharides, because of their simple structure, are highly absorbable and ready to enter the blood stream "now". Disaccharides, consisting of 2 monosaccharides, are also easily broken down into their 2 monosaccharides therefore can be readily absorbed. More complex carbs are the **oligo**saccharides which have **three to ten** monosaccharide molecules hooked in a chain. These are often found in sports drinks and are a chain of glucose molecules.

***Slow-releasing carbohydrates* are polysaccharides (many saccharides)** which are long complex chains of simple carbs which must be broken down first by enzymes. Digestion and absorption occurs slowly but over several hours. Starch is a very common form of carbohydrate in grains, legumes, and root vegetables, such as potatoes. Amylose, a plant starch, is a linear chain containing hundreds of glucose units. Amylopectin, another plant starch, is a branched chain containing thousands of glucose units.

Fibres are another form of polysaccharides that are highly branched and cross-linked. Some dietary fibres are pectin, gums, cellulose, and lignin. The human gut microbiota is unable to make dietary fibres useable as an energy source. Dietary fibres are very beneficial to our gut health but maybe not ideal to carry around during a race.

Why do I need to know all this chemistry?

It is important to know what fast-releasing and slow-releasing carbohydrates are.

Do you want energy fast (now) but for a short time or within the next hour but then for a long time. One of the most important first aid supply in sports medicine is a simple sugar solution taken orally to get the blood sugar back up very quickly but it won't last long. Starches, common in noodles, potatoes and rice, provide a slow release of carbs that can bring you through a couple of hours but will not spike your blood sugar. Fibres (in salads and other vegetables) are useless as an energy source but will fill your guts unnecessarily which can make you feel uncomfortable and even "gassy" during training or competition.

How do I know what food contains what carbohydrate?

You probably heard about the glycaemic index (GI). High GI foods release sugar (glucose) quickly, resulting in a rapid rise in blood sugar levels; a sugar level spike. In contrast, low GI foods release sugar gradually over a number of hours, resulting in less insulin being produced.

Aren't high GI- Foods bad for me?

There are no bad carbs, only carbs eaten at the wrong time in wrong amounts! I suggest leaving high GI foods for the times pre and post racing and not during your day at the office.

Glycogen, your biggest asset!

Humans (and animals) store glucose energy from starches in the form of glycogen. Glycogen has many branches but it breaks down quickly when energy is needed by cells in the body. It is predominantly found in liver and muscle tissue. As you can see in the table below, blood sugar (10g) is a minor source of energy during a race compared to the glycogen that can be stored in muscle (245g) and liver tissue (90g), depending on body weight. This puts our emphasis on enhancing glycogen storage capacity for race performance.

	Percentage of Tissue Weight	Tissue Weight	Body Content (g)
Liver glycogen	5.0	1.8 kg	90
Muscle glycogen	0.7	35 kg	245
Extracellular glucose	0.1	10 L	10

Murray RK, Bender DA, Botham KM, Kennelly PJ, Rodwell VW, Weil PA. *Harper's Illustrated Biochemistry*, 29th ed. New York, NY: McGraw-Hill; 2012.

Glycogen storage is influenced by carbohydrate consumption. The differences between a 40% carbohydrate diet (40% of total energy consumed) and a 70 % carbohydrate diet on glycogen storage is significant when training intensively. As the diagram (Fig. 15.8) shows, repeated training on a low carbohydrate diet can actually deplete muscle glycogen storage quickly and severely affect performance. In this study a 70% carbohydrate diet was necessary to bring back muscle glycogen to normal levels within 24 hours for that specific trainings intensity. Therefore carbohydrate consumption has to be adjusted towards your trainings intensity. Keep in mind that the restoration of glycogen levels will take 24 hours or even longer when muscle damage has occurred, so the storage level reflects your diet in the last 24 hours and not just your last meal.

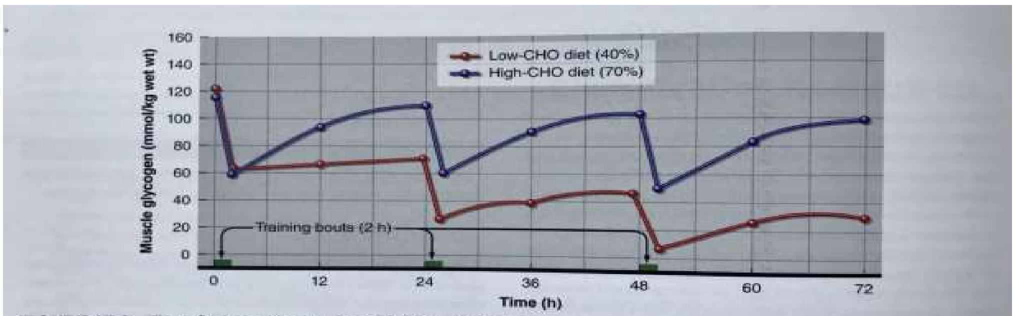

FIGURE 15.8 The influence of dietary carbohydrate (CHO) on muscle glycogen stores during repeated days of training. Note that when a low-CHO diet was consumed, muscle glycogen gradually declined over the 3 days of study, whereas the CHO-rich diet was able to return the glycogen to near normal each day.
Data from Costill and Miller (1980); Costill et al. (1971).

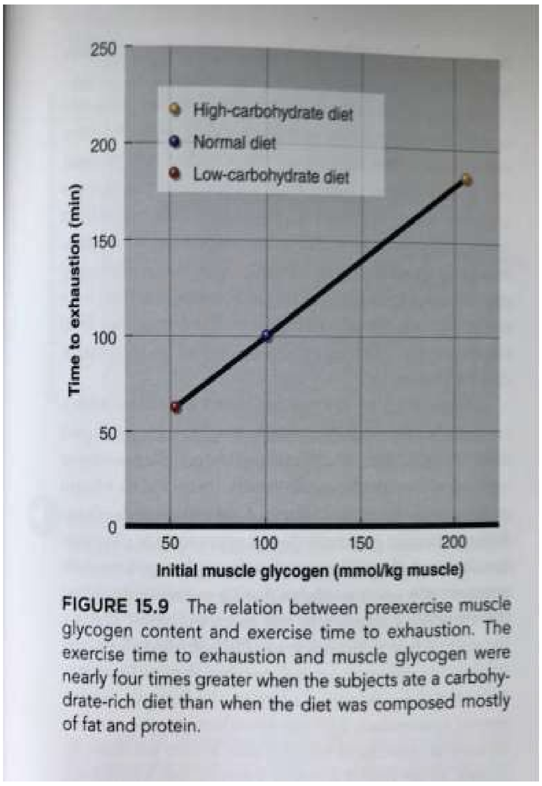

Figure 7 from Larry Kenney, W., Wilmore, J. H., & Costill, D. L. (2020). Physiology of sport and exercise (7th ed.). Human Kinetics.

When in training, a low carbohydrate diet and consequently low glycogen storage will lead to early muscle exhaustion. Figure 15.9 shows the time to exhaustion of an athlete on a low carbohydrate diet, which was 60 min. When put on a high carbohydrate diet the time to exhaustion could be extended to 180 min. This is the direct result of muscle glycogen storage level. To restore depleted glycogen level it is best to consume carbohydrates within 2 hours after the exercise as the rate of glycogen resynthesis is at its highest then.

How do I apply this to my racing schedule?

You hopefully did not skip the previous chapters above to get here. If you did, you are a most typical student.

- Trainings intensity and volume should be markedly reduced 7 days before a mayor competition (tapering) to prevent additional muscle glycogen depletion and to maximise liver and muscle glycogen reserves.
- Complex carbs in starchy foods (LOW GI foods) will bring you a long way but it is obvious that unless you have eaten it at least an hour and a half before the race you have not eaten anything. Starch takes some time to digest to be useful for you.
- Simple carbs (HIGH GI foods) will spike your blood glucose quickly but also release a lot of insulin which causes a quick drop in blood sugar levels soon after. Simple carbs are great if you need it “now” but not for very long. After the race your glycogen stores will be depleted and your blood sugar levels might be low. Try some fast release carbs and plenty of water to get you home for a proper meal.

- Glucose is the only food for the brain therefore a low blood sugar level can be recognised by irritability, difficulties performing mental tasks, disorientation and dizziness.
- Gels are highly absorbable carbs and a good way to keep your blood sugar level up during a race but should be consumed rather regular then. Gels 45min to 15 min before the race might not be a good idea as you will likely end up hypo-glycaemic when starting the race.

What about micro nutrients, do I need to supplement when training?

Micro nutrients (minerals & vitamins) come with a healthy and well-balanced diet particularly if you put emphasis on variety. In some cases, e.g. in ultramarathons or marathon season, there will be a huge turn-over of some micro nutrients such as calcium and magnesium which should be compensated by an increased intake of food in general but you can only eat so much. In other cases you might be on an exclusive diet (dairy free) and unable to provide your body with the sufficient amounts (of calcium) to support your trainings schedule. I only support supplementation in those exceptional cases as supplements can potentially become toxic, interact with or inhibit absorption and metabolism of other minerals or trace elements when taken over a long time and in high amounts. Any supplementation should be used short term only unless supervised by your health professional!

Effects of Age on Physical Performance

Aging is a natural process characterized by gradual morphological and functional changes that occur throughout the human lifespan. In sports, athletes are often classified into distinct age groups, implicitly acknowledging the negative correlation between age and physical performance. However, while some may use aging as an excuse for diminished ability, it is evident that the most successful athletes are not always the youngest, but rather those who dedicate substantial time and effort to their sport and maintain a healthy lifestyle.

The science of aging is intricate, typically explored at the cellular and molecular levels. However, by examining some fundamental aspects, we can better understand the functional consequences of aging on the body and its implications for athletic performance.

Functional Capacity of Organ Systems

In younger individuals, the functional capacity of organ systems typically exceeds the demands of normal daily life by 2 to 10 times. This physiological "reserve" is crucial for adapting to extreme life circumstances, physical exertion, and mental challenges. However, starting at around the age of 30, this reserve begins to decline significantly.

This reduction means that, as we age, functional limitations become more apparent when faced with physical or mental stressors, though they may remain unnoticed during periods of rest. Fortunately, engaging in regular exercise, maintaining an intellectually stimulating lifestyle, and adhering to a balanced diet can significantly delay this decline in functional capacity. These healthy practices mimic physiological stressors, promoting adaptability and preserving function as we age.

Cardiovascular Changes

Although resting heart rates remain relatively similar between younger and older individuals, maximum heart rate during intense exercise decreases with age. For example, a person in their twenties may have a maximum heart rate of 200 beats per minute, whereas an individual at the age of 85 may only reach a maximum heart rate of around 170 beats per minute.

Does this decline explain decreased performance with age? Not necessarily.

The reduction in maximum heart rate—levels at which athletes generally do not perform—can be offset by an increase in heart-minute volume. Heart-minute volume, which refers to the amount of blood pumped by the heart in one minute, can be significantly enhanced through consistent training. Importantly, this measure is not inherently affected by age, but rather by conditioning.

A common cardiovascular issue in older populations is arteriosclerosis, a condition where arteries harden and narrow, hindering blood circulation. It is important to note, however, that arteriosclerosis is predominantly the result of poor lifestyle choices, such as an unhealthy diet and lack of exercise, rather than aging alone.

Respiratory Changes

Aging does bring about both structural and functional changes in the respiratory system. One of the most significant changes is the loss of elasticity in lung tissue and increased rigidity in the thoracic skeletal framework, which together reduce the lung's vital capacity. Additionally, the number of lung capillaries—small blood vessels responsible for the exchange of oxygen and carbon dioxide—declines with age.

Does this have an impact on performance? Yes.

The reduced efficiency of the respiratory system can impair athletic performance, particularly in endurance-based activities. However, regular aerobic exercise can improve respiratory function, helping to mitigate these age-related declines.

Endocrine and Musculoskeletal Changes

The decline in certain hormones, such as testosterone in men and estrogen in women, begins as early as age 25 and continues into advanced age. This hormonal decrease can adversely affect muscle mass, strength, and bone density. However, these effects can be significantly mitigated through regular physical activity, which has been shown to stimulate muscle growth and preserve bone health.

Additionally, aging leads to a reduction in the elasticity of tissues, including tendons, which increases the risk of injury. Despite this, flexibility is not strictly dependent on age, as demonstrated by centenarian yoga practitioners who often exhibit greater flexibility than some teenagers. Incorporating regular stretching into one's routine becomes increasingly important over time to maintain elasticity and minimize injury risk.

Another notable aspect of aging is the gradual dehydration of cells, often referred to as a "lifelong process of dehydration." Proper hydration is therefore critical for maintaining the vitality and mobility of tissues, particularly the fascia, which plays a key role in physical movement and overall wellbeing.

Does this affect performance? Yes—if you neglect exercise, stretching, proper nutrition, and hydration!

Conclusion

As illustrated by these examples, aging does influence physical performance. The natural decline in "functional reserves" is an inherent aspect of aging. However, this decline can—and should—be counteracted by adopting a disciplined approach to health, incorporating regular exercise, a balanced diet, proper hydration, and activities that promote both physical and mental well-being. These habits should ideally be established by the age of 30 to build a strong foundation for the later years.

So, remember: Age is not an excuse!