SPORTS PHYSIOLOGY

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PREFACE

The application of science, particularly physiology, to sports has been shown over the years to be significant in improving general physical condition and specific athletic performance. This book was written with this in mind. The emphasis has been placed on the *applications* of physiology rather than on physiology itself. Accordingly, only those physiological principles that are deemed most necessary for direct applications to sports and performance are included. Often the applications of scientific principles do not demand extensive background coverage, but rather only a practical presentation commensurate with an understanding of what is safe and effective. The idea of practicality was adhered to whenever and wherever possible. Topicality is given its due as well. Two subjects of great current interest — age and sex, as variables in performance — have been included in discussions throughout the book (rather than in separate chapters).

The coaching of a sport or the teaching of a motor skill is both an art and a science. As such, coaches and physical educators must have competency in both teaching and scientific application. It is to this latter point that this book is dedicated, for it is sincerely hoped that the physiological material presented here will significantly contribute to teaching, coaching, and athletic success.

EDWARD L. FOX

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ENERGY — THE NAME OF THE GAME

INTRODUCTION

Perhaps the most valuable concept relating science to physical education and athletics is *human energy production*. The importance of this concept becomes obvious when one stops to think about how versatile the human body is with respect to the kinds of movements and sports activities it is capable of performing. The activity spectrum, for example, spans the range of human movements from those requiring large bursts of energy over short periods of time to those activities requiring small but sustained energy production. Even within the same activity, the energy requirements change from one moment to the next.

One of the purposes of this chapter is to show how the understanding of energy concepts can be applied to sport and physical education. A second purpose is to develop the concept of human energy production as it relates to these applications.

APPLICATIONS OF ENERGY CONCEPTS

Five important applications of energy concepts to sports and physical education will be outlined here.

Application One — The Construction of Physical Training Programs

In order for a training program to have the most beneficial effects, it must be constructed to develop the specific physiological capabilities required to perform a given sports skill or activity. One of these capabilities involves the supplying of energy to the working muscles. For example, the way in which energy is supplied during sprinting differs from that during the running of a marathon. As a consequence, training programs designed to improve a given type of performance must be constructed so as to increase the type of energy supply specific to that performance.

Training must also take into account physiological capabilities involving specific kinds of muscle fibers found in most human muscles. Basically, there are two types of fibers or motor units — one suited for high power output activities (called fast-twitch, or FT) and the other for low power output activities (called slow-twitch, or ST). For our purposes, we may think of most human muscles as containing a mixture of "sprint" and "endurance" fibers. This kind of specificity is in part related to the difference in energy potential between the two fiber types.

Application Two — The Prevention and/or Delay of Fatigue

Understanding how energy is produced within the body will provide us with some insight into what fatigue is and how it can be delayed or in some instances even avoided during performance. As an example, almost everyone has seen a runner lead the pack for the first part of a race but end up nearly last at the finish. In this case, running too fast at the beginning of the race causes fatigue to set in, preventing the runner from "kicking" at the finish. This kind of "early" fatigue is related to the way in which energy is produced and can be avoided or at least delayed through proper pacing.

Application Three — Nutrition and Performance

Recently, new information regarding nutrition and performance in humans has become available. For example, it has been found that endurance performance can be improved following several days of diets rich in carbohydrates. Likewise, the ingestion of glucose in low concentrations during extremely long performances (e.g., 3 or more hours) has been found to correlate with improved endurance performance and the delay of fatigue. Even the ingestion of a fatty meal several hours prior to exercise has been experimentally shown to increase endurance performance and delay fatigue. Applying these findings to sports involves an understanding of which foods are preferentially used for energy by the muscles and how the dietary regulation of these foods affects their availability as energy fuels.

Even with the latest research, serious questions regarding nutrition and performance remain. Several may have come to your mind. What, for instance, is the protein requirement of athletes engaged in heavy physical training? What about surplus iron, salt, vitamins, and so on? Do they affect energy production? Are they essential for good athletic performance? What should the pre-game meal consist of? It is hoped that an understanding of the complexities of nutrition will help you appreciate why such questions can sometimes have differing answers.

Application Four — The Control of Body Weight

One of the most important concepts regarding the control of body weight is *energy balance*. Quite simply, if more energy in the form of food is taken in than expended in the form of activity or exercise, the body weight will increase. The converse is also true. In most sports, maintenance of a desirable body weight is essential to continued good performance. Controlling energy balance and body weight necessarily involves principles of nutrition and body composition. For example, understanding the energy value of foods and the difference between weight loss due to dehydration and that due to loss of body fat will enable you to adopt scientifically sound practices regarding desirable body weight and nutritional habits. In particular, recognizing the difference between weight reduction due to water loss and that due to fat loss will allow you to recommend exercise programs that will not jeopardize the health and safety of your athletes.

Application Five — The Maintenance of Body Temperature

A stable body temperature requires that the amount of heat (energy) produced by the body equals the amount of heat given off to the environment. During exercise, heat production increases in direct proportion to the amount of work performed. To prevent an excessive rise in an athlete's body temperature during exercise, the coach has to recognize that the effectiveness of the heat loss mechanisms, particularly the evaporation of sweat, must not be inhibited by excessive clothing or athletic equipment. Football coaches who insist that their players wear full uniforms during practice sessions on hot, humid days are greatly increasing the chances of heat stroke, which if severe enough can be fatal. Certainly no coach would ever knowingly jeopardize the life of any athlete.

Each of the above applications will be discussed in further detail elsewhere in the book. Our next concern will be to develop the concept of human energy production as it relates to the above applications.

DEFINITIONS

Three components of human energy production require formal definitions: energy itself (and some of its forms), work, and power.

Energy

Energy is described as the capacity or ability to perform work. While the definition is simple, the concept of energy is not necessarily easy to grasp.

We are interested mainly in only two of the six forms of energy—*mechanical* and *chemical.* In baseball, a swinging bat performs mechanical work by virtue of its motion. The same is true of the golf club, the tennis racket, or other such sports tools. In like manner, mechanical work can be performed by acceleration of the center of gravity of the body in a frontal direction, such as in running. Energy associated with motion is known as *kinetic energy.* Mechanical work performed by virtue of position, such as a bent bow in archery or lifting the body against gravity, is a result of *potential energy.*

Chemical energy also represents a source of potential energy. For example, in the body, foodstuffs are degraded through chemical reactions, releasing chemical energy, which in turn is used to synthesize other chemical compounds. Some of the latter compounds are called "energy-rich" compounds; when broken down, these compounds release chemical energy that is used by the skeletal muscles in performing mechanical work. Notice that we are back to mechanical work or energy. In other words, some of the chemical or potential energy represented by the foods we eat is converted to mechanical or kinetic energy by the skeletal muscles.

The most common unit of measure of energy is the *calorie.* A calorie is the amount of heat energy required to raise the temperature of one gram of water one degree centigrade. A *kilocalorie* (kcal) is equal to 1000 calories and is the unit most often used in describing the energy content of foods and the energy requirements of various physical activities.

Work

Since energy is the capacity to perform work, the definition of work becomes important in understanding the total energy concept. Quantitatively, mechanical work (W) is the product of a force (F) acting through a distance (d). In mathematical form:

$$W = F \times d$$

Work = force times distance

As an example, if you weigh 70 kilograms (force) and you ascend a flight of stairs 2 meters in height (distance), you will have performed 70 kg × 2 m = 140 kg-m of mechanical work. Energy and work have the same units of measure; in our example, 140 kg-m is equivalent to 0.33 kcal or 1,012 foot-pounds.

Although the terms work and energy may be used interchangeably, it should be pointed out that it is possible to expend energy but perform no mechanical work. For example, holding a weight at arm's length requires energy, but no mechanical work is performed while the weight remains stationary.

Power

Power (P) is work per unit time (t), or:

$$P = W/t = (F \times d)/t$$

From our earlier example, if you ascended the flight of stairs in one second (t), then you would have generated (70 kg × 2 m)/1 = 140 kg-m/sec of power.

The importance of power in athletics can be readily appreciated. In most sports activities, the greatest energy produced in the shortest period of time is a prime factor in a successful performance. This is true, for instance, of jumping, running (particularly sprinting), and throwing. One of the most frequently used screening tests for potential success in football at any position is the time of the 40-yard dash (from a standing start). The reason for this, of course, is that the 40-yard dash is a test of power — and the ability to generate power is obviously necessary for football performance.

A summary of the definitions and common units of measure for energy, work, and power is given in Table 1–1.

THE ENERGY SYSTEMS

As was mentioned earlier, various sports activities involve specific demands for energy. For example, sprinting, jumping, and throwing are high power output activities, requiring a relatively large production of energy over a short period of time. Marathon running, distance swimming, and cross-country skiing, on the other hand, are mostly low power output activities, requiring energy production over a

TABLE 1–1. DEFINITIONS AND COMMON UNITS OF MEASURE FOR ENERGY, WORK, AND POWER

Term	Definition	Common Units
Energy	capacity to perform work	calorie, kcal
Work	product of a force acting through a distance	kg-m, ft-lbs, kcal
Power	time rate of performing work	kg-m/sec, ft-lbs/sec, kcal/sec, watts

prolonged period of time. Other sports activities, as we shall soon see, demand a blend of both high and low power output. These various energy demands can be met because there are three distinctly different ways in which energy can be supplied to the skeletal muscles.

The Immediate Energy Source — ATP

Adenosine triphosphate, or, more simply, ATP, is the immediately usable form of chemical energy for muscular activity. This is one of the most important of the so-called "energy-rich" compounds mentioned earlier. It is stored in most cells, particularly muscle cells. Other forms of chemical energy, such as that available from the foods we eat, must be transferred into the ATP form before they can be utilized by the muscle cells.

The chemical structure of ATP is complicated but for our purposes can be simplified as shown in Figure 1–1A. As you can see, ATP consists of a large complex of molecules called adenosine and three simpler components called phosphate groups. The last two phosphate groups represent "high energy bonds." In other words, they store a high level of potential chemical energy. When the terminal phosphate bond is broken, as shown in Figure 1–1B, energy is released, enabling the cell to perform work. The kind of work performed by the cell depends on the cell type. For example, mechanical work (contraction) is performed by muscle cells (smooth, skeletal, and heart muscle), nerve conduction by nerve cells, secretion by secretory cells (e.g., endocrine cells), and so on. All "biological" work performed by any cell requires the immediate energy derived from the breakdown of ATP. (The amount of energy released in the body per *mole* of ATP broken down is estimated at 7 to 12 kcal. A mole is a given amount of a

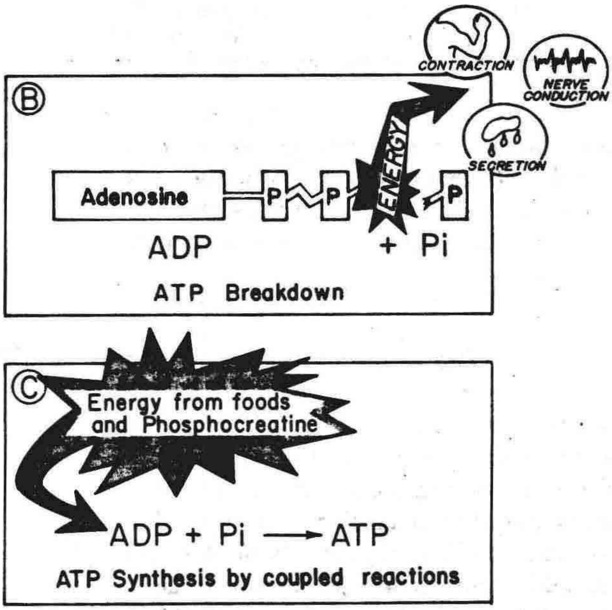

Figure 1–1. (A) ATP consists of a large molecule called adenosine and three simpler components called phosphate groups. (B) The energy released from the breakdown of ATP is used to perform biological work. The building blocks for ATP synthesis are the by-products of its breakdown, adenosine diphosphate (ADP) and inorganic phosphate (Pi). (C) The energy for ATP resynthesis comes from the breakdown of foods and phosphocreatine. This energy is *coupled* with the energy needs of the reaction that resynthesizes ATP.

chemical compound by weight; the weight is dependent upon the number and kind of atoms making up the compound.)

The Principle of Coupled Reactions

Since energy is released when ATP is broken down, it is not too surprising that energy is required to rebuild or re-