OVERVIEW

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Physiology – Its role in explaining athletic performance

by David E. Martin

The article begins with a definition of the science of physiology and a description of the fundamental physiological concept concerning the constancy of the fluid bathing all the cells of the body and the various ways in which this constancy is maintained (homoeostasis). From a general description of the various regulatory processes concerned, leads to the important concept of adaptation and its specific effect on athletic performance. Many examples of adaptations favourable to physical performance are discussed and their physiological bases explained in clear, easily understandable language.

The author comments upon the problems of undertaking research into the complexities of the nervous system in relation to athletic performance and how much more needs to be known in this field. He finishes with a plea for a better co-operation between physiologist and coach, to blend the science of the one with the artistry of the other, in order to 'extend the limits of human performance'.

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Physiology is analogous to anatomy in the same way that history relates to geography. Anatomy and geography describe the *Scene* of events, but the *Action* that occurs is the substance of physiology and history. As such, physiology – the study of how the cells and organ systems of the body perform their functions – is one of the most fundamental of medical and biological disciplines. This is the 'how' discipline: how the heart beats, how muscles shorten and lengthen, how the intestine absorbs nutrients, how we breathe, how organ systems and cells respond when they are stressed, and more. Its relevance to an athlete attempting to be the best should be obvious. As a scientific discipline, physiology has a conceptual framework upon which facts regarding the particular cells and organs in question are placed.

The first fundamental concept that identified physiology as a discipline was formulated in 1859 by the Frenchman Claude Bernard. This was the realization of a constancy of the fluid environment bathing all the cells in the body. Whatever changes might occur as a result of a temporary deviation from the normal composition of body fluids, such as dehydration with endurance exercise or blood lactic acid accumulation with intensive work, compensatory physiological mechanisms should ensure a rapid restoration of the normal fluid milieu, both surrounding and within the cells. Thus, in response to the two changes cited above, drinking replenishes the fluid lost and increased breathing, after the exercise, provides the additional oxygen for complete metabolism of the lactic acid as fuel. Such continually maintained constancy over time is fundamental to the survival of the species.

Physiologists devote their careers to the identification of these so-called dynamic, self-regulating processes, which maintain an essentially constant internal environment. The American physiologist Walter B. CANNON in 1933 coined the term homeostasis to describe these processes. The most typical kind of homeostatic control mechanisms functions with what has been termed a negative feedback type of control. Thus, the stimulus which initiated the compensation (for example, drinking) is removed after restoration of the normal resting environment (body fluid concentration).

Several other physiological principles help to explain the function of organs and cells. One principle is that of continual renewal of structure, while still ensuring constancy in function. A few examples may already be familiar. The cellular lining of the gastrointestinal tract is continually being replaced with healthy, functional cells, without impairing the ongoing function of this system in the absorption of nutrients. The respiratory tract has a constantly moving layer of mucus flowing along its surface, transporting debris, humidifying the inspired air and preventing invasion by foreign microbes. Mucus is continuously produced by the respiratory tract lining cells. It moves towards the entrance to the oesophagus, where it is then swallowed and removed through digestion.

Another concept is that of adaptation by the body tissues, when their normal function is challenged. An immediate response results from the altered environmental situation, which may also cause a long-term adaptation of positive benefit. One familiar example is altitude acclimatization. Compared to those at sea level, cities at even moderate altitude, such as Denver (1,609m), Johannesburg (1,753m) or Mexico City (2,300m), have a sizable reduction in barometric pressure. This decreases the available inspired oxygen which is essential for aerobic metabolism. The resulting hypoxia (low tissue oxygen) triggers the appropriate homeostatic response, to compensate for this decreased available environmental oxygen. Within a few days, increased release of a hormone produced in the kidneys (erythropoietin) stimulates the bone marrow to accelerate its production of red blood cells. About one third of the volume of these cells is composed of haemoglobin, which is responsible for transporting fully 98.5% of the blood's oxygen. Thus, within a few weeks, the increased quantity of haemoglobin, due to the additional red cell population, helps to restore normal oxygen transport capabilities.

Other examples of adaptation are probably also familiar. One example is the increase in skeletal muscle mass, seen when field-event athletes embark on a serious strength-training programme. This increase in muscle mass represents an increase in the number of protein molecules within the already existing muscle cells (hypertrophy), rather than an increase in the number of muscle cells (hyperplasia). Another example is the increase in stored glycogen in the liver and skeletal muscles of marathon runners, following a long energy-depletion run. If the energy depletion is sizable, which occurs when these athletes prepare for a marathon competition, not only will they replenish the glycogen lost, once they begin eating after their period of depletion but they will also actually store more than they had before their depletion run. This is literally a super-compensation, suggesting a response to prevent a recurrence of a similar starved situation. It provides a very beneficial energy reserve for long distance races.

Training produces other physiological changes in the working muscles of distance runners. There is an increase in the size and number of mitochondria within the muscle cells. Contained within these mitochondria are the enzymes required for fuel metabolism. An increase in enzyme content increases the maximum rate of aerobic breakdown of fuel, thereby increasing the running speed that can be maintained without entering into acidosis. An increased number of capillaries eventually surrounds these endurance-trained muscles. This allows oxygen to diffuse in more quickly and easily and also facilitates the removal of the products of anaerobic metabolism (such as lactic acid). The end result is a higher rate of total metabolism and a quicker sustainable pace.

Another principle is that of symmorphosis. This relates to the extent of adaptation, which will not be in excess of needs but just sufficient to meet the particular challenge applied (the training load). Thus, strength-training athletes will increase their functional muscle mass only enough to permit easy management of the loads they apply in training. The concept of progressive resistance/overload in strength training, therefore, has its physiological basis in this need for a gradual increase in the size of the stimulus, due to the ongoing adaptation to the increased load applied. The reason for such limitation to adaptation is logical. It would be metabolically too costly to 'over-adapt'.

The body is thus an amazing example of a self-optimizing machine. Some well known examples make this more clear. We know that the quantity of blood pumped into the vascular system by the heart is determined by the product of heart rate and volume per beat (stroke volume). We also know that the greater part of the blood flowing into the cardiac muscle, to ensure its nutritional needs (the coronary vessel flow), actually does so primarily during the resting phase of the heart (i.e. between heart beats). It is most interesting that one of the adaptations of marathon training is an increase in the size of the ventricular chambers. The increased stroke volume, together with a lower heart rate, in order to maintain a very high level cardiac output, also provides optimum heart muscle perfusion – the time in between beats even during exercise is still fairly long.

There are other cases where oxygen system performance is determined by two primary factors, each of which has its own limitations. In raising the level of performance, it is more efficient to increase the contribution of both factors – each well within their limits – than it is to rely on stressing only one factor excessively. A runner, for example, when accelerating, increases both breathing and forward speed. Breathing volume is the product of the number of breaths per minute and the volume of air with each breath. Running speed is determined by the number of strides per minute and the distance covered with each stride. Increasing only breathing rate or only stride frequency is too energy costly, when the work load becomes intensive. It is more efficient to increase both the frequency of breaths and the volume of each breath – and both the length of each stride and the frequency of strides. The body self-optimizes: that is, it automatically selects the most energy-efficient combination of breathing rate/volume and stride frequency/length to manage the workload.

It is easy to develop a fascination for identifying explanations, which describe how the human body adapts favourably (or unfavourably) regarding many other stresses of training. Such studies can be quite challenging, however, because there is a large individual variability in responsiveness, not only to the environment but also to training. As just one example, there is individual variation in how our air passageways respond to the presence of cold, dry or rapidly moving air. For most of us, the small airways (bronchioles) remain open and fully functional. However, for others, they can contract severely and impair breathing efficiency. This so-called exercise-induced bronchospasm can be controlled with appropriate medications, which have been developed to modify the altered physiological functioning of the processes which regulate airway diameter.

As another example, an interesting relationship exists in women between blood oestrogen levels, total body fat, the menstrual cycle and bone mineral density. An unfortunate opinion held by many women athletes, especially in endurance events, is that to win, one must be thin. This results in a tendency to decrease food intake so as to provide weight loss. This is an enormous stress, for the body then enters into a semi-starvation state. The stress can be sufficient to cause a disturbance of the menstrual cycle and the monthly rise and fall in oestrogen hormone levels. Oestrogens are crucial for ensuring adequate bone mineralization. Months or years of inadequate nutrition, loss of bone mineral content and hard training result in increased risk of stress fractures. A complete understanding of the various factors involved in maintaining an optimum balance between good nutrition, low-but-adequate body fat, the normal menstrual cycle and a bone mineral density adequate for the prevention of injury is the best basis for the achievement of long-term athletic success.

One can imagine that there are innumerable cases of physiological processes determining performance. Up to now, the nervous system has not been mentioned, but here some of the most fascinating unsolved physiological questions remain. In physical activity, the nervous system must acquire information about ongoing movements of the body and use this information to determine the next movements. In events requiring specialized technique, this challenge is enormous. Consider the task of elite high jumpers, who are approaching the bar head-on, at almost sprint speed. They then must turn very sharply, suddenly stop their horizontal momentum and now convert this to vertical momentum. The combination of movements in three planes will provide a rotation which, if executed perfectly, provides a back layout, with the athletes lifting their centre of mass many centimetres higher off the ground than their standing height. What physiological processes co-ordinate the muscular, skeletal and nervous system activity, which permits this complicated interaction to be repeated flawlessly, in many different environmental conditions? And how can these processes be analyzed, to permit the athlete either to perform even better or perhaps emerge from a temporary slump, when subtle imperfections cause missed bar clearances? Much is known but much needs yet to be learned.

Although the study of high-level human performance physiology dates back many decades, in the early days very few laboratories were involved. In the 1920's, physiologists, at such facilities as the Harvard Fatigue Laboratory, were concerned primarily with the scientific study of challenging work environments, with a view towards providing practical guidelines for occupational safety. In this context, some of the pioneering studies on work output in excessively cold, warm or humid environments, as well as at altitude, were conducted. Systematic studies of athletic performance, however, were relatively rare in those days. One of the more well-known studies, involving seven-time Boston Marathon winner Clarence DeMar, was conducted at the Harvard laboratory during the 1920's. His treadmill runs, under scientific supervision, formed some of the original studies describing the dynamics of lactic acid production during intense exercise. The data collected from him indicated an incredible performance potential. However, the scientists were unable to satisfy his desire to improve even further his athletic skills, because they could not practically interpret his laboratory data to design an optimal training plan.

Such a challenge remains true today. Physiologists marvel at the extent to which athletes in hard training demonstrate remarkable adaptive responses – physiological changes – in response to hard work. However, as they are seldom interested in the training of athletes, it remains difficult for them to 'translate' their scientific knowledge into practical wisdom for the athletes who were studied. Similarly, coaches are quite often not very knowledgable about anatomy and physiology, as they relate specifically to organ and cellular adaptation to stresses such as those of arduous training. Training plan design then becomes increasingly subject to the risks of inappropriate loading of tissues – with injuries, excessive fatigue and anaemia just a few of the possible end results, which could compromise performance. A goal for the future will be for a better 'coming-together' of the disciplines of coaching and physiology.

A more effective sharing of each other's expertise – the artistry of the coach, in blending the various types of physiological stressors that will improve the athlete's performance, and the science of the physiologist, in explaining precisely what kinds of stressors will bring the optimum adaptation – will go far towards exploring and extending the limits of human performance. Teaching athletes to train around their excellence instead of around their injuries can and ought to be a stimulating challenge for both coaches and physiologists.