Chapter 1

Basic Considerations for Exercise

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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

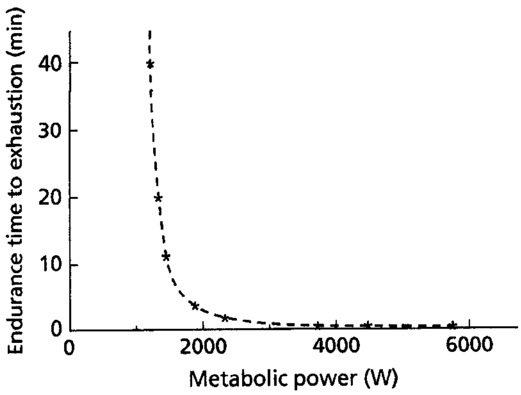

Fig. 1.1 The relationship of endurance time to human metabolic power production for an 80-kg athlete with a maximal oxygen uptake of 2.7 mmol·s^{-1}.

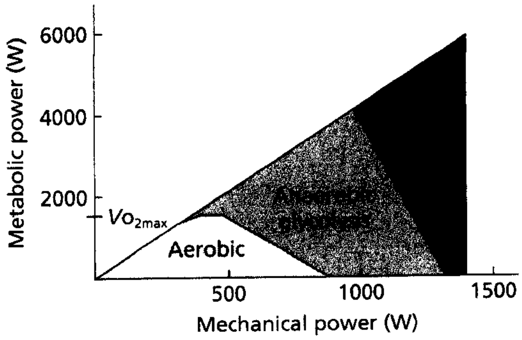

Fig. 1.2 The sources of energy (aerobic metabolism, anaerobic glycolysis and the high-energy phosphates) when metabolic power is related to mechanical power production.

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.

In many situations, the muscles first act eccentrically with a concentric action following immediately. The combination of eccentric and concentric action forms a natural type of muscle function called a *stretch–shortening cycle* or SSC (Norman & Komi 1979; Komi 1984). A SSC is an economical way to cause movement and, consequently, the performance of the muscle can be enhanced. Chapter 10 in this volume has been especially devoted to muscle performance in SSC.

Strength and high levels of power production

The term *strength* will be employed to identify the maximal force or torque that can be developed by the muscles performing a particular joint movement (e.g. elbow flexion, knee extension). However, the muscles may perform at maximal effort as either isometric, concentric or eccentric actions and the two dynamic actions may be performed at a wide range of velocities. An infinite number of values for the strength of muscle(s) may be obtained either for an isolated muscle preparation or for a human movement as related to the type of action, the velocity of the action, and the length of the muscle(s) when the measurement is accomplished.

Therefore, strength is not the result of an assessment performed under a single set of conditions. Because of the number of variables or conditions involved, *strength* of a muscle or muscle group must be defined as the maximal force generated at a specified or determined velocity (Knuttgen & Kraemer 1987). For a particular exercise performance with free weights (e.g. military press in power lifting, clean and jerk in Olympic weightlifting), the combination of strengths employed to complete the manoeuvre is assessed as the largest mass lifted.

Strength assessment and strength exercise prescription

Increases in maximal force production (strength) and maximal power of the muscles are brought about through exercise programmes of very high opposing force (routinely termed 'resistance') that limit repetitions to approximately 20 or fewer and therefore a duration of less than 30 s. Exercise programmes based on higher repetitions (e.g. 30–50 repetitions leading to exhaustion in a 'set') develop local muscular endurance but are not conducive to strength development. Exercise involving a very large number of repetitions in a set (e.g. 400–1000 repetitions) brings about physiological adaptations that result in enhanced aerobic performance that can be especially counterproductive to the development and expression of strength and high levels of power.

Mechanical power will be discussed extensively in Chapter 9 with regard to the force–velocity relationships obtained with constant activation either with isolated muscles or even in human muscle. The obtained force–velocity curves (and consequently power–velocity curves) are not, however, representative of naturally occurring muscle function, in which the activation is continuously variable. In these situations the terms instantaneous force–velocity and power-velocity relationship are more appropriate (see also Chapter 10).

'Resistance training' is performed with a variety of exercise machines, free weights, or even the use of gravity acting upon the athlete's body mass. Most resistance training (strength) programmes are based on a system of exercise to a *repetition maximum* (RM) as presented in the mid-1940s by T.L. De Lorme (De Lorme 1945) for use in physical medicine and rehabilitation. Every time the athlete performs a particular exercise, the bout (or 'set') is performed for the maximum number of repetitions possible (repetition maximum or RM) and this number is recorded along with the mass lifted or opposing force imposed by an exercise machine. Repeated testing at increasingly higher opposing force will eventually lead to the determination of a 1 RM, in which the athlete can perform the movement only once and not repeat it. In this system, the mass lifted or opposing force for the 1 RM is described as the athlete's strength at that particular point in time and for the particular movement (see example presented in Fig. 1.3).

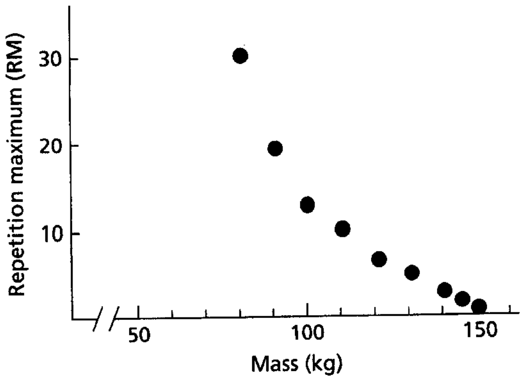

Fig. 1.3 The relationship of endurance capability in repetition maximum (RM) to the mass of the free weights being employed for an athlete performing a particular exercise (in this case, a bench press).

Bouts of strength exercise and the daily programme can be based on percentages of 1 RM or, preferably, within heavy (3–5) medium (9 or 10), and light (15–18) RM zones (Fleck & Kraemer 1997). The number of bouts performed in a set, the number of sets performed per day and the number of daily workouts per week are then prescribed for each movement or muscle group as based on the point in time in the competitive season, the physical condition of the athlete, programme variation for both physiological and psychological considerations, and programme objectives.

The principal adaptation of the athlete's body is the increase in size (commonly termed hypertrophy) of Type II muscle cells. It is generally held that no interchange takes place between Type I and Type II fibres as the result of specific conditioning programmes.

Summary

The performance of sport and all exercise can be assessed and described in terms of force, work, torque, power and endurance time, and presented in the units of the International System of Measurement (the SI). The human body is capable of power production over a wide range from low-intensity aerobic exercise, to exercise eliciting peak oxygen uptake for the muscles involved, high-intensity anaerobic exercise emphasizing anaerobic glycolysis as the main energy source, and the highest power productions which rely solely on the high-energy phosphates as the energy source. The chapters of this volume will concentrate on the highest expressions of power which involve predominantly the high-energy phosphates, with the possible contribution of anaerobic glycolysis when the short, intense exercise performance lasts for periods somewhat longer than a few seconds.

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