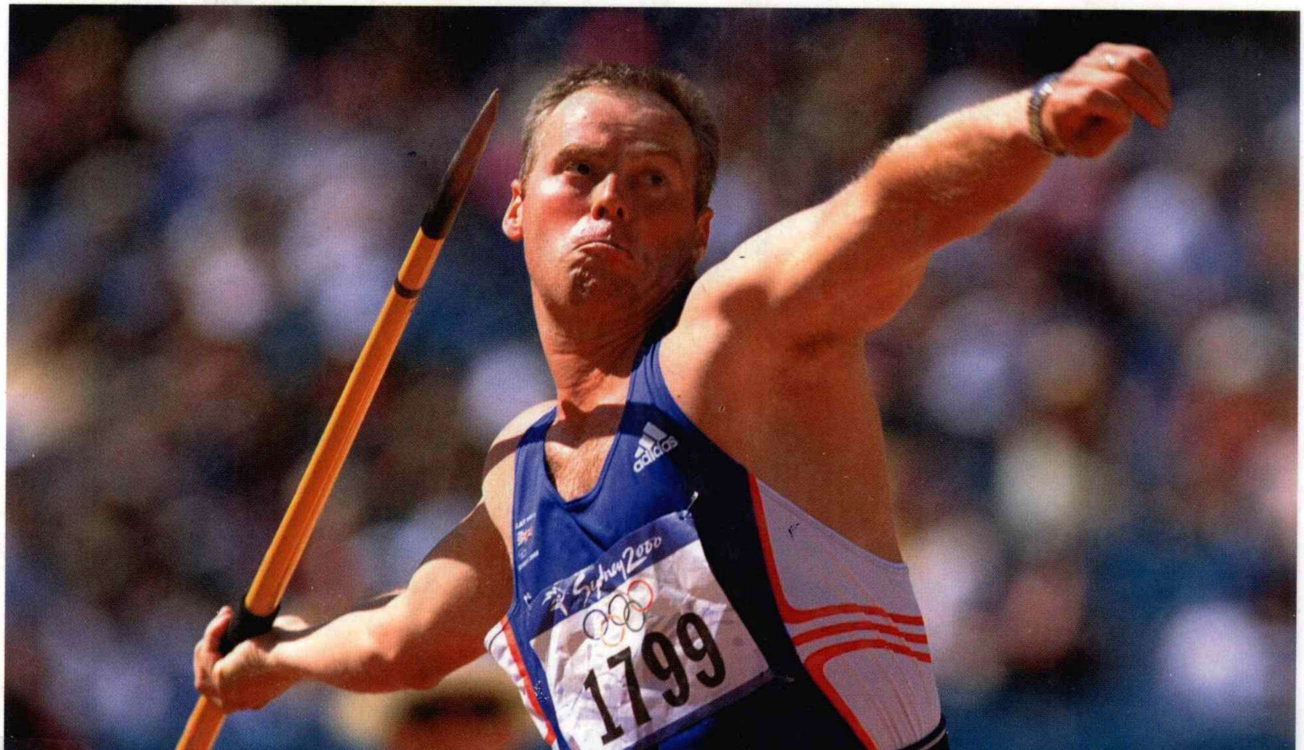
STRENGTH AND POWER IN SPORT

SECOND EDITION

EDITED BY P.V. KOMI

THE ENCYCLOPAEDIA OF SPORTS MEDICINE
AN IOC MEDICAL COMMISSION PUBLICATION
IN COLLABORATION WITH THE
INTERNATIONAL FEDERATION OF SPORTS MEDICINE



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Science

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Forewords

In 1991, the IOC Medical Commission published Vol. III of the Encyclopaedia of Sports Medicine series, on the topic *Strength and Power in Sport*. Professor Paavo V. Komi, as editor, recruited a team of 29 internationally renowned scientific colleagues to produce a reference volume that constituted an important contribution to scientific literature in an area which arrived relatively late in the study of exercise and sports science.

Since the publication of the first edition of *Strength and Power in Sport*, a large volume of research literature has appeared both to reinforce the information contained and to expand the body of literature relative to the training and performance of strength and highest power. The popularity of the first edition and the availability of such a large amount of new information led the IOC Medical Commission to decide that a second edition of this important volume was both justified and essential.

I would like to thank the IOC Medical Commission for yet another valuable contribution to literature in sports medicine and the sport sciences.

Dr Jacques Rogge
IOC President

Extensive research started appearing in the literature of the 1950s concerning aerobic metabolism and the importance of cardiopulmonary function to relative long periods of physical activity. Additional research subsequently appeared on the subject of sprint events and team sports. The physical expression of explosive movements and the training of strength relative to sport were, however, neglected. 'Strength training' in earlier times prompted unjustified fears of the athlete becoming 'muscle bound' with a resultant loss of flexibility. These mistaken beliefs discouraged athletes from training with free weights and high-resistance exercise machines now associated with the training of strength and highest power.

This second edition adds valuable information concerning the basic science and provides additional information that can result in better performance, the prevention of injuries, and greater enjoyment of sports participation by the elite athlete, the recreational athlete, the young athlete and the veteran athlete.

Strength and Power in Sport will certainly continue to be the most frequently cited source of information on this topic area and, in its new and expanded second edition, will make an even greater contribution to the health, well-being and success of athletes of all ages.

I would like to thank Professor Komi for having again gathered a team of authoritative scientists from around the world as co-authors to produce this all-new second edition.

Prince Alexandre de Merode
Chairman, IOC Medical Commission

Preface

It was a rewarding pleasure to follow the success of the first volume of *Strength and Power in Sport*. Since its publication in 1991, the volume has been reprinted several times. In addition, it has been translated into German (1994). Despite the continuous interest in this first volume, it became obvious that the material had to be updated before any additional printing or translating could be planned. During the last 10 years, a considerable amount of knowledge has become available through an increasing number of studies performed both on basic mechanisms and applied aspects of strength and power training. Thus, it was necessary to produce a new volume with the latest possible information.

The editorial work of the first volume was a challenge, but the second volume of *Strength and Power in Sport* was perhaps an even more motivating experience. We were fortunate to receive acceptance of most of the previous authors to revise their chapters, but new contributions from other authors were also included in this second volume. The recruited team now consists of 39 contributing authors representing the most prominent scientists and clinicians, all of whose interest have involved the various problems related to strength and power training. But more importantly, they have all established themselves as world leaders in their particular research or applied area.

Several books have been published related to strength and power which have advanced our understanding of the subject area. In the present volume, we have made an effort to take a slightly different approach to the problem. While it is very easy to demonstrate improvement of muscle strength with almost any method (if sufficiently intensive), the present volume, *Strength and Power in Sport*, examines the basic mechanisms and reasons for beneficial strength exercises. In order to give state-of-the-art information – as is the purpose of the Encyclopaedia of Sports Medicine – a great portion of the book is devoted to the basics of strength and power and their adaptation. The material is divided into five sections.

1 Definition of fundamental terms and concepts.
2 A comprehensive coverage of the biological basis for strength and power including the structural, hormonal, neural and mechanical aspects. This material is presented in 10 different chapters.
3 A detailed examination of the reasons (mechanisms) leading to the adaptations of the organism when subjected to various strength and power exercises. This section covers nine different topics ranging from cellular and neural adaptation to endocrine and cardiovascular responses.
4 Special problems of strength and power training including age-related changes, the potential use of electrical stimulation, and clinical aspects.
5 The volume finishes with a more applied and solely sports-orientated section where three chapters cover the current knowledge of the practical strength and power training principles, as based on available scientific knowledge.

The way the material has been presented varies slightly among the chapters. In some cases, considerable depth and detail were necessary while, on the other hand, a few chapters have been written in a more readable and overview-type format. Whatever the writing style has been, the material should be accessible to readers with a background in the biological aspects of sport sciences. Because of the wide coverage of the basic mechanistic features of strength and power training, it is expected that this volume will become required reading for many graduate programmes in the medicine and science of sport. The study of strength and power is one of the major components of sports science and an understanding of the relationships among neural, hormonal, muscular and mechanical factors is central to athletic performance as well as to strength and power needs of other human populations. Thus, it is believed that this second volume of *Strength and Power in Sport* fulfills well the major objectives established by the IOC Medical Commission for this material: Importance of understanding the basic problems in various aspects of Strength and Power in order to analyze different sport events and to plan objectively training and conditioning not only of athletes but other groups as well.

Paavo V. Komi
Jyväskylä, Finland

Units of Measurement and Terminology*

Units for quantifying human exercise

Mass	kilogram (kg)
Distance	metre (m)
Time	second (s)
Force	newton (N)
Work	joule (J)
Power	watt (W)
Velocity	metres per second ($m \cdot s^{-1}$)
Torque	newton-metre (N·m)
Acceleration	metres per second^2 ($m \cdot s^{-2}$)
Angle	radian (rad)
Angular velocity	radians per second ($rad \cdot s^{-1}$)
Amount of substance	mole (mol)
Volume	litre (1)

Terminology

Muscle action: The state of activity of muscle.

Concentric action: One in which the ends of the muscle are drawn closer together.

Isometric action: One in which the ends of the muscle are prevented from drawing closer together, with no change in length.

Eccentric action: One in which a force external to the muscle overcomes the muscle force and the ends of the muscle are drawn further apart.

Force: That which changes or tends to change the state of rest or motion in matter. A muscle generates force in a muscle action. (SI unit: newton.)

Work: Force expressed through a displacement but with no limitation on time. (SI unit: joule; note: 1 newton × 1 metre = 1 joule.)

Power: The rate of performing work; the product of force and velocity. The rate of transformation of metabolic potential energy to work or heat. (SI unit: watt.)

Energy: The capability of producing force, performing work, or generating heat. (SI unit: joule.)

Exercise: Any and all activity involving generation of force by the activated muscle(s). Exercise can be quantified mechanically as force, torque, work, power, or velocity of progression.

Exercise intensity: A specific level of muscular activity that can be quantified in terms of power (energy expenditure or work performed per unit of time), the opposing force (e.g. by free weight or weight stack) isometric force sustained, or velocity of progression.

Endurance: The time limit of a person's ability to maintain either an isometric force or a power level involving combinations of concentric and/or eccentric muscle actions. (SI unit: second.)

Mass: The quantity of matter of an object which is reflected in its inertia. (SI unit: kilogram.)

Weight: The force exerted by gravity on an object.

* Compiled by the Sub-commission on Publications in the Sports Sciences, IOC Medical Commission.

(SI unit: newton; traditional unit: kilogram of weight.) (Note: mass = weight/acceleration due to gravity.)

Free weight: An object of known mass, not attached to a supporting or guiding structure, which is used for physical conditioning and competitive lifting.

Torque: The effectiveness of a force to overcome the rotational inertia of an object. The product of force and the perpendicular distance from the line of action of the force to the axis of rotation. (SI unit: newton-metre.)

Strength: The maximal force or torque a muscle or muscle group can generate at a specified or determined velocity.

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PART 1

DEFINITIONS

Chapter 1

Basic Considerations for Exercise

HOWARD G. KNUTTGEN AND PAAVO V. KOMI

The performance of sport as for all physical exercise is the result of a coordinated activation of the appropriate skeletal muscles. These muscles, acting through the lever systems of the body skeleton, provide the forces and the power that can be translated into skilled movement. The assessment and quantification of such physical performance is accomplished by use of the International System of Measurement (the SI) for force (newtons); energy, work and heat (joules); torque (newton-metres); and power (watts). If the term *exercise* is defined as any and all activity involving force generation by activated muscles (Knuttgen & Komi 1992; Knuttgen & Kraemer 1987), the resultant physical performance must be described in these terms.

Force is that which changes or tends to change the state of rest or motion in matter. *Work* is equivalent to a force expressed through a displacement with no limitation on time. *Torque* is the effectiveness of a force to produce rotation of an object about an axis. *Power* is the rate at which work is performed or the rate of the transformation of metabolic potential energy to work and/or heat.

The exercise intensity can therefore be quantified in various situations as: the opposing force in dynamic exercise (e.g. provided by a free weight, exercise machine or ergometer); isometric force sustained; power (energy expenditure or work performed per second or force times velocity); or velocity of progression (e.g. running, cycling, rowing). Endurance is the time limit of a person's ability to maintain either an isometric force or a power level of dynamic exercise—the basic SI unit of time is the second (s).

Power can be determined for a single body movement, a series of movements or, as in the case of aerobic exercise, a large number of repetitive movements. Power can be determined instantaneously at any point in a movement or averaged for any portion of a movement or bout of exercise.

Energy, power and endurance

The relationship of the ability to continue exercise to power is presented in Fig. 1.1 where endurance time to exhaustion is plotted against metabolic power during steady state for an average-sized male athlete. In Fig. 1.2, the relative

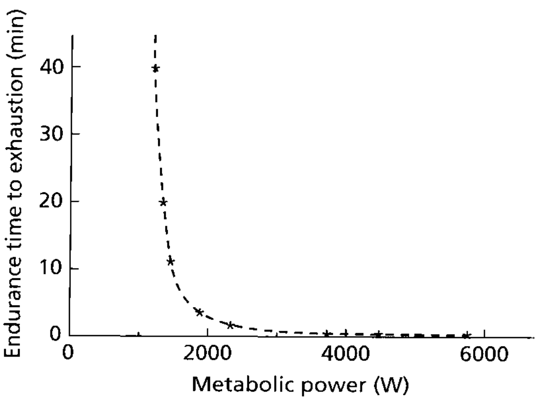

Fig. 1.1 The relationship of endurance time to human metabolic power production for an 80-kg athlete with a maximal oxygen uptake of 2.7 mmol·s^{-1}.

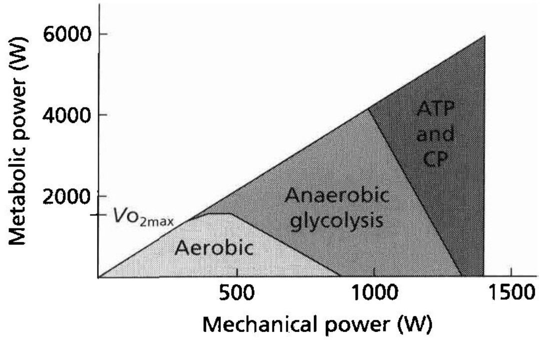

Fig. 1.2 The sources of energy (aerobic metabolism, anaerobic glycolysis and the high-energy phosphates) when metabolic power is related to mechanical power production.

contributions of aerobic metabolism, anaerobic glycolysis (leading to lactic acid formation), and the combination of adenosine triphosphate (ATP) and creatine phosphate (CP) being considered as an energy store are presented when metabolic power is plotted against mechanical power.

The final biochemical carrier of energy to the myofilaments for the development of force by muscles is the high-energy phosphate compound, ATP. A second high-energy phosphate compound, CP, can provide energy for immediate resynthesis of ATP during high-intensity exercise when other sources of energy are not available. Under conditions of the very highest intensities of exercise (i.e. power development), ATP is not only the final carrier of energy but, as the sole source brought into play, it could be considered to have an important role as an energy store as well. Similarly, ATP continues to be the final step in energy transfer at slightly lower intensities of exercise (e.g. 5–10 s until exhaustion), but ATP together with CP constitute the energy storage employed.

As exercise intensity is lowered and ability to continue is increased, anaerobic glycolysis can provide energy for resynthesis of ATP and CP. At much lower intensities of exercise, muscle cells depend upon the oxidation (aerobic metabolism) of fat (fatty acids), carbohydrate (glucose and glycogen) and, to a very limited extent, protein (amino acids) as the sources of energy to resynthesize both ATP and CP.

Power in sport

The metabolic power for such events as throwing and jumping in track and field, weightlifting, and springboard and platform diving is obtained solely from the high-energy phosphate compounds. Events lasting approximately 10 s or somewhat longer (e.g. 100-m run) utilize anaerobic glycolysis for energy in ATP resynthesis. The lower the intensity and the longer the event, the better is the mechanism of anaerobic glycolysis able to contribute energy. In events that last at least 60 s, the aerobic metabolism of carbohydrate and fat begin to contribute energy. The longer lasting the event (lasting minutes and hours), the greater is the aerobic contribution.

For the male athlete described in Fig. 1.1, metabolic power production higher than 5000 W can be obtained solely from ATP. Between 3500 and 5000 W, CP is utilized to resynthesize ATP from adenosine diphosphate (ADP) and CP and the total energy required is obtained from these two high-energy phosphates. In the range of 1500–3500 W, anaerobic glycolysis constitutes the major source of energy for ATP resynthesis. When the power requirement becomes less than 2000 W, aerobic metabolism begins to make a small contribution to ATP resynthesis and the lower the power requirement is from that point on the greater is the contribution of the aerobic metabolism of carbohydrate and fat. Below 1000 W for this athlete, ATP resynthesis during exercise is accomplished totally by the aerobic metabolism and the athlete can continue to run, swim, cycle, row, ski, etc. for extended periods, as can be assessed from the endurance time to exhaustion.

The authors of the various chapters in this volume will consider only the highest levels of force development and the highest levels of mechanical and metabolic power production. Anaerobic glycolysis will contribute energy at intensities lower than are totally accommodated by the high-energy phosphates by themselves but at intensities much higher than those that elicit peak oxygen uptake. Aerobic metabolism will be considered to play no role in the performance of such high-intensity exercise but, on completion of any such conditioning activity or competitive event, aerobic metabolism will assume its role as the sole source of energy for recovery.

Muscle actions

The interaction of the force developed by muscle groups with the external forces presented by the mass of the body parts, gravity, sports objects (e.g. ball, discus, javelin, shot), or opponents in body contact sports will result in muscle actions that produce static exercise (no movement about the related joints) or dynamic exercise (involving either a decrease or an increase in joint angles). Static exercise of activated muscle is traditionally described as an *isometric* action. Force is developed but, as no movement occurs, no work is performed. The other muscle actions involve movement and therefore are designated as dynamic. The term *concentric* is used to identify a shortening action and the term *eccentric* is used to identify a lengthening action (see Table 1.1).

Isometric and dynamic actions can be assessed at any particular length of the muscle and/or positioning of the related body parts in terms of: directly measured force from the muscle or its tendon; force at a particular point on the related body parts; or torque about the axis of rotation. A dynamic action must be further described in terms of directionality (shortening or lengthening) and the velocity of muscle length change or body part movement.

Table 1.1 Classification of exercise and muscle action types.

Exercise	Muscle action	Muscle length
Dynamic	Concentric	Decreases
	Eccentric	Increases
Static	Isometric	No change

The definitions given in Table 1.1 refer, however, to the entire muscle–tendon complex. As will be discussed in Chapter 9, and especially in Chapter 10, the fascicle and tendon may not follow each other (and the entire muscle–tendon complex) in various measures of muscle mechanics, such as force–length and force–velocity relationships. It will further be demonstrated in Chapter 10 that in natural movements involving several joints, these relationships are not only effort dependent, but also muscle and joint dependent.

Because of the variation in mechanical advantages as a joint angle is changed, as well as the differences in maximal force capability of a muscle through its range of length, no dynamic action of a muscle in exercise and sport performance involves constant force development. Therefore, the term 'isotonic', implying uniform force throughout a dynamic muscle action, is inappropriate for the description of human exercise performance and should not be employed. Equally inappropriate is the older practice of identifying all muscle force development as a contraction, thereby leading to 'eccentric contraction' signifying a lengthening shortening and 'isometric contraction' signifying a no-change-in-length shortening. Certain authors contributing to this volume have been granted leeway as regards continuation of this practice.

Furthermore, a variation in linear movement occurs with muscles during both sport skill performance and exercise on mechanical devices. For this reason, the term 'isokinetic' to denote constant velocity should not be employed to describe a muscle action. Although the controlled movement of an exercise machine or ergometer may be at constant velocity and described as being isokinetic, this provides no guarantee that the muscles that are providing force in the movement are acting at constant velocity.

Human locomotion seldom involves pure forms of isolated concentric, eccentric or isometric actions. This is because the body segments are periodically subjected to impact forces, as in running or jumping, or because some external force such as gravity causes the muscle to lengthen.