Edited by
Gerald Finerman

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Symposium on
Sports medicine
The knee

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Symposium on
Sports medicine: the knee

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Symposium on

Sports medicine: the knee

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Preface

The fitness explosion in this country has resulted in the public's increasing involvement in recreational sports. Unfortunately, an estimated 25 million people are injured each year while participating in these recreational activities. Studies indicate that the knee is the most commonly injured area of the body and possibly accounts for over 45% of sports-related injuries.

This course, sponsored jointly by the American Academy of Orthopaedic Surgeons and the National Institutes of Health, was held in Denver, Colorado, April 30-May 2, 1982, in an effort to bring together the most current scientific and clinical sports medicine research relating specifically to knee injuries. The authors' presentations stress meniscal injuries, ligamentous instability, and cartilage damage. Biomechanical information with relevant basic science is included, as well as a discussion of surgical techniques and alternative treatments.

As chairman of this symposium, I wish to thank the authors for their generous efforts in preparing this course and these papers.

Gerald Finerman, M.D.

Contents

PART ONE

Functional principles

1. Physiologic basis for athletic training

Peter Snell

Human physical performance depends on a large number of physical, psychologic, and environmental factors (Fig. 1-1). These factors affect performance to an extent that is largely determined by the nature of the task to be accomplished. Training programs are generally designed for the specific requirements of a particular athletic

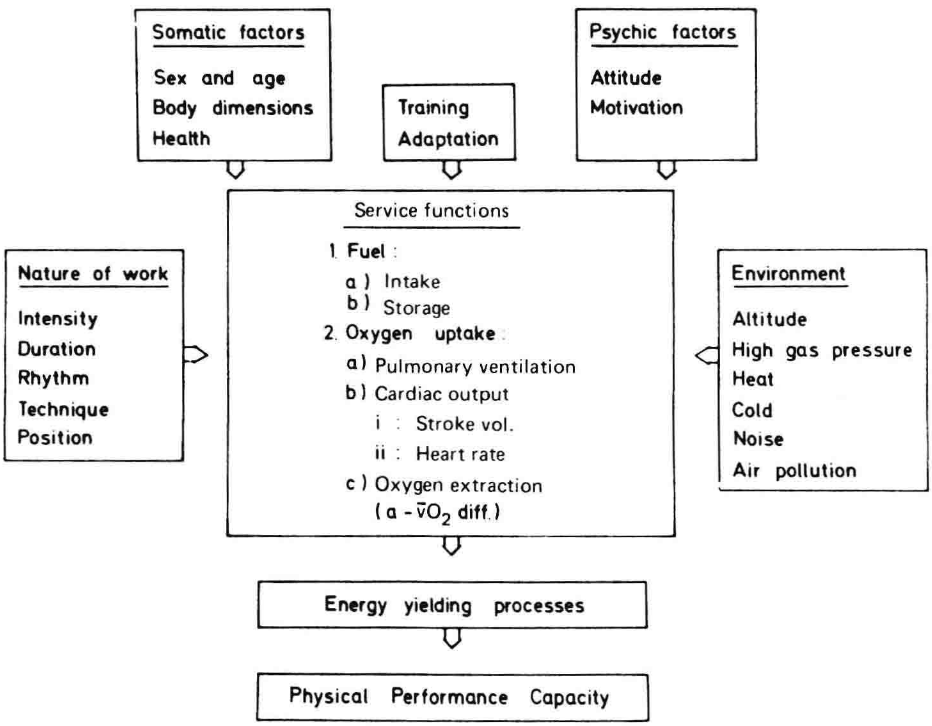

Fig. 1-1. Factors affecting physical performance capacity. (From Astrand, P.O., and Rodahl., K.: Textbook of work physiology, New York, 1970, McGraw-Hill, Inc.)

event. Because athletic performance has multiple determinants, understanding, measuring, and evaluating the relative contribution of each physical component should lead to a more rational approach to training.

Historically, coaches and athletes assess speed, strength, and endurance by using empirically derived criteria. This approach has been successful, since few insights or training innovations originated from physiology laboratories; instead researchers have been active in documenting the physical characteristics of individuals who are successful in various sports. These studies include descriptions of anthropometric features[15,60] and measurement of physiologic function.[11,16,49,52] While these studies have been important in identifying the physical qualities needed for top-level performance, the goal of research now tends toward a better understanding of the nature of the adaptive response, the mechanisms involved in fatigue, and the means by which physiologic function and characteristics may be modified.

Although the development of endurance in running and cycling has been most studied in the laboratory, the principles offered here may be applied to other endurance activities such as swimming, rowing, and cross-country skiing.

METABOLIC COMPONENTS OF PERFORMANCE

Muscular contraction requires energy in the form of adenosine triphosphate (ATP), and performance in any running event may be considered in terms of the amount of ATP that the athlete produces and uses during the race. ATP production involves processes that will ultimately require oxygen. Therefore the ability of the body to use oxygen and to acquire an *oxygen debt* provides a means of assessing the capacity for energy production.

Aerobic metabolism

The relationship between oxygen uptake ($\dot{V}O_2$) and increasing levels of work is linear until reaching a point when increases in the work rate do not result in any increase in $\dot{V}O_2$ (Fig. 1-2). This plateau of $\dot{V}O_2$ indicates the maximal rate of total body use of oxygen, and in healthy persons it is limited by the capacity of the oxygen transport system to deliver oxygen to the working muscles.[44,45,51,58,61] The primary factor in oxygen transport is the cardiac output ($\dot{Q}$), and a high $\dot{Q}$ depends on a high stroke volume. Data from world class middle-distance and long-distance runners.[49,54,62] indicate that values in excess of 70 ml/kg/min are needed for success. This corresponds to a running speed of approximately 350/min or 4½ min/mile. Thus events up to 3000 meters are run at speeds equal to or greater than that necessary to elicit max $\dot{V}O_2$.

Although a high max $\dot{V}O_2$ (also known as maximal aerobic power) is an important factor in endurance performance, the limits will be set by the aerobic capacity. This capacity is the total quantity of oxygen that can be used for the duration of an event. In essence, it depends on the $\dot{V}O_2$ that is maintained without provoking excessive anaerobic metabolism and the rate of rise of $\dot{V}O_2$ to this level.[26] During maximal

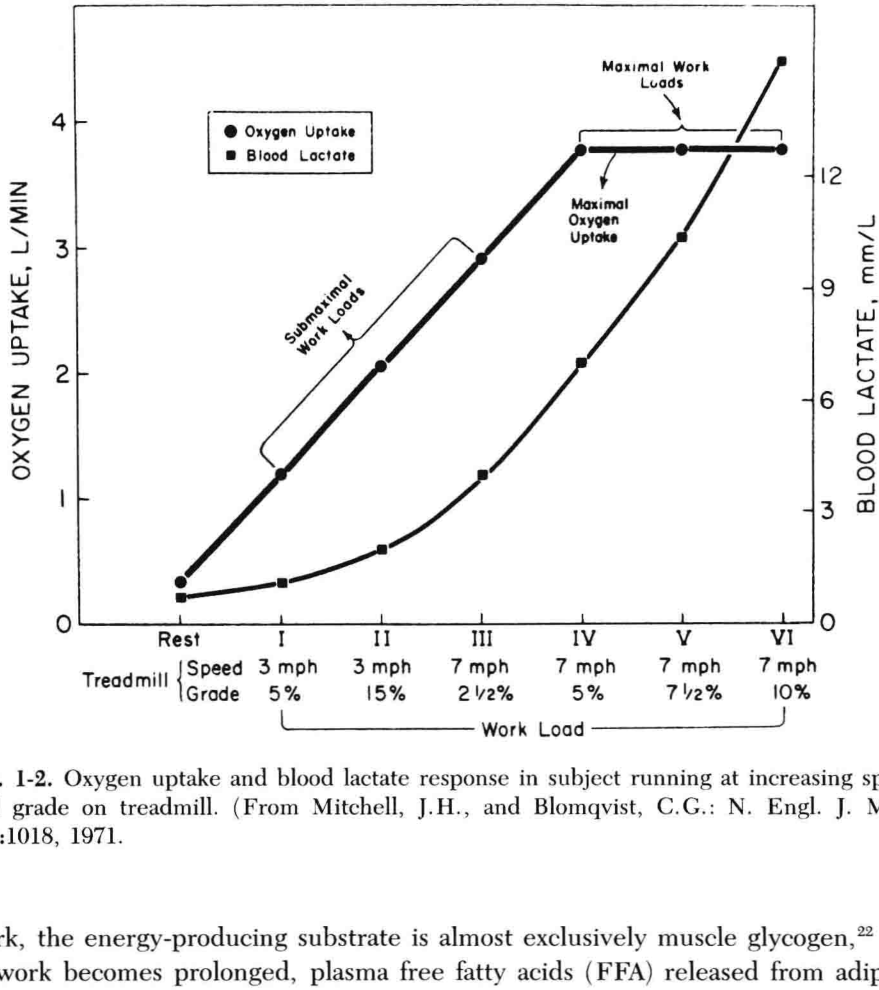

Fig. 1-2. Oxygen uptake and blood lactate response in subject running at increasing speed and grade on treadmill. (From Mitchell, J.H., and Blomqvist, C.G.: N. Engl. J. Med. **284:**1018, 1971.

work, the energy-producing substrate is almost exclusively muscle glycogen,[22] but as work becomes prolonged, plasma free fatty acids (FFA) released from adipose tissue play a major role with an additional contribution of glucose released from the liver.[28] Generally, in well-trained individuals substrates do not limit performance in races up to 1½ hours' duration when depletion of muscle glycogen may become a factor.

For events of shorter duration the time an athlete is able to sustain max $\dot{V}O_2$, or a high percentage of it, depends on the oxidative capacity of the muscle fibers in use.[19,37] Fibers with high oxidative capacity contain a high density of mitochondria and a well-developed capillary supply[14,36] that allows a given submaximal exercise to be performed with less lactate production than when fibers of lower oxidative capacity are recruited. The concept of oxidative capacity is illustrated in Fig. 1-3. In this example max $\dot{V}O_2$ can be sustained for only a brief period, and as the duration of the work is extended the percentage of max $\dot{V}O_2$ that can be used declines. Although this concept has been used to explain variability of performance in distance runners,[8,9]

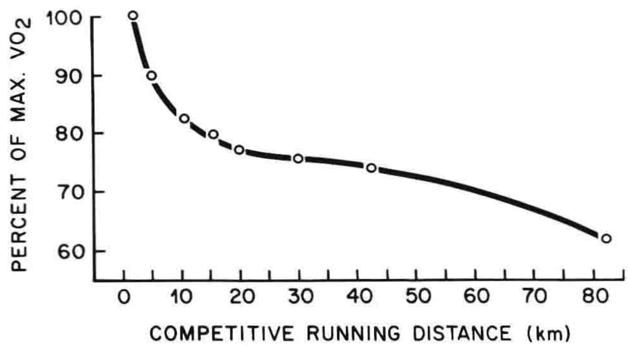

Fig. 1-3. Maximal energy expenditure expressed as percentage of max $\dot{V}O_2$, that may be used by well-trained marathon runners during various distance races. (Modified from Costill, D.L., and Fox, E.L.: Med. Sci. Sports **1**:81, 1969.)

it may be relevant for events as brief as 2 to 3 minutes when the oxygen demands are supramaximal.

Anaerobic metabolism

The ability to produce a large amount of energy rapidly and to increase the level of work beyond that which elicits max $\dot{V}O_2$ (Fig. 1-2) is provided by anaerobic pathways. Two systems are important: (1) energy residing in the muscle in the form of ATP and creatine phosphate (CP), which is immediately available for muscle contraction, and (2) energy produced by metabolic pathways that results in the accumulation of an end-product that cannot be readily excreted, such as lactic acid.

Anaerobic power is the rate at which energy can be released over a short period of time. Factors governing the use of ATP are: (1) the number of muscle fibers recruited, (2) the rate of hydrolysis of ATP, and (3) the rate of replenishment of ATP stores. In short bursts of effort, like those in weight lifting, the amount of energy released depends on the cross-sectional area of muscle involved in the task and the ability to recruit a large fraction of the available muscle fibers. In repetitive movements or in single *explosive* movements such as jumping, the rate of ATP hydrolysis will govern the energy release. Individuals who perform well at these activities tend to have muscle comprised of a high percentage of fast-twitch fibers (FT). These fibers have a more rapidly acting enzyme (myofibrillar adenosine triphosphatase [ATPase]) than slow-twitch fibers (ST).

The speed at which ATP can be resynthesized is governed by the rate of glycolysis.[10] Newsholme[47] hypothesizes that individuals who are able to produce energy quickly may have their muscle glycolytic pathways primed for action as a result of *substrate cycles* operating through the rate-limiting step catalyzed by phosphofructokinase in the forward direction and fructose diphosphatase in the reverse direction. Although it is not clear what factors contribute to such a cycle, hormone-induced

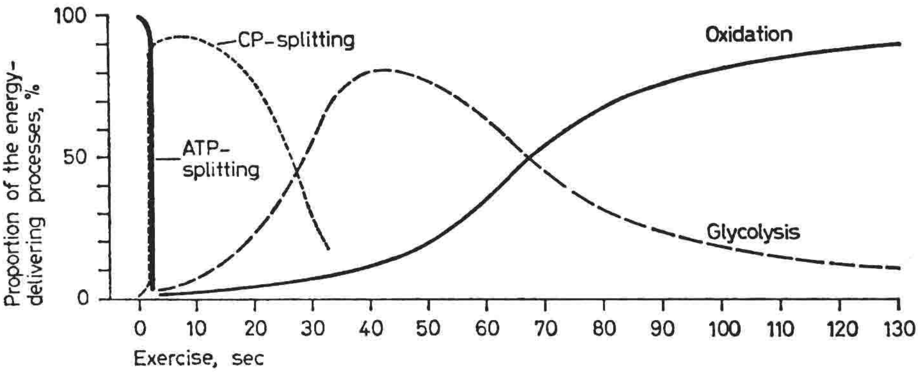

Fig. 1-4. Schematic representation of relative contribution of energy-supply substrates to total energy requirement. (From Keul, J., Doll, E., and Keppler, D.: Energy metabolism of human muscle, Baltimore, 1972, University Park Press.)

increases in the level of cyclic adenosine monophosphate (AMP) in muscle fibers are responsible for the acceleration of glycogenolysis.[10]

Anaerobic capacity also refers to the total amount of energy that may be released in excess of that produced by the complete oxidation of substrates to carbon dioxide and water. Muscle stores of ATP and CP are theoretically capable of providing sufficient energy for approximately 5 seconds of a maximal activity such as sprinting. Glycolysis may sustain maximal energy requirements for another 30 to 40 seconds depending on the state of training. Anaerobic metabolism is probably limited by the lowering of intracellular pH as a consequence of lactic acid production.[32,53]

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The relative contribution of aerobic energy and the various sources of anaerobic energy during strenous activity are represented schematically in Fig. 1-4.

DETERMINANTS OF PHYSICAL PERFORMANCE

Heredity

The extent to which athletes are *born* rather than *made* is the subject of long-term debate. It is clear to coaches that there is considerable variability in the adaptation of individuals to similar training programs. Much of our knowledge in this area comes from studies of identical and fraternal twins.[42,43] These studies indicate that performance capacity has a significant genetic component (Fig. 1-5). The possibility does exist, however, that early intervention in the development of an individual may affect the ultimate level of max $\dot{V}O_2$ that may be attained in adulthood.

Age

While it is known that age results in a substantial decline in athletic performance, experience with athletes who maintained good physical condition and remain injury