HANS VAN DIJK | RON VAN MEGEN | GUIDO VROEMEN

THE SECRET OF CYCLING

MAXIMUM PERFORMANCE GAINS THROUGH EFFECTIVE POWER METERING AND TRAINING ANALYSIS

PREMIUM

MEYER & MEYER SPORT

THE SECRET OF CYCLING

Hunter Allen, Legendary Coach and Co-developer of TrainingPeaks' WKO+ software

"When Dr. Coggan and I wrote Training and Racing with a Power Meter, there were some very elite coaches that took this information and became experts around the world. The authors of this book are such experts. They used the laws of nature to describe and calculate the performance in running as well as in cycling. This book will help to take your cycling to the next level and the concepts written inside are foundations to creating success."

Asker Jeukendrup, Sports Nutrition Scientist, Professor of Exercise Science

"One of the best books about endurance performance I have ever seen, with an evidence based analytical approach to performance in cycling. The many practical examples make it easy for the reader to understand and apply this to improve their own performance. The breakthrough of power meters is analyzed critically, including the possibilities to increase cycling economy and cycling performance."

Maria Hopman, Professor of Integrative Physiology, Radboud University, Nijmegen

"I like the quantitative approach to the physics and physiology of cycling in this book. I feel this is important to understand and improve the performance in sports. I believe this book will help coaches and cyclists as theory and practice are combined in a highly understandable way."

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Contents

WHY DID WE WRITE THIS BOOK?

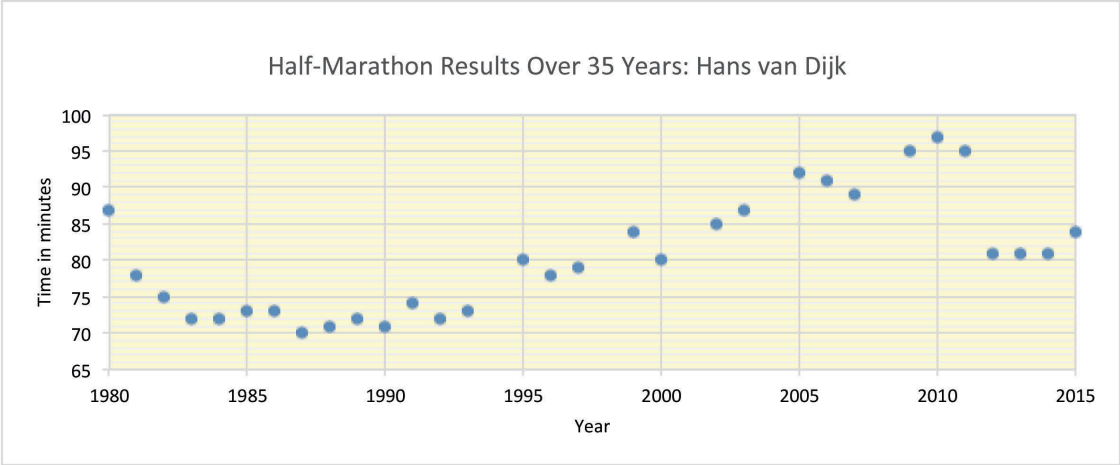
In theory, there is no difference between theory and practice. In practice, there is!

The Success of Our Books on the Dutch Market

Our previous Dutch books[1,2,3] were an instant success in the running and cycling communities in the Netherlands and Belgium. Apparently many thousands of runners and cyclists share our passion to understand, quantify and optimize the power of our human engine and to calculate and predict our attainable performance in sports. More than 10,000 copies of our books have already been sold in the (relatively small) Dutch market. We get tons of enthusiastic reactions from fans, who call our quantitative approach "a revelation in sports books." The calculators at our websites www.thesecretofrunning.com and www.thesecretofcycling.com are visited by many thousands of runners and cyclists, who enjoy calculating how they can optimize their performance.

How to Get Fitter and Faster

We share a lifelong passion for running, cycling and science. The remarkable story of our books starts in 2011 when Hans retired (at the age of 57) from his position as full professor at Delft University of Technology. Hans decided to devote his time to running and studying the science of running to see if he could get fitter and faster. Hans has been a committed runner since 1980, but over the years his race times had declined slowly as shown in the figure below. Obviously, the decline in performance with age will not surprise our readers, but the fact that he got significantly faster after 2011 should! From 2013 onwards he even managed to become a multiple Dutch Masters Champion (M60)! The reasons for this amazing improvement are the topic of our books. You will gain insights into the factors that determine your performance and how you can get fitter and faster.

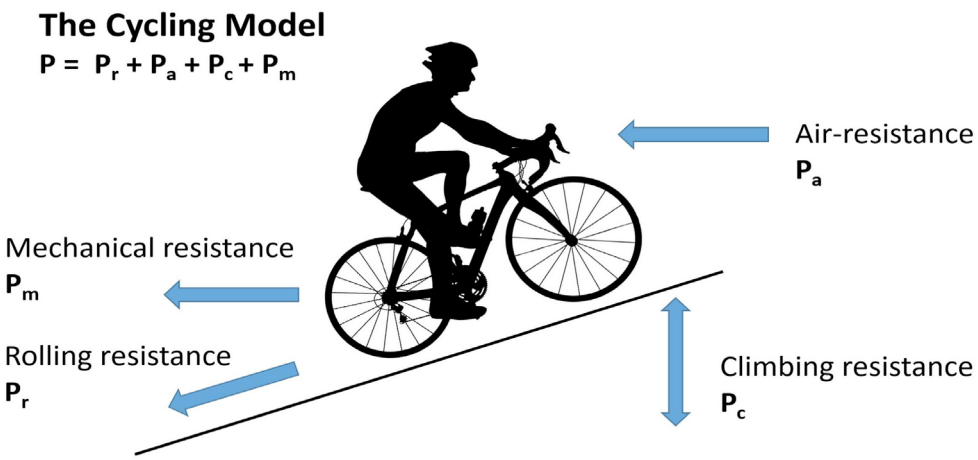


The Quantitative Approach to Sports

As scientists, we were not satisfied with the traditional handbooks on running and cycling which are based mostly on the experiences of athletes and coaches. They do describe the factors which influence the performance, but only in a qualitative way. We were interested in hard numbers and formulas that would enable us to calculate the performance exactly. We also wanted to differentiate between scientific proof and the opinions of athletes and coaches, so we have set out to develop science-based models for all factors influencing the running and cycling performance and to test these models with hard data from measurements.

Cycling Science: The Laws of Physics and Physiology

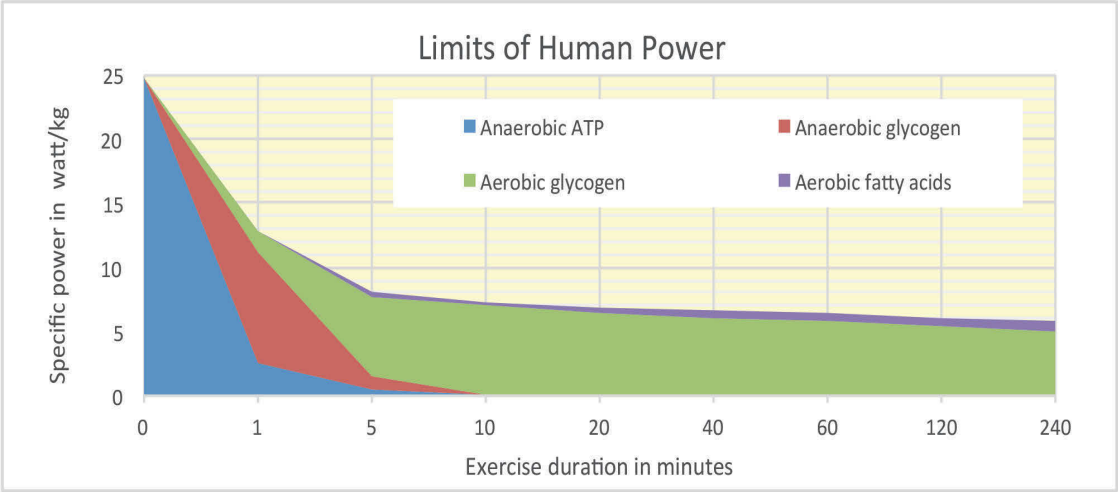
We have developed a complete cycling model based on the laws of physics and physiology. The figure below illustrates the model, which enables us to calculate the race time exactly.



The model is based on the fact that your muscles and your cardiovascular system form your human engine. Your human engine has a certain capacity, which can be described in terms of the traditional notion of oxygen uptake capacity (VO_2 max), but better in terms of the amount of power (P, in watt). Obviously, the power (P) depends as factors such as talent, training, endurance time or distance, altitude, tapering and so on.

In the equilibrium condition, the power of your human engine (P) is used to surmount the rolling resistance (P_r), the air resistance (P_a), the climbing resistance (P_c) and the mechanical resistance (P_m). Consequently, we can calculate your cycling speed and race time when the conditions of the race (such as distance, pavement, wind, temperature, hills, and altitude) are known.

We believe that our cycling model is a major step forward as it is based on the laws of physics and physiology. This applies particularly to our model of the human power. Based on the biochemistry of the four energy systems of the human muscles, we managed to calculate the ultimate limits of human power as a function of time, as illustrated in the figure below.



Our calculations show that these ultimate limits of human power match perfectly well with the current world-class performances in cycling and in other sports, including running.

The Theory of Nearly Everything: How to Calculate and Optimize Your Race Time

We have never met a cyclist that did not want to get faster. Moreover, most cyclists are keen to learn the impact of all factors that may affect their performance. Consequently, in this book we have systematically analyzed the impact of nearly everything on your cycling performance. In 66 chapters, you will find the answers to questions like:

- How big is the power of your human engine?
- How fast can you race with your human engine (both at the flat and uphill)?
- How much slower do you get with age?
- How much faster can you get by shedding body fat?
- How much faster can you get from training?
- How can you optimize your training?
- How much time can you gain from a perfect bike position?
- How much time can you gain from an aero bike?
- How much time can you gain from a lightweight bike?
- How much time can you gain from better bearings and gearing?

- How much time can you gain from high-performance tubes?
- How much time do you lose on account of the wind?
- How much slower do you go uphill and how much faster downhill?
- How can you use power meters?
- How can you optimize your pedaling efficiency?
- What is the ultimate limit of the world hour record?
- What is the ultimate limit of the clean climbing time to the Alpe d'Huez?
- How big is the impact of the air pressure on your race time?
- How big is the impact of the temperature?
- How big is the impact of altitude and training at altitude?
- How much time can you gain from riding together or in a pack?
- How big is the impact of nutrition and carbo-loading?

Who Are the Authors?

Hans van Dijk is a lifelong runner and scientist. Since retiring from a full professorship at Delft University of Technology, he has devoted his time to studying the laws of sports, developing new concepts and models and writing books and columns on running, cycling and other endurance sports. Hans has also developed the running and cycling calculators, enabling the readers to analyze and calculate their own performances. As an added bonus, his research has led to a spectacular improvement in his race times at the age of 60!

Ron van Megen is a lifelong runner, engineer and managing director. He has been a friend and running mate of Hans for over 30 years. He enjoys quantifying his running results and using new running technologies, including power meters. Just like Hans, he is also keen on improving his race times, and was happy to see them go down by 20% at the age of 55! He has organized the production of the book and provided many of the photographs.

Guido Vroemen is a cyclist, triathlete and sports physician. He is the team physician and trainer and coach of the Dutch Pro-Continental Cycling Team Roompot-Nederlandse Loterij. He is the owner of a sports medical and performance centre and combines this with many coaching activities (e.g., elite cyclists, ironman triathletes, the Dutch Triathlon Association). His expertise is in the field of exercise physiology and in training and racing with power meters.

Hans van Dijk (right), Ron van Megen (left) and Guido Vroemen (middle), authors of this book.

Website and Calculators

The website www.thesecretofcycling.com contains many columns, papers, media reports, Q&As and our calculators, which the readers can use to calculate and predict their own race times, depending on many variables. The authors welcome reactions from readers and cyclists around the world, and hope that the readers will enjoy the calculators and give us their feedback!

Hans van Dijk, Ron van Megen and Guido Vroemen

Leusden, the Netherlands, September 2016

PART I

THE BASICS OF CYCLING

1. CYCLING IS GOOD FOR YOU!

I have two doctors, my left leg and my right.
—George M. Treveyan

A Dutch magazine once summarized the advantages of cycling with the headline "Miracle cure within reach!" A daily routine of exercise and cycling indeed provides a miracle cure. The best thing you can do if you want to improve your fitness and health is to become a biker.

A daily ride has an amazing positive impact on your physical and mental health, while a lack of exercise is the single largest health risk in Western society—even larger than the risk of smoking! A paper in The Lancet of July 2012[4] concluded that presently 1 out of 10 people die from insufficient exercise. This adds up to 5.3 million premature deaths worldwide as opposed to 5.1 million from smoking.

Anima Sana In Corpore Sano

The importance of physical fitness has been known through the ages, as evidenced by the above Roman proverb which translates to "A healthy mind in a fit body." Cycling improves your fitness and health in many ways:

1. The daily training has a direct and large positive impact on your physical fitness. Your body will slowly be transformed into that of an athlete.
2. Your habits will automatically become healthier. You will start to eat and drink less and more healthily, you will stop smoking and you will drink only the occasional glass of alcohol.
3. Your blood values and other health indicators will change for the better.
4. Your disease risk will decrease and your resistance to diseases will increase.

Cycling also has a big positive impact on your mental health, as millions of cyclists experience every day. This will be discussed in the next chapter.

Medical professionals and sport coaches know that the human body has a tremendous capacity to adapt to training. By training on a daily basis, you can gradually transform your body. On a long-term basis, your

body gets fitter. Your body is then able to achieve better results with less effort. Many aspects of fitness respond to training, such as endurance, speed, strength, agility and coordination. The box summarizes this miracle of training.

Positive Impact of Training on Physical Fitness

1. The oxygen transport capacity of your heart–lung system increases substantially.
2. Your heart rate drops (both at rest and during exercise).
3. Your heart gets stronger and more efficient.
4. Your blood pressure lowers and your blood vessels become more flexible.
5. Your lungs get stronger and more efficient.
6. Your muscles become stronger (particularly the muscles of the legs, heart and lungs).
7. Your bones become stronger.
8. Your joints stay agile and flexible.
9. The energy production in your muscles becomes more efficient.
10. You lose weight and become leaner.

We have not found any scientific papers detailing why cyclists automatically change their lifestyle, but this is by no means less certain. We have never met a serious cyclist who smokes, and almost all cyclists change their eating and drinking habits after some time. They realize that their fitness and performance will improve when they eat and drink less and healthier. Cyclists are aware of their body and the need to take care of it. You are what you eat!

If You Could Stuff the Impact of Cycling in a Pill, You Could Make a Fortune!

The positive impact of cycling is really amazing. Obviously, you get fitter and your body looks much better. Additionally, many processes in your body change with the result that many blood values and other health parameters get better. The box summarizes the positive impact of training on health parameters.

Positive Impact of Training on Health Parameters

1. Your cholesterol levels change for the better (LDL lower, HDL higher).
2. Your insulin values get better (lower).
3. Your blood glucose values get better (lower).
4. Your bone density increases.
5. Your body fat percentage (BFP) decreases markedly.
6. Your blood volume increases.
7. The level of hemoglobin and myoglobin in your blood increases.
8. The buffer capacity of your blood increases.
9. Your immune system becomes more effective.
10. The hormone levels in your brain change for the better (adrenalin lower, serotonin higher).
11. The enzymes in your muscles become more efficient.
12. The level of uric acid in your blood decreases.

Prevention Is Better Than Cure

Proverbs like "Good health is above wealth" and the above "Prevention is better than cure" sum up the importance of the positive impact of cycling on the risk of disease, as indicated in the box below. No wonder that some health insurance companies offer cyclists a rebate on their premium! In the Netherlands a discount is offered on the use of health centers. Cycling is also used as a therapy in the treatment of mental health issues. In general, cycling is considered to be an excellent therapy for many physical and mental complaints.

Physical and Mental Complaints Positively Affected by Training

1. Heart and coronary diseases
2. Diabetes
3. Osteoporosis
4. Stroke
5. Certain types of cancer (colon, uterus, breast)
6. Certain lung diseases (bronchitis, emphysema and asthma)
7. Depression, fears and stress
8. Rheumatoid arthritis
9. Cystic fibrosis
10. Aging problems
11. Gout

Of course, cycling should not be seen as a panacea to all problems for all people. However, we feel that cycling has strongly improved the quality of our own lives and many others. We hope that you will have the opportunity to try it and experience the advantages for yourself, just like we have.

The best thing you can do if you want to improve your fitness and health is to become a cyclist. Enjoy a workout in the great outdoors, take a shower and feel fit and strong!

2. CYCLING IS FUN!

Every day is a good day when you bike!

Cyclists are positively addicted; they enjoy their sport and rejoice in life and cycling outdoors, preferably in nature. During these rides, you enjoy the splendor of the landscape, which may include stunning heath fields, mysterious forests and historical landmarks. You may spot deer, squirrels, woodpeckers and buzzards, while talking about work and life. When you return home after a couple of hours, you feel tired, but happy and full of beans!

Enjoy the splendor of the landscape, which may include mysterious forests.

Positive Impact of Training on Mental Health and Well-Being

1. You feel better.
2. You sleep soundly and wake up smiling.
3. You become more calm and relaxed.
4. You enjoy your body and your performance.
5. You feel younger and fitter.
6. Your concentration improves.
7. You get good ideas and see things more clearly.
8. You enjoy life and feel more energetic.
9. You feel free and in control of your life.
10. Your willpower increases.
11. You become more resistant to stress.
12. The quality of your life increases.

These are the moments when life is lived most intensely. You experience strong feelings of freedom, happiness and power. Most probably, this is related to some subconscious memories of prehistoric man, who roamed the landscape in search of his prey. The positive impact of cycling on our mental health and well-being is very broad and diverse. They are summed up by the ancient Roman proverb Anima sana in corpore sano, meaning "A healthy mind in a fit body." The box gives an overview of these positive effects and experiences.

Somebody who does not cycle may find it hard to believe all these advantages. But they are experienced by almost everybody who starts cycling! You leave your home, meet the elements and enjoy cycling in the great outdoors. Soon, your body becomes your friend and you feel fitter and happier. Even beginners soon become ambassadors of the sport and advocate the many advantages.

Scientific research has established that the natural hormones endorphin and serotonin are produced during cycling. These are the hormones that stimulate a euphoric senses of happiness, often called a biker's high. Unfortunately, not everybody produces the same amount of these hormones and it may take some time before you feel more happy than tired. But research has shown that the level of endorphin in our brain is definitely statistically increased by cycling. Our ancestors may have needed this in order to escape predators and survive in the prehistoric landscape. We can enjoy the feelings of happiness without the use of drugs. As a matter of fact, most cyclists are pleasantly addicted to their sport.

Cycling can be done at any available time slot and you can do it by yourself, relaxing or meditating, and listening to the birds. It is also great fun to cycle with some friends and chat and exchange ideas. The most serious cyclists join a cycling team. Together with their comrades they travel to the great races, telling tall stories en route and celebrating their performances and successes. One of the nicest things about cycling is that everybody is a winner. You mainly compete with yourself, trying to improve your performance and race times. Once you have made your first progress, your sense of pride and self-esteem will only grow.

There is also a belief that cyclists enjoy happier marriages and do not divorce. Althouigh this has not been studied scientifically, it is true in our own circle of cycling friends!

Finally, cycling is a tested cure for aging problems and guaranteed to improve the quality of the life of the elderly. In many places, cycling therapy is used to improve the mental well-being of senior citizens.

Youngsters and seniors enjoy their sport and rejoice in life and cycling outdoors, preferably in nature.

Former elite cyclist Michael Boogerd, famous for his big smile.

3. SPORTS PHYSIOLOGY

The heart of a cyclist is a superior and more efficient organ.
—Cardiologist Dr. J. Wolffe, MD

In this chapter we will give some background information on the human engine. In short, the human engine comprises of the leg muscles and the cardiovascular (or heart–lung) system, which ensures the supply of oxygen to and the disposal of metabolites from the muscles.

Which factors determine the capacity of the human engine? Which fuels are used by the muscles and how much power can be produced? And what is the impact of training? Training leads to huge adaptations in our body as a result of which we become fitter. In many handbooks[5,6] and papers, this miracle of training has been described. Below, we present a summary of the most important aspects of the human engine.

Training Effects

Consistent and balanced training leads to the following adaptations of the muscles and the cardiovascular system:

1. **Muscles**
   The leg muscles become stronger. There is an increase of:

   - the number of mitochondria (the energy producers of the cells);
   - the number and size of the muscle fibers;
   - the number of capillaries and the blood flow through the capillaries;
   - the stockpile of ATP (adenosine triphosphate) and glycogen;
   - the number and activity of enzymes (improving the breakdown of glycogen and fatty acids).

   Recent research has shown that training can even lead to a modification of the ratio of fast-twitch (FT) muscles to slow-twitch (ST) muscles. As a consequence, both speed and endurance can be improved by training. Such training should be continuous and focused. As a result of the training stress, initially some muscles will be damaged. You can feel this, as your muscles may ache the first days after the training. However, in time your body will react by strengthening the muscles. Consequently, they can better cope with the training load. Training your leg muscles is a protracted process and you have to put many miles in the tank to get the best results. The majority of the training can be done at an easy pace, but in order to develop the FT muscles it is necessary to do some speed work as well.

2. **Heart**

The adaptation of the heart to the training is most remarkable. The number of heart muscle fibers increases and so do the number of the capillaries and the blood flow through the capillaries, in particular those of the left heart chamber. As a result of this, the sports heart is much more efficient than the heart of untrained, sedentary people. We can illustrate this by considering the heart as a pump. The discharge of this pump (called cardiac output or heart minute volume) is the number of liters of blood pumped per minute. This equals the stroke volume (in liters) times the heart rate (HR, in beats per minute). The stroke volume of a trained cyclist can be twice as large as that of an untrained person. Consequently, at rest the heart of a trained cyclist has a large spare capacity and the HR can be quite low. It is quite common for well-trained cyclists to have a resting heart rate (RHR) of 40 or even lower! During exercise, the sports heart is capable of pumping much more blood, leading to an increased oxygen transport to the leg muscles. As the muscles need oxygen to produce energy, this oxygen transport capacity is the single most important factor to determine the performance in sports in general and in cycling in particular. The increase in stroke volume and the corresponding decrease of the RHR are important physiological adaptations of the heart. These adaptations increase the capacity of the heart. The sports heart is able to increase the blood flow during exercise from 5 l/min to 40 l/min, thus by a factor of eight. This is achieved by a combination of the increase in the stroke volume and the HR. The adaptation of the sports heart depends mainly on the intensity of the training (a high HR and thus a high intensity of the training is required) and can occur relatively quickly. It is possible to achieve a significant reduction in the RHR in as little as six weeks.

3. **Blood**

The blood volume of a well-trained cyclist is some 10% larger than that of an untrained person. This is mainly caused by an increase of the plasma volume. Of course this increase has a positive impact on the oxygen transport capacity. Another important adaptation is an increase in the flexibility of the blood vessels, leading to a decrease in blood pressure. The blood composition also changes: the cholesterol levels decrease, in particular those of the bad LDL and the total cholesterol. The good HDL increases. The level of hemoglobin may increase as a result of altitude training. Hemoglobin is vital for the oxygen transport by the blood. One gram of hemoglobin can transport 1.34 ml oxygen (O_2), so an average hemoglobin level of 15 g/100 ml blood leads to an oxygen transport capacity of 15*1.34 = 20 ml O_2/100ml blood or 20%. A low level of hemoglobin may indicate an iron deficiency in the nutrition or increased iron loss. A high level of hemoglobin may be the result of blood or EPO doping. Finally the blood vessels dilate during exercise, leading to a reduction of the peripheral resistance and an automatic increase of the blood flow to the leg muscles. Less blood is diverted to nonessential body parts, such as the digestive system.

4. **Lungs**

As a result of training, your breathing muscles become stronger and the tidal volume (functional lung volume) increases. We illustrate this in the same way as we did for the heart: by considering the lungs as a pump. The capacity of this pump (called respiratory minute volume) is the tidal volume (in liters) times the breathing frequency (in breaths per minute). At rest, we breathe around 10-15 times per minute and the tidal volume is around 0.5 liter, so the respiratory minute volume is 5-7.5 l/min. During exercise, the respiratory minute volume can increase dramatically to 180-200 l/min for well-trained athletes. This is the result of an increase of both the breathing frequency (to 60 breaths per minute) as well as the tidal volume (to 3-4 liters). The increase in the capacity of the lungs is even larger than that of the heart, so the lungs are usually not the limiting factor. Consequently, we can conclude that normally the oxygen transport capacity of the cardiovascular system is the main factor that determines the performance in endurance sports. However, we should remark that the breathing muscles themselves need a significant amount of oxygen. This can amount to some 10% of the maximum oxygen transport capacity or VO_2 max.

Energy Systems

In order to cycle we need energy. This energy is produced in our muscle cells, to be precise in the mitochondria. The cells can do this by using any (or a combination) of the four following energy systems:

1. **ATP**

   Adenosine triphosphate (ATP) is the primary fuel for sprinters. ATP can be transferred to ADP very quickly, releasing a large amount of energy and thus providing the muscles with the largest amount of power. Moreover, the process does not require oxygen. However, the stockpile of ATP in the muscles is extremely small, lasting only for a short sprint of some 10 seconds. During recovery, the muscle cells are able to regenerate the ATP from the ADP. This process requires energy, which has to be supplied by the aerobic (using oxygen) breakdown of glycogen. The amount of oxygen needed to regenerate the ATP is called the oxygen debt. So, the energy debt is created during exercise and needs to be redeemed during recovery. As a result of training the efficiency of the stockpiling and the use and recovery of ATP can be increased. This requires many repetitions of short sprints at top speed.

2. **Anaerobic glycolysis**

   The anaerobic breakdown of glycogen or glycolysis is the most important energy system for breakaways and prologues, lasting a few minutes. Glycogen is composed of large chains of glucose (sugar) units. Glycogen is stored in the muscles and the liver. The blood also contains a small amount of glycose. Glycogen can be broken down anaerobically (without the use of oxygen) into lactic acid. This lactic

acid may accumulate and cause exhaustion and pain in the muscles. During recovery, the lactic acid can be broken down using oxygen, thus redeeming another oxygen debt. With training the efficiency of the glycolysis can be improved. This requires training at a high intensity so that lactic acid is accumulating. This occurs only at a high HR, around 85-90 % of the maximum HR (MHR). This is called the anaerobic limit or threshold limit. The anaerobic breakdown of glycogen produces less power than the ATP system, but it is somewhat more durable. The time to exhaustion is a few minutes, depending on the speed and fitness.

3. **Aerobic breakdown of glycogen**

The aerobic breakdown of glycogen is the main energy system for endurance athletes, including cyclists. Glycogen is broken down into carbon dioxide and water, using oxygen. The carbon dioxide is removed from the muscles by the blood and the lungs. The oxygen is supplied to the muscles by the lungs and the blood. This is a very durable process that can be maintained for a very long time when the oxygen transport capacity of the cardiovascular system is large enough. This oxygen transport capacity can be increased by training at an intensity just under the anaerobic or threshold limit. Training at a lower intensity (e.g., 70% of MHR) is also useful as it stimulates the muscles themselves. The aerobic breakdown of glycogen produces less power than the glycolysis, but the stockpile of glycogen lasts for at least 1.5 hours. With training and optimized nutrition (e.g., carbo-loading), this period can be increased to 2-3 hours.

The Dutch time trial king Tom Dumoulin in the Grande Partenza (prologue) of the 2016 Giro d'Italia in Apeldoorn.

4. Aerobic breakdown of fatty acids

The aerobic breakdown of fatty acids is the main energy system for cyclists and triathletes. Fatty acids are broken down into carbon dioxide and water, using oxygen. Consequently, this system is quite comparable to the previous one (the aerobic breakdown of glycogen). The main drawback is that it produces less power. This is the reason for the well-known phenomenon of hitting the wall. This happens when the stockpile of glycogen in your muscles is exhausted, so the muscles have to transfer to the breakdown of fatty acids. From that moment onwards, your power output is greatly reduced and your speed drops dramatically. The main advantage of the breakdown of fatty acids is that the stockpile is extremely large and sufficient to cycle for many days. We use this system during rest and when exercising at low intensities. When the exercise intensity increases, our muscles switch to the other systems. This depends on the required amount of power: so first fatty acids, then glycogen, then glycolysis and finally ATP. The efficiency of the fatty acid system can also be improved by training. This should be done by long rides at low intensity (less than 70% of your MHR). Eating less carbohydrates may also help, as well as early morning trainings prior to breakfast. We should realize that the fatty acid system is used by all cyclists at low and moderate intensities. When we ride slowly, the amount of fatty acids in the fuel mix of our muscles may be as high as 90%. At threshold pace this percentage may be only 25%.

The box summarizes some important aspects of the 4 energy systems of the human engine.

1. **ATP**

ATP → ADP + energy

Small stockpile, 10 seconds, sprint, maximum power and speed

2. **Glycolysis**

Glycogen → Lactic acid + energy

Limited time to exhaustion, few minutes, breakaways, high power and speed

3. **Aerobic breakdown of glycogen**

Glycogen + $6O_2$ → $6CO_2$ + $6H_2O$ + energy

Large stockpile, 1.5 hours, long distance, endurance power and speed

4. **Aerobic breakdown of fatty acids**

Fatty acids + $23O_2$ → $16CO_2$ + $16H_2O$ + energy

Very large stockpile, many days, ultra-distance, low power and speed, higher oxygen use

The theory on the human engine applies to all endurance sports. The performances of elite cyclist Robert Gesink (left) and multiple world champion speed-skating Sven Kramer (right) can be compared with our unified model.