Chapter 1

General Principles of Training

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Exercise training can be defined as a systematic process of preparing for a certain physical goal. This goal used to be synonymous with peak physical performance; however, exercise training is also used to achieve targets for health-related fitness. As society evolves and becomes more sedentary (Dollman *et al*. 2005) there is greater emphasis on habitual physical activity with the aim of reducing obesity, adult onset diabetes, hypertension and the risk of heart disease. Indeed, there are specific guidelines which have been have written for prescribing exercise for these conditions (American College of Sports Medicine 1998).

An understanding shared by coaches and athletes alike, all over the world, is the general concept that physical performance improves with training (Foster *et al*. 1996). The specific guidelines on how to achieve peak performance are not so clear, because of the diverse capabilities, goals and types of sport. For example, a sedentary person may have a goal of training to develop sufficient fitness for running 5 km without stopping. This can be compared to the goal of a professional athlete who trains according to a program with the aim of reducing his 5-km time by 3 s. However, irrespective of the goal, there are basic principles of training which can be applied to plan training programs.

Training for peak sporting performance includes training for physical development (general and sport-specific factors), and technical and tactical training (Bompa 1999). Athletes also have to train psychologic aspects and in team sports athletes have to train for the development of team compatibility to ensure harmony within the team structure. To complete the requirements for achieving peak performance, athletes need to be healthy and free of injuries and have a theoretical knowledge of their training in preparation for their sport so that they can take some responsibility for their progress (Bompa 1999).

Long-term planning for the career of an elite athlete covers 10–15 years (Smith 2003). However, the age at which competitors reach their peak varies according to the sport. For example, in sports such as gymnastics, figure skating, and swimming competitors reach their peak in their late teens or early twenties, in contrast to other sports such as soccer, rugby, and distance running where competitors reach their peak success in their late twenties or early thirties (Bompa 1999). In sports such as golf and lawn bowls, in which the technical attributes are the most important factors determining success, the age of elite performers may be 40 or 50 years. Generally, the starting age of athletes in the more technical sports, which require the development of fine motor coordination skills, is younger than athletes competing in sports that are less technical but depend more on physical ability.

This chapter discusses the evolution of training principles with a contemporary view of the factors that need to be considered in devising a training program. Specifically, it discusses the principles of training programs that are designed to improve peak performance coinciding with competition.

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This is followed by sections on specific training principles for strength, endurance, and skill acquisition.

History

Exercise training to improve performance can be traced back to early civilizations (Kontor 1988). There is evidence for both strength training and strength contests as early as 2040 BC with illustrations of weightlifting and strength movements on the tomb of the Egyptian Prince Baghti (Stone *et al*. 2006). Other forms of training are described in folklore. For example, there is the story of the Milo the Greek wrestler who won six titles at the Olympic Games, getting his first title in 540 BC. In preparation for his competition Milo supported a calf above his head daily. As the calf grew, Milo became stronger and was the credited with being the first person to practice the principle of overload (Kontor 1988). This principle was only studied systematically nearly 2500 years later (Hellenbrandt & Houtz 1956). Planning a training program for improving performance was documented by Flavius Philostratus (AD 170–245), a coach of Greek Olympians. He mentioned that a coach should "be a psychiatrist with considerable knowledge in anatomy and heritage" (Bompa 1999).

In Britain towards the end of the 18th century methods of training were discussed by trainers of athletes from different sports involving humans (runners, boxers) and animals (racehorses) (Radford 2000). The description of these training methods became more formal after Sir John Sinclair completed a national survey of coaching methods and published his findings in 1806. These guidelines for training were based on anecdotal evidence and personal experiences of coaches and were devoid of any scientific testing or scrutiny. During this era, success in high performance sport could be attributed mainly to two factors: (i) the athlete had a predisposition to the sport; (ii) a coach with a disciplined approach to training supervised the athlete (Lambert 2006). The first scientific investigation into sports training methods occurred in 1950 (Tipton 1997) and since then there has been an acceleration in the discussion and scientific evaluation of athletic training programs (Booth *et al*. 2000).

The "scientific approach" to training coincided with the application of the principles of sports physiology to training (Tipton 1997). This initiated a systematic application into training programs of interval training (Laursen & Jenkins 2002) and other types of training such as acceleration sprints, circuit training, continuous fast running, continuous slow running, fartlek training, jogging, and repetition running.

During the 1960s and 1970s the development of sports science coincided with the transition of amateur into professional sports (Booth *et al*. 2000). This also prompted creative thinking about improving performance through strategies other than training. Not all the methods were accepted. Indeed, the use of drugs to improve performance was banned by the International Olympic Committee (IOC) and implemented at the Olympic Games in Mexico City in 1968 (Papagelopoulos *et al*. 2004). Nearly 40 years later this problem is still rife in competitive sport, with athletes and their medical support staff becoming more elusive in their use of drugs. This is countered by the authorities who have to invest large amounts of money to use more sophisticated methods to detect athletes who have used any substance that appears on the IOC banned list.

Equipment has also improved over the years and contributed significantly to an improvement in performance in sports such as golf, soccer, kayaking, cycling, and javelin. This has resulted in legislation standardizing the equipment to prevent competitors from having an unfair advantage over their rivals with less sophisticated equipment. A specific example of equipment influencing performance is pole vaulting where at the 1896 Olympics a bamboo pole was used and the height achieved was 3.2 m. In modern times, with the use of poles made out of carbon-fiber composite material, the current world record is nearly double that at 6.14 m (2008).

Despite the refinement in the preparation for elite performances, the improvement in world records in the last 20 years has been moderate. For example, the World Record in the marathon has improved by 2 min 17 s (1.8%), the 10,000 m and 5000 m track race times by 56 s (3.4%) and 22 s (3.0%), respectively, and the shot put distance has increased by 50 cm (2.2%) during this time.

In summary, the factors associated with improvement in the performance of contemporary athletes compared with the top athletes several decades ago are:

- Improvements in coaching;
- Advances in nutrition;
- Perfection of athletic facilities;
- Refinement of equipment; and
- Contributions from sports medicine (Tipton 1997).

Biologic process of training

Exercise training can be explained according to the principles of biologic adaptation. In accordance with this explanation, each training session imposes a physiologic stress (Brooks *et al*. 2005). As with all forms of physiologic stress, there is a homeostatic reaction. This results in transient physiologic and metabolic changes (Coyle 2000) which return to their pre-exercise resting levels during the recovery period when the exercise session is over. Examples of these transient changes are as follow (Brooks *et al*. 2005):

- Altered blood flow to the active muscles;
- Increased heart rate;
- Increased breathing rate;
- Increased oxygen consumption;
- Increased rate of sweating;
- Increased body temperature;
- Secretion of stress hormones such as adrenocorticotropic hormone (ACTH), cortisol and catecholamines;
- Increased glycolytic flux; and
- Altered recruitment of muscles.

If these acute bouts of exercise are repeated over time they induce chronic adaptations that are also known as training adaptations (Coyle 2000). Most of these changes involve remodeling of protein tissue as a consequence of changes between protein synthesis and degradation (Mader 1988). These changes are semi-permanent and do not disappear after the bout of exercise or training session. However, they do regress if regular exposure to the stress of training ceases, as occurs during periods of detraining (Mujika *et al*. 2004). Training adaptations result in altered metabolism (Coyle 2000), changes in neuromuscular recruitment patterns during exercise, and remodeling of tissue (Hakkinen *et al*. 2003). The specific type of changes that occur after training depend on the type of stimulus, defined by the mode of exercise, intensity, and volume of training (Brooks *et al*. 2005; Coyle 2000). For example, the outcome of a resistance training program can increase either muscular endurance, hypertrophy, strength, or power. This depends on the manipulation of the training variables: (i) muscle action; (ii) loading and volume; (iii) selection of exercises and the order in which they are performed; (iv) rest periods; (v) repetition velocity; and (vi) frequency (Bird *et al*. 2005). The choice of the application of the training load (free weight vs. machine weights) can also influence the type of adaptation (Stone *et al*. 2000a).

The overt symptoms of training adaptations are shown by well-defined muscles, low body fat, and skilful movements. The covert symptoms of training are increased mitochondria in skeletal muscles (Irrcher *et al*. 2003), increased capillarization (Henriksson 1992), cardiac hypertrophy (Urhausen & Kindermann 1992), and increased density of bones (Chilibeck *et al*. 1995). The first signs of increased capillarization occur about 4 weeks after starting a training program (Jensen *et al*. 2004), while it takes at least 4 weeks for the mitochondrial mass in the skeletal muscle to increase (Lambert & Noakes 1989). A few days after starting an endurance training program there is an increase in plasma volume (Green *et al*. 1990), while an altered muscle recruitment is the earliest adaptation that occurs after resistance training (Carroll *et al*. 2001; Gabriel *et al*. 2006). This is followed by muscle hypertrophy which occurs after about 8 weeks, depending on the training status of the athlete.

Training adaptations can be classified either as those changes that increase performance (through either an increased muscle power, increased ability to resist fatigue, or increased motor coordination) or those changes that reduce the risk of injury. There is generally a positive relationship between training load and the physiologic adaptations resulting in improvements in performance. However, if a critical training load is exceeded there will be diminishing returns. For competitors at the elite level there is a fine line between insufficient training or too much training (Kuipers & Keizer 1988; Lehmann *et al*. 1993; Meeusen *et al*. 2006; Morton 1997).

Insufficient training does not induce adequate adaptations and results in suboptimal performance. In contrast, too much training results in maladaptations or the failure to adapt, causing symptoms of fatigue and poor performance (Budgett 1990; Derman *et al*. 1997). A more scientific approach to training with a systematic approach to monitoring training increases the chances of the athlete peaking at the correct time coinciding with important competition (Lambert 2006; Lambert & Borresen 2006).

Factors affecting physical performance

The many factors that have the potential to affect physical performance are shown in Table 1.1 (Lambert 2006). Exercise training is the overriding factor in the list and can account for an improvement in performance of over 400% in an untrained person who undergoes a systematic training program (Noakes 2001). The magnitude of this improvement is in stark contrast to the magnitude of improvement (1–30%) caused by the other factors shown in Table 1.1. All these factors are discussed in detail in various sections in this book.

Fitness components associated with sport

Performance in most sports requires integrated functioning of the different systems in the body. However, it is useful to compartmentalize these systems in order to gain a better understanding of how the athlete has developed and which aspects of their fitness need to be further developed. Accordingly, the systems can be compartmentalized into the following categories.

Table 1.1 Factors that have the potential to affect performance.

Exercise training and preparation, including tapering
Health
Nutrition
Nutritional ergogenic aids
Drugs (positive and negative)
Inherited characteristics
Opposition
Tactics
Equipment
Home ground advantage
Environmental conditions (heat, cold, wind, altitude, allergens)
Mental readiness
Sleep (and circadian rhythms)

Strength

Muscle strength is defined as the ability to produce force. While a minimal amount of strength is needed for normal daily activities, the demands of certain sports require well-developed strength. In some sports strength is needed just as a basic component of fitness, while in other sports (e.g., weightlifting) strength is the main outcome variable which determines success or failure in competition. Strength can be increased by systematic resistance training using either specially designed machines or free weights (Stone *et al*. 2000a). The manifestation of an athlete's strength depends on muscle morphology and the motor system (Enoka 1988). Strength can be increased without any change in muscle size, but it is always dependent on changes in the neural system (Carroll *et al*. 2001). Increases in strength are transferred to sporting performances in varying amounts. For example, a weight-training program increased squat one-repetition maximum (1 RM) by 21% and this increase in strength was accompanied by improvements in vertical jump performance (21%) and sprinting speed (2.3%) (Young 2006).

Power

Muscle power, which is a function of the interaction between force of contraction and the speed of contraction, is associated with the explosiveness of the muscle. The relationship between force and speed of contraction and the subsequent point at which peak power occurs varies between athletes (Jennings *et al*. 2005). For example, peak power occurs at 50–70% of the maximum weight that can be lifted for one repetition for the squat and at 40–60% of 1 RM for the bench press (Siegel *et al*. 2002). A fundamental way of increasing muscle power is to increase maximal strength, particularly in untrained athletes (Stone *et al*. 2000a).

Muscle endurance

Muscle endurance is dependent on the muscle being able to contract repetitively without developing fatigue. A combination of muscle strength, metabolic characteristics, and local circulation in the muscle influence the endurance characteristics. Several tests have been developed to measure muscle endurance. A feature of these tests is that they all monitor the ability of a specific muscle, or group of muscles, to contract repetitively. Examples of these tests are the number of push-ups and abdominal curls in 1 min (Getchell 1985; Semenick 1994). Muscular endurance can also be measured with repeated static contractions (isometric) (Coetzer *et al*. 1993).

Repeat sprint

The ability to resist fatigue after repeated short duration, high intensity sprints is a fitness characteristic that is important for team sports such as soccer, rugby, football, basketball, and netball. Repeat sprint performance and, by implication, fatigue resistance during intermittent, short duration, high intensity activities, can be improved by decreasing body mass, specifically body fat, and by increasing strength and muscular endurance, providing this does not result in an increase in body mass (Durandt *et al*. 2006). Training that results in improvements in agility and/or aerobic power may also improve the ability to resist fatigue during repeat sprint activities (Durandt *et al*. 2006).

Speed

Speed consists of a number of components (Cronin & Hansen 2005; Delecluse *et al*. 1995), all of which are independent qualities: acceleration speed, maximum speed, and speed endurance. Performance in the 10-m sprint is influenced by acceleration speed, while performance in the 40-m sprint is dependent on both acceleration speed and maximum speed (Delecluse *et al*. 1995). Speed can be improved by increasing the power to weigh ratio. Plyometric training (i.e., counter-movement jumps or loaded squat jumps) is effective for improving speed (Cronin & Hansen 2005).

Motor coordination (skill)

Performance in sport often has a component of skill. This depends on the combined interaction of agility, balance, coordination, power, speed, and reaction time. Another aspect of skill, which is difficult to define or measure, is the ability of a sports person to make a strategic decision very quickly. The accuracy of this decision-making contributes to the success of the team. There are examples in different sporting codes of players who seem gifted and on most occasions make the correct decision during competition compared to their less "talented" team mates. While motor coordination can be trained, the superior decision-making ability that some players have, making them appear more skilled, is probably an intrinsic characteristic rather than being acquired by training.

Flexibility

Flexibility represents the range of motion specific to a joint. Flexibility can be dynamic or static. Dynamic flexibility involves the range of motion during movement of muscles around a joint whereas static flexibility defines the degree to which a joint can be passively moved through its full range of motion. Changes in flexibility occur after stretching exercises. Flexibility training is used in the warm-up before training or competition (Shellock & Prentice 1985) and also with the goal of preventing injuries. Although there is theoretical evidence to support the positive link between stretching and lowered risk of musculoskeletal injuries during exercise, the clinical evidence is not so strong (Gleim & McHugh 1997). Specific joint angle can be measured as a marker of flexibility for various joints with a goniometer, or a Leighton flexometer (Leighton 1966). A sit-and-reach field test has also been developed to measure the range of motion of the lower back and hamstring muscles.

Cardiovascular fitness

Cardiovascular fitness, also referred to as cardiovascular endurance or aerobic fitness, refers to the collective ability of the cardiovascular system to adjust to the physiologic stress of exercise. Cardiovascular fitness is usually measured in the laboratory during a high intensity exercise test to exhaustion with a mode of exercise that recruits a large muscle mass and with rhythmic muscle contractions (e.g., cycling, running, rowing). A feature of the test is that it should have a progressively increasing intensity which continues until the athlete is exhausted. Oxygen consumption and carbon dioxide produced are measured continuously during the test. The oxygen consumption coinciding with exhaustion is called the maximum oxygen consumption ($\dot{V}O_{2max}$). An athlete who excels in an endurance sport generally has a high $\dot{V}O_{2max}$. Although endurance training increases the $\dot{V}O_{2max}$, and by implication the cardiovascular fitness, the increases are generally moderate (about 15%; Zavorsky 2000) and are dependent on the level of fitness of the person at the start of the training program.

A 20-m shuttle test has also been developed to predict cardiovascular fitness in a field setting (Léger & Lambert 1982). In this field test athletes run backwards and forwards between two beacons 20 m apart, maintaining a prescribed pace which gets faster and faster until the athlete is unable to maintain the pace. The stage coinciding with fatigue is directly proportional to $\dot{V}O_{2max}$.

Body composition

Body composition is defined by the proportions of fat, muscle, and bone. Fat occurs beneath the skin and around the internal organs and is also found within tissues such as bone and muscle. Fat can be divided into non-essential and essential compartments. Fat tissue insulates and protects organs and is a storage form of energy and substrates for metabolism. Fat mass may vary from about 6% to 40% of body mass. Endurance athletes who perform at a high level have low levels of fat. Sumo wrestlers are examples of elite athletes who have a high fat content. Many sports have weight categories (e.g., boxing, judo, wrestling, rowing), and therefore the manipulation of body mass, in particular fat mass, becomes an important part of the athlete's preparation for competition (Fleck 1983).

Muscle mass can vary from about 40% (anorexic person) to 65% of body mass (e.g., a body builder with hypertrophied muscle) (Martin *et al*. 1990). The main function of muscle, from a sport and exercise perspective, is to contract and generate force. Depending on the sport and the type of training, some muscle is adapted to contract several thousand times per training session without developing fatigue (e.g., endurance activity), whereas other muscle is adapted to generate high levels of power with only a few contractions (e.g., powerlifting, shot put, weightlifting). This type of muscle fatigues rapidly.

Bone is a specialized type of connective tissue which is also dynamic and responds to stimuli by changing its shape and density, albeit at a much slower rate than fat and muscle tissue (Chilibeck *et al*. 1995). Bone mass varies from 10% to 20% of total body mass.

The diversity of body composition among elite athletes is dramatic and can be observed during a visit to the Olympic village. The smallest men competing at this level are the endurance athletes. Indeed, the winner of the marathon at the Atlanta Olympics in 1996 was Josiah Thugwane of South Africa who weighed 43 kg (Noakes 2001). The larger men who compete in the sports requiring strength and power weigh about 130 kg. The body mass of the champion women athletes competing at the Olympic Games range from about 35 to 110 kg. The body composition can be regarded as an inherited trait, although it can be manipulated to a certain extent by training and nutritional intervention.

Basic principles of training

In planning a training program there are some basic principles that need to be considered. They are discussed under the following headings.

Overload

An athlete has to be exposed to an overload stimulus at regular intervals for the induction of training adaptations. An overload stimulus can be manipulated by changing the mode of exercise, duration, frequency, intensity, and recovery period between training sessions (Bompa 1999). An overload training stimulus can also be imposed by altering nutrition and influencing the intracellular milieu before the training session. For example, to mimic the metabolic stress in the muscles towards the end of a marathon an athlete could start the training session with a low muscle glycogen concentration. This can be achieved by reducing carbohydrate intake about 24 hours before the training session. The athlete then begins the training session with lower than usual glycogen levels in the liver and muscles. After about 20–30 km of the training run the metabolic flux will be similar to the metabolism that occurs towards the end of a marathon. An advantage of this strategy is that a metabolic overload can be imposed without the same mechanical muscle stress and damage that occurs towards the end of a marathon.

Frequency

Training frequency refers to the number of training sessions in a defined period. For example, training frequency may vary between 5 and 14 sessions per week depending on the sport, level of performance of the athlete, and stage of training cycle (Smith 2003).

Duration

This refers to the time or amount of the exercise session. This is sometimes confused with the volume of training, which quantifies training over a period of time and combines duration and frequency (Smith 2003). Athletes competing at the international level need to train for approximately 1000 hours per year (Bompa 1999).

Intensity

Exercise intensity is a measure of "how hard is the exercise?" and is related to the power output. The exercise intensity lies somewhere on a continuum between rest (basal metabolic rate) and maximal effort, which coincides with the maximal oxygen uptake for that activity. Exercise intensity can be monitored by measuring submaximal oxygen consumption (Daniels 1985), heart rate (Lambert *et al*. 1998), blood lactate (Swart & Jennings 2004), the weight lifted during the exercise (Sweet *et al*. 2004), or the perception of effort (Foster *et al*. 2001). Training intensity is the major training stimulus that influences adaptation and performance. Athletes are only advised to incorporate high intensity training into their training programs after they have developed a sufficient base (Laursen & Jenkins 2002). If too much high intensity training is carried out the athlete will be at risk of developing symptoms of fatigue associated with overreaching (Meeusen *et al*. 2006) and overtraining or will increase the risk of getting injured (Noakes 2001).

Rest and recovery

Rest and recovery are important, often neglected principles of training. Factors that need to be considered during the recovery process after a training session are as follow:

1 *Age* Athletes older than 25 years need longer recovery periods than younger athletes (Bompa 1999).

2 *Environmental conditions* Training and competing in the heat imposes more physiologic stress on the athlete and requires a longer recovery period (Noakes 2001).

3 *Type of activity* Training and competition that induces muscle damage requires longer recovery periods than activities that cause fatigue but no muscle damage or soreness.

Even within a specific sport the demands on the players varies depending on their playing position (Takarada 2003). Ideally, the recovery for each player should be customized. It is recommended that players are monitored using subjective and objective strategies to ensure that the recovery period is customized (Lambert & Borresen 2006). Decisions about the different recovery strategies have to be made considering the team as a whole. A study of rugby players (Gill *et al*. 2006) showed that recovery was accelerated if the players performed low impact exercise immediately after competition, wore compression garments (Kraemer *et al*. 2001), or had contrast water therapy (Higgins & Kaminski 1998) compared with a situation where they recovered without any intervention.

A practical tool has been developed to assist coaches and athletes with monitoring recovery (Kenttä & Hassmen 1998). This is a simple questionnaire which the athletes complete on a daily basis. The questions probe aspects of recovery such as: (i) nutrition and hydration; (ii) sleep and rest; (iii) relaxation and emotional support; and (iv) stretching and active rest.

PSYCHOLOGIC STRESS

If the psychologic side of training and competing is not considered in the recovery process the athlete may develop symptoms of staleness or overtraining (Morgan *et al*. 1987). The Profile of Mood States (POMS) questionnaire, which was developed in 1971, is a useful tool for this purpose (McNair *et al*. 1971). The test was initially designed for patients undergoing counseling or therapy but has subsequently evolved to be used in sport. The POMS is a self-report test designed to measure the psychology of mood state, mood changes, and emotion (McNair *et al*. 1971). The test has 65 items which measures six identifiable moods or feelings: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, and Confusion-Bewilderment. The respondents answer according to a scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely).

The Daily Analysis of Life Demands for Athletes (DALDA) questionnaire can also be used to monitor stress that high performance athletes have to encounter (Rushall 1990). This test monitors the physiologic stress of training in addition to the stresses that may exist outside the training environment but which may contribute significantly to the total stress exposure. The DALDA can be administered throughout a training season and can easily be incorporated into a training logbook. The scoring can be done by the athlete or coach. The test is widely used by coaches and is also sufficiently robust to be used in research (Halson *et al*. 2002).

Specificity

The principle of specificity states that adaptations are specific to the type of training stress. It follows that the type of training must be structured and planned in accordance with the requirements of the competition. However, this principle can be applied inappropriately if it is assumed that all training should simply mimic the demands of competition (Young 2006). In certain sports the physical demands of competition can induce muscle imbalances and the risk of injury is also higher in many types of competition compared to training for the competition. Therefore, it is necessary to vary training and structure it so that the athlete develops a good base of fitness before attempting the more high risk, competition-specific fitness. This concept of varying training volume at various stages of the season is explained by the principle of periodization.

Periodization

Periodization is the process of systematic planning of a short- and long-term training program by varying training loads and incorporating adequate rest and recovery. The plan serves as a template for the athlete and coach (Smith 2003). While it is important to have a plan, the day-to-day implementation of the plan should not be rigid, but rather should be modifiable based on the symptoms of the athlete (Lambert & Borresen 2006; Noakes 2001).

The classic approach of periodized training has been to distinguish between high volume, low intensity training designed to develop aerobic capacity, usually in the early part of the season, and high intensity training designed to develop qualities linked to performance, as the season progresses (Hellard *et al*. 2005). This approach to training reduces the risk of overtraining, while the athlete is more likely to peak at a predictable time, usually coinciding with important competition (Hellard *et al*. 2005; Stone *et al*. 1999). Another reason for this systematic approach to training is that different physiological systems vary in their retention rate after training (Hellard *et al*. 2005). Therefore, by varying the training loads as the season progresses, the desired adaptations, which are associated with peak performance, are achieved.

An advantage of periodization is that it provides a structure for controlling the stress and recovery for inducing training adaptations (Smith 2003). The success of the plan can also be tested regularly to confirm that specific goals have been met in preparation for the main competition (Lambert 2006).

A study of Olympic swimmers showed that the relationship between training load and performance varied according to the different phases of training. Low intensity training had a positive effect on performance in the long term, suggesting that this type of training is necessary to induce the adaptation of various physiologic mechanisms necessary for the subsequent high intensity training (Hellard *et al*. 2005). This study also concluded that the swimmers' response to a given training volume may vary between seasons and even between training sessions. They found that at the elite level training variables only accounted for 30% of the variation in performance (Hellard *et al*. 2005). This supports the concept that training programs need to be highly individualized for elite athletes (Hellard *et al*. 2005). Monitoring the training load–response relationship is important for elite athletes to ensure that the training program is individualized and accommodates the needs of each athlete (Lambert 2006).

There are several different models for periodizing training (Bompa 1999). These models differ depending on the sport, but they all share a common principle in having phases of general preparation, specific preparation, competition preparation and competition, transition or active rest. The terminology for dividing the cycles is referred to as follows:

- *macrocycles:* long plan, usually 1 year;
- *mesocycles:* shorter plan from about 2 weeks to several months; and
- *microcycles:* short plan of about 7 days (Stone *et al*. 1999).

Basic errors in training

The principles of training are guidelines that can be used to customize a training program. A deviation from, or inappropriate application of these guidelines, has consequences that can negatively affect performance. Common basic errors in training that detract from achieving peak performances include the following (Smith 2003):

- Recovery is neglected;
- Demands on the athletes are made too quickly;
- After a break in training because of illness or injury, the training load is increased too quickly;
- High volume of maximal and submaximal training;
- Overall volume of intense training is too high when the athlete is training for endurance events;
- Excessive time is devoted to technical or mental aspects, without adequate recovery;
- Excessive number of competitions – this includes frequent disturbances of the daily routine and insufficient training time that accompanies competition;
- Bias of training methodology; and
- The athlete has a lack of trust of the coach because of inaccurate goal setting.

Conclusions

This section attempts to discuss the basic principles of training. These principles have evolved from practical experience, but are also based on biologic principles of stress and adaptation. The next sections in this chapter discuss more specific examples of the basic principles of training, focusing on resistance training, endurance training, and skill acquisition.

TRAINING TO INCREASE MUSCLE STRENGTH AND POWER

The primary focus of research in the physical conditioning field has been on the promotion of physical activity and aerobic type exercise regimes (Winett & Carpinelli 2001). Strength or resistance training has generally taken a back seat in comparison. However, to perform activities of daily living efficiently and to maximize sporting performance capabilities one needs the muscles and joints of the body to function optimally. To ensure that this happens, one needs to strengthen and condition these structures sufficiently. One way of accomplishing this is by regular resistance training.

Program design

"The act of resistance training, itself, does not ensure optimal gains in muscle strength and performance" (Kraemer & Ratamess 2004). The key to successful resistance training is an appropriate program design. To obtain the best results, one has to consider the science behind exercise prescription and also take a practical approach. To perform this process efficiently one has to consider the following training variables: the exercise and workout structure, mode of resistance training, exercise intensity, rest intervals and frequency of training, volume of training, speed of movement, and progression. It is the correct manipulation of these training variables that optimize the resistance training outcomes.

Exercise and workout structure

There are three main types of strength training programs: total body workouts, upper body/lower body split programs, and muscle group split programs (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). The *total body workout* is a commonly used approach that incorporates 1–2 exercises for each main muscle group covering the whole body in one session. The *upper body/lower body split* program is also a favored program design that focuses on training either the upper body or lower body on alternate days. The *muscle group split* approach is mainly used for people who wish to maximize hypertrophy of selected muscle groups. The choice of program depends on individual requirements and objectives (Kraemer & Ratamess 2004). The advantage of training using a split-program routine is that one can select a wider range of exercises which allows more focus on specific muscle groups than with the total body workout approach (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). The split-program approach also allows a higher frequency of resistance training, but still provides adequate recovery periods for specific muscle groups during a training cycle (Pearson *et al*. 2000).

Exercise order

It is important to maximize the benefits obtained from each exercise and to train at maximum effort for optimal results. Therefore, multi-joint exercises should be performed earlier on in the workout while the person is less fatigued (Kraemer & Ratamess 2004). Because multi-joint exercises involve more muscle groups, require lifting heavier weights, and necessitate enhanced balance and control, they also demand more physical effort to perform. If fatigue is present by the time these exercises are performed, the athlete will not be able to gain the maximum benefit from the exercise. Furthermore, there is a risk of losing good form and technique, which predisposes one to an increased risk of injury.

The general recommendations for sequencing of resistance training exercises for strength and power are as follows (American College of Sports Medicine 2002; Kraemer & Ratamess 2004):

- Large muscle groups before small muscle groups (all programs)
- Multi-joint exercises before single-joint exercises (all programs)
- Most complex exercises before least complex exercises (all programs)
- Rotate upper body and lower body exercises (total body programs) *or*
- Rotate opposing muscle groups; for example, push then pull movements, biceps then triceps (total body or upper body/lower body split programs)
- Higher intensity before lower intensity exercises (muscle group split programs)

These recommendations are primarily focused on maximizing the effort and strength gains via performance of the exercises in combination and minimizing the effects of fatigue in the execution of the more difficult multi-joint exercises.

Variation within a program

There is sufficient evidence to support the concept that varying the exercises trained on a specific body part (e.g., the chest musculature) improves strength and power gains (Pearson *et al*. 2000). There are a few ways of doing this. One can either change the exercises trained every 2–3 weeks, or one can use two program variations on alternate training days (Pearson *et al*. 2000). However, one should be cautious not to vary core exercises too much, as this might hinder progression.

Mode of resistance training

MACHINE VS. FREE WEIGHTS

There is little evidence to suggest that one type of resistance training (e.g., machines vs. free weights) is superior to the other in terms of results, as long as the training prescription is correctly designed (Feigenbaum & Pollock 1999; Haff 2000; Winett & Carpinelli 2001). Training with free weights requires more functionality such as dynamic proprioception, stabilization, balance, and control, allows more variation and mimics activities of daily living and athletic movements more closely (American College of Sports Medicine 2002; Cronin *et al*. 2003; Field 1988; Haff 2000; Hass *et al*. 2001). It is better to train movements rather than muscles. The shift in resistance training has moved towards functional training, because of its strong neuromuscular contribution to muscle function (Santana 2001). The more specific the movement trained, the greater the transfer of training adaptations to performance of the intended skill or activity (Pearson *et al*. 2000), and free weight exercises have a greater degree of mechanical specificity (Haff 2000). One should therefore preferentially include exercises that mimic activities, as human movement and adaptation is very task-specific (Kraemer & Ratamess 2004). However, training on resistance training machines can still be advantageous, as certain movements are difficult to perform using free weights and can be simulated using machine apparatus. Examples of these exercises are leg extensions and seated cable pulls (for tibialis anterior; American College of Sports Medicine 2002; Haff 2000). For sports conditioning there are advantages for using free weight exercises for functional acceleration, speed, and power (Field 1988). However, most strength and conditioning coaches seldom train their athletes exclusively with machines or free weights but usually combine the two modes of training (Haff 2000).

MULTI-JOINT VS. SINGLE-JOINT EXERCISES

Multi-joint exercises involve more than one joint or major muscle group and are favored as being more effective than single-joint exercises for improving strength and power (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). Examples of single-joint exercises are bicep curls and leg extensions; examples of multi-joint exercises are bench press and leg press. Multi-joint exercises generally involve more muscle mass and include integrated movement with more balance, coordination, and neuromuscular control than single-joint exercises (Kraemer & Ratamess 2004). However, for beginners, single-joint exercises might be more advantageous in that they require less skill and pose less risk of injury than the more complex multi-joint exercises (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). When learning multi-joint exercises one should start with very light resistance such as a bar or even a long wooden stick, and not add any weights until the technique is adequate (Pearson *et al*. 2000).

SPECIFICITY OF RESISTANCE TRAINING

Specificity is one of the main principles of resistance training in preparation for sports performance. This principle is not as important for general health and well-being, as most resistance training programs will lead to improved strength and muscle mass. Specificity in resistance training for sport is designed to train the body to react in a similar way to that required during competition (Field 1988). As an example, it is inappropriate for a power athlete who needs explosiveness to train exclusively for maximum 1 RM strength. Becoming stronger at slow velocities will not ensure that strength necessarily improves at the same rate for ballistic movements such as jumping. To develop strength at faster velocities an athlete would need to include high-speed resistance training activities to address this component of strength development.

Exercise intensity

When prescribing the load used during resistance training, one usually uses a reference load to gauge the relative intensity of the exercise. For multi-joint, core, and power exercises with larger muscle mass involvement, this reference point would normally be in the form of a 1 RM load (Feigenbaum & Pollock 1997) or the maximum load that can be lifted only once with correct form and technique (Cronin & Henderson 2004; Evans 1999). The intensity of training would then be described as a percentage of this measured maximum or 1 RM (Baker 2001b,c; Campos et al. 2002; Feigenbaum & Pollock 1997; Fry 2004; Goto *et al*. 2004; Haff 2004a; Hass *et al*. 2001; Izquierdo *et al*. 2002; Robinson *et al*. 1995). This is a useful method of quantifying the training load and prescribing a similar training stimulus relative to the individual strength capabilities (Fry 2004).

Another method of gauging the relative intensity is that of the *multiple-RM* method (Baker 2001b; Feigenbaum & Pollock 1997; Fleck & Kraemer 1997; Haff 2004a). This is probably the easiest method of resistance prescription and functions on a load-repetition continuum (Fleck 1999; Fleck & Kraemer 1997). It is also a convenient method of gauging the physiologic stress of the exercise session (Fry 2004). An example of this would be selecting a 6 RM load. What the 6 RM effectively means is that a training load should be selected that only allows six repetitions to be performed. If six repetitions cannot be performed, then the load is too heavy, and if more than six repetitions can be performed then the load is too light. This technique is easy to understand and is usually determined in practice by trial and error, as it becomes logistically very time-consuming and impractical to test directly for every exercise prescribed (Haff 2004a).

EFFORT AND EFFECTIVE STRENGTH GAINS

Resistance training should generally be performed with moderate to high effort levels, where effort is defined as the relative amount of exertion that one has to employ to perform the exercise (Winett & Carpinelli 2001). A high level of exertion can be equated to a situation where one terminates the set because one is unable to perform another repetition with good technique or proper form. High effort levels do not necessarily equate to heavy loads! For example, if one aims for 15 repetitions in a set and the athlete manages to complete the 15th repetition yet cannot perform a 16th repetition, then they are exercising at a high level of exertion or relative intensity. For optimal strength development, the greater level of exertion (i.e., training to failure vs. discomfort), the greater the outcome (Fleck & Kraemer 1997).

Frequency of training and rest intervals

FREQUENCY OF TRAINING

Ideally, each major muscle group should be trained twice a week (Feigenbaum & Pollock 1999; Winett & Carpinelli 2001). Those athletes who have more time and want to improve further can increase their frequency of resistance training per muscle group to three times per week (Feigenbaum & Pollock 1999; Hass *et al*. 2001). For adequate recovery, resistance training days for specific muscle groups should be separated by at least 48–72 hours (Feigenbaum & Pollock 1999; Winett & Carpinelli 2001) and a minimum of 24 h should normally separate training sessions (Pearson *et al*. 2000). The recovery period is important for muscle recovery and adaptation, and also to prevent overtraining (Feigenbaum & Pollock 1997; Hass *et al*. 2001; Pearson *et al*. 2000). Based on an extensive literature review in this regard, there seems to be no optimal frequency of training as various muscle groups respond differently to frequency overload (Feigenbaum & Pollock 1997). The chest, arms, and leg muscle groups may respond better on ≥3 days per week; however, the lumbar extensors and smaller trunk muscles respond favorably to less training sessions per week (Feigenbaum & Pollock 1997). Generally, lesser trained athletes need more recovery time than their more highly trained counterparts (Kraemer & Ratamess 2004). Two to 3 days per week has been shown to be effective during the initial phases of resistance training, but the number of training days can be increased as one becomes more experienced and conditioned (American College of Sports Medicine 2002). Advanced training and increased training frequency leads to variations in program design such as split routines such as upper body/lower body and muscle group split programs, where more specialized and focused training is prescribed (American College of Sports Medicine 2002; Kraemer & Ratamess 2004).

REST INTERVALS

Rest intervals are extremely important in program design (Rhea *et al*. 2002b), as they do not only effect hormonal, metabolic, and muscular adaptations, but also effect acute force and muscle power generation, and their rates of improvement (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). With shorter rest intervals the rate of strength gain will be limited (American College of Sports Medicine 2002; Kraemer & Ratamess 2004; Willardson & Burkett 2005). If the rest interval is too short, it will compromise the ability of the muscle to perform and lift the weight (American College of Sports Medicine 2002; Robinson *et al*. 1995; Willardson & Burkett 2005). It has been shown that by increasing the rest interval between sets with the same load, more repetitions can be performed in the subsequent sets and that this leads to improved strength gains (Robinson *et al*. 1995; Willardson & Burkett 2005). This is extremely pertinent when training specifically for strength and/or power.

Not every exercise requires the same rest interval (American College of Sports Medicine 2002). For the more complex core exercises rest periods should be longer (e.g., 3–5 min) between sets and exercises for optimal recovery (González-Badillo *et al*. 2005) and gains in strength and/or power (Kraemer & Ratamess 2004). A general guideline is to gauge the complexity of the exercise, the number of muscle groups involved, and the actual weight lifted to determine the rest period. For example, in a heavier strength program design, an exercise such as the power clean or back squat (multi-joint, complex, large muscle group involvement) would require 3–5 min rest, an exercise like the Lat pulldowns (multi-joint, less complex, moderate muscle group involvement) 2–3 min and a bicep curl (single-joint, simple, small muscle group involvement) 1–2 min between sets. All programs will lead to improvements in strength regardless of the length of the rest interval, but the design should be such that it optimizes the time utilized during training in relation to the expected training outcomes.

Volume of training

Underprescription of training volume may lead to not achieving the desired improvements in strength and muscle performance, and overprescription of training volume may lead to overtraining and overuse injuries (Rhea *et al*. 2003). As a result, the optimal number of sets still remains an extremely controversial topic (American College of Sports Medicine 2002; Carpinelli & Otto 1998; Feigenbaum & Pollock 1997; Kraemer & Ratamess 2004; Pearson *et al*. 2000; Wolfe *et al*. 2004). Of all the training variables, most of the research around resistance training has focused on volume, and more particularly single vs. multiple set training (Rhea *et al*. 2003).

SINGLE SETS

Most research shows no difference between single and multiple set training in terms of superiority in strength gains in the *untrained, non-athletic* population. It would therefore seem as if within the first 3–4 months of training single set programs are equally efficient in developing strength (American College of Sports Medicine 2002; Carpinelli & Otto 1998; Feigenbaum & Pollock 1997, 1999; Fleck 1999; Hass *et al*. 2000). Eighty to 90% of the strength gains of a multiple set protocol are achieved during this initial period of resistance training using a single set approach (Hass *et al*. 2001). The increased gains in strength using a multiple set program do not seem to justify the time spent in performing additional sets in healthy, untrained adults (Carpinelli & Otto 1998; Hass *et al*. 2000, 2001). It has been proposed that once a basic level of fitness is acquired multiple sets are superior to single set programs in muscle development (Fleck & Kraemer 1997; Wolfe *et al*. 2004).

MULTIPLE SETS

Many meta-analyses on this topic have shown significant support that multiple sets are superior to single set programs in developing strength (Peterson *et al*. 2004; Rhea *et al*. 2002a, 2003; Wolfe *et al*. 2004). These superior strength gains were more noticeable in trained vs. untrained individuals (Rhea *et al*. 2002a), and were especially significant over longer duration programs (Wolfe *et al*. 2004). Rhea *et al*. (2003) determined the optimal dose–response relationship for strength gains in *untrained* individuals to be an average load of 60% of 1 RM (± 12 RM), training a muscle group three times per week, and performing four sets per muscle group (not per exercise!). For *trained* individuals, an average load of 80% of 1 RM (± 8 RM), training a muscle group twice a week, and performing four sets per muscle group was indicated for maximal strength gains (Rhea *et al*. 2003). For *athletic* individuals, the optimal dose–response relationship for maximizing strength in this population group lies at an average intensity of 85% of 1 RM, training a muscle group twice a week, and performing eight sets per muscle group per session (Peterson *et al*. 2004). Because of the limited data available above this training load, interpretation within this range is difficult. Additionally, strength benefits were minimal training with 1–3 sets at 50–70% of 1 RM training loads (Peterson *et al*. 2004), which strongly supports the conclusion that higher volume training with heavier loads is necessary for maximizing strength development in athletic and highly trained individuals. It has been shown that there might be a threshold or optimal volume of training to maximize strength gains, whereafter increases in volume add no further benefit (González-Badillo *et al*. 2005; Peterson *et al*. 2004; Rhea *et al*. 2003) and might even lead to decrements in muscle performance (González-Badillo *et al*. 2005).

Kraemer and Ratamess (2004) highlight some key issues to consider:

1 In the short term, untrained individuals respond equally well to single and multiple sets;

2 In the long term, higher volumes (i.e., more sets) are required to increase the rate of progression;

3 No studies have shown single set approaches to be superior to multiple set programs; and

4 Not all exercises need to be performed with the same number of sets.

This latter point is paramount to understanding program prescription. Depending on which muscle groups need more attention, the number of sets can be increased or decreased for the respective exercises or muscle groups accordingly.

Speed of movement

Winett and Carpinelli (2001) recommend using 4 s for lifting and 4 s for lowering in concentric and eccentric muscle actions, respectively, as it decreases momentum, creates a higher training stimulus for the working muscles, and reduces the injury risk. Many researchers and trainers recommend using approximately 2 s and 4 s when lifting and lowering weights, respectively (Evans 1999; Hass *et al*. 2000; Pollock & Graves 1994; Pollock *et al*. 2000). However, movement speeds requiring less than 1–2 s for completion of concentric muscle actions and 1–2 s for completion of eccentric muscle actions have been shown to be the most effective movement velocities during resistance training for enhancing muscle performance (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). Force equals the product of mass and acceleration. By performing the lifts too slowly the muscles are exposed to less force generation and therefore have lesser strength gains in the long term (American College of Sports Medicine 2002). It is therefore important to train at moderate to higher velocities and at moderate to higher loads for effective strength development (Kraemer & Ratamess 2004). From a practical perspective, novice trainers would initially train more conservatively because of the possible risk of injury and muscle damage, and progress the velocity of muscle action accordingly as they become stronger, more trained, and proficient in resistance training.

Progression

Progressive overload is an essential component of any resistance training program whether it may be for improving muscle size, strength, or power (Pearson *et al*. 2000; Winett & Carpinelli 2001). To sustain increases in muscle development and performance one constantly needs to progress the program by gradually increasing the demands placed on the body (American College of Sports Medicine 1998, 2002; Evans 1999; Kraemer & Ratamess 2004; Pearson *et al*. 2000; Rhea *et al*. 2003; Winett & Carpinelli 2001). This can be incorporated into a training program by manipulating any of the following training variables appropriately: increasing the frequency of training; increasing the repetitions in each set; increasing the number of exercises; decreasing the rest periods between sets and/or exercises; increasing the load utilized; or changing the speed of movement (American College of Sports Medicine 2002; Fleck 1999; Haff 2004a; Hass *et al*. 2001; Kraemer & Ratamess 2004; Pearson *et al*. 2000).

Resistance training for sport

Training for strength

The best results for strength and power gain are achieved when heavier loads are utilized during resistance training (Hass *et al*. 2001). Strength and power will be developed to a certain extent regardless of whether one trains with heavy weights or light weights. However, within the light–heavy weight continuum, the load utilized will favor a specific component, either strength or power (American College of Sports Medicine 1998; Campos *et al*. 2002; Fry 2004; Hass *et al*. 2001). Heavier loads, which are maximal or near to maximal, elicit the greatest gains in absolute strength (American College of Sports Medicine 1998; Campos *et al*. 2002; Fry 2004), and regular exposure to this loading range will ensure improvement (Fry 2004). Heavy training is not a prerequisite for strength gains in untrained individuals as almost any form of resistance training increases strength initially (Cronin & Henderson 2004). During this phase the emphasis should be on form and technique. However, loads in excess of 80–85% of 1 RM, or alternatively in the range of 1–6 RM loads (preferentially 5–6 RM; American College of Sports Medicine 2002), are required to maximize the increase in strength (American College of Sports Medicine 2002; Campos *et al*. 2002; Fry 2004; Kraemer & Ratamess 2004). Maximizing strength is only possible if more muscle is recruited during the exercise, and for this to happen one needs to lift heavier loads (Kraemer & Ratamess 2004). Additionally, it seems that using a variety of training loads within this 80–100% of 1 RM or ± 1–8 RM range in a periodized fashion is the most effective way to maximize strength in advanced trainers (American College of Sports Medicine 2002).

A key factor to consider in strength training is that everyone does not need to develop maximal strength. Depending on individual requirements or training goals, strength training may be prescribed differently (i.e., using lesser loads, e.g., 70–80% of 1 RM or ± 8–12 RM loads), and sufficient strength gains, albeit not maximal, may be incurred specific to each individual and their respective training goals. However, it is recommended that even distance runners should occasionally train within the loading range of ≥80% of 1 RM for other performance and physical benefits such as maintained or improved strength and muscle power. Another reason is to counteract the catabolic effects that occur during repetitive exercise such as long distance running (Fry 2004). Even though a specific training zone on the load–repetition continuum favors a specific type of muscle development, it is not recommended to spend all the time training in one zone as it can lead to overtraining or stagnation in performance benefits (Kraemer & Ratamess 2004).

Training for power

The ability to effectively generate muscle power is believed to be an essential component of athletic and sporting performance and as a result has been extensively researched (Cronin & Slievert 2005). To maximize power through resistance training one first has to understand what is meant by muscle power. Power is a product of force and velocity (Baker *et al*. 2001a; Cronin & Henderson 2004; Cronin & Slievert 2005; Hedrick 2002; Kawamori & Haff 2004; Kawamori *et al*. 2005; Stone *et al*. 2003b), and is generally defined as the amount of work that can be performed in a specific time period (Cronin & Slievert 2005; Fry 2004; Kawamori & Haff 2004;

Kawamori *et al*. 2005; Stone *et al*. 2003a). Work in this case is defined as the amount of force produced to move a weight over a distance traveled (force × distance). Generally, during weight training, the distance that the weight moves is determined by the length of the arms, legs, and torso, and remains constant for each individual. Bearing this in mind, the main effectors that can be manipulated in power training are the load lifted and the speed of the movement. So, practically, there are two ways of intervening for developing muscle power (American College of Sports Medicine 2002; Baker 2001c; Baker *et al*. 2001a; Field 1988; Hedrick 2002; Kawamori & Haff 2004; Kraemer & Ratamess 2004; Stone *et al*. 2003a):

1 by training to develop the force component (i.e., strength); and

2 by training the speed component, which reduces the time period over which the work is performed.

For the strength component of muscle power one trains specifically using the method mentioned above, and in novice athletes this form of training should predominate (Baker 2001a,c). The strength component is extremely important because it forms the basis of powerful movements (American College of Sports Medicine 2002; Baker 2001c). One should not underestimate the importance of strength training in this role (Baker 2001a), as it is strongly related to both peak power output and sports performance (Stone *et al*. 2003b). Maximum strength contributes significantly to power production in moving both light and heavy resistances (Baker 2001b; Stone *et al*. 2003b). However, strength training only forms half of the equation (Hedrick 2002) and the highest power outputs in a movement come at a compromise between force and velocity components (Kawamori *et al*. 2005). Training the velocity component for developing muscle power appears to be vital in highly trained individuals who have already developed a base level of maximal strength. The focus of resistance training should then shift to primarily accommodate this component (i.e., train to lift large loads at higher speeds rather than merely lifting larger loads; Baker 2001c; Cronin & Slievert 2005).

To develop high-speed movement ability optimally, one should train specifically using high-speed movements (Hedrick 2002; McBride *et al*. 2002). Therefore, one should utilize relatively lighter loads than for strength training and perform the movement explosively (Kawamori & Haff 2004). This form of training will more likely induce high-velocity adaptations within the muscle (Cronin *et al*. 2003). For developing this velocity component for optimal muscle power development one should generally train at moderate to light loads ranging 30–60% of 1 RM performed at high velocity (American College of Sports Medicine 2002; Baker 2001c; Baker *et al*. 2001a,b; Cronin & Slievert 2005; Izquierdo *et al*. 2002; Kraemer & Ratamess 2004; Newton *et al*. 1997; Wilson *et al*. 1993).

Single-joint and upper body exercises, and untrained individuals might respond better to power training at a lower range of loads (30–45% of 1 RM), while multi-joint and lower body exercises, and trained individuals might respond better to a higher range of loads (30–70% of 1 RM; Kawamori & Haff 2004). The optimal relative load for developing maximal power is yet to be determined as there is conflicting evidence as a result of different assessment techniques and protocols (Baker *et al*. 2001b; Cronin & Slievert 2005; Dugan *et al*. 2004; Kawamori & Haff 2004; Stone *et al*. 2003a). Therefore, it is pragmatic to train for power within the full range of loads specified above (American College of Sports Medicine 2002; Baker 2001b,c; Baker *et al*. 2001b; Cronin & Slievert 2005; Kraemer & Ratamess 2004; Wilson *et al*. 1993), as each force–velocity relationship will develop a different component of muscle power (Baker 2001b; Cronin & Slievert 2005). To illustrate this point more effectively it has previously been shown that there is a velocity-specific adaptation when training for muscle power and using different loading strategies (McBride *et al*. 2002). Training with lighter loads significantly improves the velocity of movement over a range of loads, and training with heavier loads significantly improves the force capabilities of the involved muscles over the same range of loads. However, the one aspect of muscle power that the one training strategy develops, the other does not (McBride *et al*. 2002). This reinforces the need to develop both the strength and velocity aspects that affect muscle power, as they both contribute in different ways to functional capacity and ability.

TRADITIONAL WEIGHT TRAINING

One problem with utilizing traditional high-speed weight training exercises for power is that of deceleration (American College of Sports Medicine 2002; Baker *et al*. 2001a; Kawamori & Haff 2004; Siegel *et al*. 2002). During traditional weight training exercises, the initial part of the movement involves acceleration and a considerable part of the remainder of the movement is spent on deceleration (American College of Sports Medicine 2002; Kraemer & Ratamess 2004). The reason for this is that they are closed-loop movements. The movement has to stop at the end-range before joint or muscle injury occurs. Therefore, the acceleration part of the movement is limited. For effective development of power using traditional resistance training exercises, one needs to increase acceleration and limit deceleration (American College of Sports Medicine 2002). The only way of doing this is to slightly increase the loads utilized (McBride *et al*. 2002), compared to open-loop movements such as ballistic resistance exercise where, for example, the weight is released or the body is projected off the ground (Kraemer & Ratamess 2004; Pearson *et al*. 2000). Siegel *et al*. (2002) demonstrated peak power outputs in traditional exercises such as the Smith machine squat and barbell bench press within slightly higher ranges of 50–70% 1 RM and 40–60% 1 RM, respectively, which supports this rationale.

BALLISTIC RESISTANCE EXERCISE

Ballistic resistance exercise is a popular form of training used in the development of explosive power, as the movement is open ended and acceleration continues into the release of the weight, bar, or object (American College of Sports Medicine 2002). This technique offers far greater movement specificity than traditional strength training (Cronin & Henderson 2004; Cronin & Slievert 2005; Cronin *et al*. 2003). It also allows for greater force, velocity, acceleration, and power output (Baker 2001c; Cronin & Slievert 2005; Cronin *et al*. 2003; Hedrick 2002) and relatively less weight is required compared to the closed-loop traditional resistance exercises, as the deceleration component is significantly reduced (Baker *et al*. 2001b; Cronin & Slievert 2005; Kraemer & Ratamess 2004; Siegel *et al*. 2002). Examples of these types of exercises are jump squats, bench throws, and medicine ball toss. The potentiating effect of ballistic resistance exercise compared to traditional resistance exercises, however, becomes insignificant when using heavier loads (≥70% 1 RM), as the ability to release the bar or object or project the body off the ground becomes compromised (Cronin *et al*. 2003).

OLYMPIC LIFTS

Apart from ballistic resistance exercise, predominantly multi-joint exercises, such as power cleans, hang snatches and so forth are used in resistance training for power (Hedrick 2002; Tricoli *et al*. 2005). A well-balanced resistance training program for advanced trainers and athletes incorporates the use of these Olympic lifts, multi-joint and single-joint exercises (Pearson *et al*. 2000). Olympic lifts and their derivatives are considered to be the best resistance training exercises for maximizing dynamic muscle power, as they incorporate multi-joint movement patterns that are highly specific, have significantly less deceleration, and generate extremely high power outputs (Kawamori & Haff 2004; Kawamori *et al*. 2005). A key concern in using these types of exercises, especially the Olympic lifts, is the skill required to perform them correctly. A significant amount of time is spent in developing the correct technique of execution and form, and for novice and intermediate trainers it is highly recommended to focus primarily on this aspect (American College of Sports Medicine 2002). Even though teaching and learning these exercises can take a long time, once the correct technique and skill has been acquired, the benefits and transfer to functional performance are substantial (Tricoli *et al*. 2005). Because of the already ballistic nature, heavier loads may additionally be required to maximize power output in these exercises (i.e., 70–90% of 1 RM) depending on the sporting requirements and training status of the athletes (Baechle *et al*. 2000;

Baker *et al*. 2001a,b; Kawamori & Haff 2004; Kawamori *et al*. 2005). Power training over the range of lesser intensities (30–70% of 1 RM) will nonetheless provide sufficient benefits for a variety of sporting events.

PRACTICAL CONSIDERATIONS

No studies have focused on each individual training at their respective optimal loads for developing power output (Cronin & Slievert 2005), so it is not known how effective it is in maximizing power output in comparison to training at the immediate range of loads surrounding it. Depending on individual needs analysis, heavier resistances may be required to improve the force component, and lighter resistances may be required to maximize speed of movement (Baker 2001b; Baker *et al*. 2001a; Hedrick 2002; Kawamori & Haff 2004). One should also consider sport specificity when selecting appropriate loads. For example, in rugby union, which is an explosive, high intensity, full contact sport with high external resistances encountered during tackling, mauling, at a loose ruck (Duthie *et al*. 2003), training for power at higher loads with greater external resistance might be more beneficial (Baker 2001a; Kawamori & Haff 2004). The ability to generate maximal power against large resistances has been shown to be a significant predictor of performance level in rugby league players (Baker 2001a). However, a volleyball player might benefit more from training with lighter loads and focusing more on velocity training, as they do not move heavy loads.

Because athletic performance is so diverse and characterized by many different force–velocity qualities, it seems prudent to vary constantly the load used for power training (Cronin & Slievert 2005). Employment of this strategy may induce improved power output over the entire force–velocity spectrum (Baker 2001b). It is generally recommended for novice and intermediate athletes to train initially for power using the lower range of the loads specified earlier on. For competitive athletes a similar approach is used except that they should progress towards the higher range of loads, especially for the last few weeks in the training block to peak at the right time (Baker 2001a). Practically, it is also recommended to reduce the resistance used for power training during hard training sessions and/or hard training weeks to avoid inducing excessive fatigue (Baker 2001a).

It is also recommended that one does not train to fatigue, especially in novice and intermediate trainers. Power exercises incorporated into a resistance training program are usually performed first (i.e., before fatigue develops). Also, power exercises should generally not be performed for more than six repetitions in a set (Fry 2004; Haff 2004a), as the focus should be on quality or maximal velocity of movement (Haff 2004a; Hedrick 2002). One should also try to maximize power output during a training set. One technique that can improve the quality of the exercise in power training is the cluster set (Kawamori *et al*. 2005). This incorporates adding an interval of 10–30 s rest between repetitions in lieu of performing all the repetitions continuously. This minimizes fatigue and maintains power output within the set (Kawamori *et al*. 2005). For advanced power training, the program design should also follow a periodized approach to ensure appropriate progression and avoid overtraining (American College of Sports Medicine 2002).

It is of utmost importance that different components of muscle power are trained at different times within the training cycle to avoid stagnation and optimize muscle performance. For example, the strength components should be trained early on in the season, with the focus gradually shifting towards the speed and power components closer to the competition season, when performance needs to be at a peak (Kawamori & Haff 2004).

Periodization

Periodization is not a rigid entity, but is rather an adaptable concept for a more pragmatic and effective approach to resistance training (Haff 2004a). This may take the form of a systematic and planned variation of training volume and load within a defined training period (Pearson *et al*. 2000) to bring about optimal gains in muscle performance (Fleck 1999). The main objective of periodization is to avoid stagnation and overtraining, and to promote peaking of athletic performance (Pearson *et al*. 2000; Stone *et al*. 2000b). Periodization also caters for long-term improvements in muscle strength and power (Fleck 1999). Significant gains in strength can be achieved through systematic variation of the program. Variation is the key principle used in resistance training programs (Field 1988) to optimize training by constantly shifting the training stimulus (Haff 2004a) and thereby changing the demands placed on the body (Fleck 1999). Periodization incorporates this principle of variation as the core component in its application (American College of Sports Medicine 2002). However, periodized training is not necessary until some form of base fitness has been obtained (Fleck 1999; Haff 2004b).

There are two main models of periodization (American College of Sports Medicine 2002; Haff 2004a; Kraemer & Ratamess 2004; Pearson *et al*. 2000; Wathen *et al*. 2000):

1 Linear or classic model of periodization; and

2 Non-linear or undulating model of periodization.

CLASSIC OR LINEAR MODEL OF PERIODIZATION

The classic or linear model is subdivided into different training phases, each with a specific training focus (e.g., hypertrophy, strength, power) and usually starts with high volume, low intensity workouts and progresses to low volume, high intensity workouts with the main aim to maximize the development of strength and/or muscle power (American College of Sports Medicine 2002; Haff 2004a; Kraemer & Ratamess 2004; Stone *et al*. 2000b). Sequenced progression from one type of training such as strength training can boost the gains obtained by another type of training such as power training (Haff 2004a), and this is where a periodized program is so effective. An adequately designed and periodized training program in the off-season lays the broader foundations to a successful competitive season (Haff 2004b). Generally, classic periodization plans are divided into different training epochs: a macrocycle (e.g., a 4–6 month period), which is subdivided into smaller epochs called mesocycles (e.g., 4–6 week blocks), which is further subdivided into even smaller units called microcycles (e.g., 1 week blocks; Haff 2004a). The time periods of these training blocks can vary significantly between sports. Each mesocycle has a very specific training focus and these all build up to preparing athletes to reach their peak athletic ability during competition (Pearson *et al*. 2000). Examples of these mesocycles are:

1 A preparatory period (which is predominantly in the off-season), which is subdivided into microcycles focusing on hypertrophy/strength endurance, basic strength, and strength/power in that order;

2 A first transition phase, which indicates a shift in focus from a high volume to high intensity training; followed by

3 The competition phase, where the focus can either be peak performance for a specific tournament or tournaments, or maintenance of strength/power throughout the in-season; and finally

4 An active rest or second transition phase, where a period of downtime/cross-training is allocated for recovery and regeneration (Haff 2004a; Stone *et al*. 2000b; Wathen *et al*. 2000).

Various combinations of these phases can be applied depending on the sport and/or individual's training goals, and each phase requires different levels of variation in training prescription (Stone *et al*. 2000b). The off-season period is where the most resistance training is performed and therefore also has the greatest application and manipulation of periodization (Haff 2004b).

It is important to note that one does not train at maximal effort (i.e., repetition maximum for every session). Day-to-day variation of intensity and/or volume across the various microcycles is also very important (especially for advanced trainers) in avoiding overtraining or stagnation (Stone *et al*. 2000b). In the linear periodization model, the volume (i.e., the number of repetitions within a weekly microcycle) remains the same, but the intensity fluctuates. For example, on Monday the athlete trains 8–12 repetitions using 8–12 RM loads, on Wednesday 8–12 repetitions with 5–10% less weight, and on Friday 8–12 repetitions with 10–30% less weight than the Monday's session (Pearson *et al*. 2000). Training blocks usually last ± 4 weeks (Haff 2004a). Variation in strength and power training is key for continuous improvement in muscle performance, especially during long-term resistance training. Therefore, it is common practice to repeat a macrocycle, such as indicated in the example above, 2–3 times within a 1-year period (Haff 2004a; Pearson *et al*. 2000).

UNDULATING OR NON-LINEAR MODEL OF PERIODIZATION

Because it has been shown that variation in training allows for greater gains in muscle development, conditioning specialists have begun to use a less traditional model of periodization called the non-linear or undulating model (Haff 2004a; Pearson *et al*. 2000). The key difference is that the non-linear variation is more dramatic during the individual microcycles than the more traditional linear model (Haff 2004a). The non-linear or undulating model allows for random variation in training focus (i.e., changes in volume and intensity within a smaller time-period, e.g., a 10-day training cycle; American College of Sports Medicine 2002; Fleck 1999; Kraemer & Ratamess 2004; Pearson *et al*. 2000). As with the linear model, it is recommended that the athlete performs some form of base training before embarking on this undulating periodized training model. As an example of the non-linear model, if one resistance trained on Mondays, Wednesdays and Fridays, one could train on the first Monday using 2–4 RM loads, on Wednesday at 12–15 RM loads, on Friday at 6–10 RM loads, and the following Monday using 15–20 RM loads where the cycle is repeated, this time starting on the Wednesday. Each day has a specific training focus (Rhea *et al*. 2002a). One can also add a power day where necessary; this design remains flexible according to the sport and individual requirements involved. This cycling of training continues for a predetermined time period (e.g., 16 weeks) and then progresses either into an in-season variation of this form of periodization, or an active rest period ranging 1–3 weeks.

Astute variation and combination of high intensity and low intensity resistance training can optimize strength development (Goto *et al*. 2004). The non-linear model appears to benefit sports that have a long competitive season (e.g., rugby union and hockey); in other words, there is not a specific build-up towards one specific event where they have to peak (Pearson *et al*. 2000). Also with long-season sports, there is not always sufficient time to focus on a big off-season build-up, as the off-season is sometimes too short in duration. This form of training allows these athletes to continue training throughout the season, except the volume and frequency of resistance training is reduced substantially and adjusted according to matches, tournaments, and sports practice (Pearson *et al*. 2000). This is where the undulating model has been used with great success (Haff 2004b). The non-linear model of periodization allows for great design flexibility and should be tailored specifically for individual needs.

PRACTICAL CONSIDERATIONS IN PERIODIZATION

Monitoring exercise tolerance and controlling recovery are important aspects in resistance training (Pearson *et al*. 2000). After individual training phases (mesocycles or microcycles), it is also common practice to allow a transition week, where a variation of active rest is incorporated before advancing onto the next phase; this is usually achieved by reducing the training volume and intensity within the week's training schedule (Haff 2004a). Incorporating this transition or recovery week is usually left to the discretion of the strength and conditioning specialist and can be very effective in avoiding overtraining and increasing performance levels in the following cycle.

Maintenance training is a popular form of resistance training which is frequently utilized by athletes during the competitive season (Allerheiligen 2003; Stone *et al*. 2000b) and by people who are not competitive but who train for health and fitness (Kraemer & Ratamess 2004). If the training is prescribed at too low an intensity to create some sort of training overload, one can actually stagnate and/or detrain. This can be detrimental for both general fitness and sports performance. Therefore, a structured and periodized approach to maintenance programs where smaller subprograms are prescribed in a cyclic fashion as part of the bigger training goal is recommended (Kraemer & Ratamess 2004). To prevent this detraining effect and/or stagnation it has been suggested that one applies a periodized approach using 2-week cycles within the in-season using primarily the core or complex multi-joint exercises such as squats, bench press, and power cleans (Allerheiligen 2003). This creates enough variation to challenge the body in different ways so that stagnation does not occur. Furthermore, it retains the strength, power, and muscle mass developed in the off- and preseason training programs (Allerheiligen 2003).

Programming of periodization and/or specific resistance training within the competitive season should also be micromanaged according to the weekly match or competition schedule. It has been suggested that one should schedule higher intensity training earlier on in the week, preferably at the beginning of the training week, and taper towards the matches or competition by lowering the intensity of training (Haff 2004b). With multiple matches or competitions, it is also recommended to shift the higher intensity strength and power training sessions to that period of the week, which allows maximum recovery before the following match or competition (Haff 2004b). An example of this form of manipulation is the "heavy/light" day system, resistance training 2 days per week (Haff 2004b). For example, training on the Monday would use RM loads (e.g., 3–5 RM, heavy day) and on the Thursday the loads utilized would be reduced by 15% (light day) using the same number of repetitions (Stone *et al*. 2000b). This method of training has been shown to be effective in developing muscle power (Baker 2001b). A major goal of the in-season program is to maintain as much of the athlete's strength and power developed in the off- and preseason as possible (Haff 2004b).

The value of periodized versus non-periodized resistance training programs becomes noticeable in programs of longer duration where the risk of overtraining is prevented through variations in training and systematic progression (Kraemer & Ratamess 2004). Untrained individuals do not appear to be sensitive to volume, and sometimes even intensity during initial resistance training exposure, so a general strength program will accommodate their needs quite sufficiently (Kraemer & Ratamess 2004). However, advanced resistance training programs are much more complex and require great variation with specific training goals in mind to maintain progression (Kraemer & Ratamess 2004).

Conclusions

Strength and power training forms an integral part of many sports conditioning programs. The appropriate development of strength and power can complement an athlete's sports-specific training and significantly enhance sports performance. The correct manipulation of resistance training variables and programs to develop these components requires a systematic and varied approach combining both science and practical experience. Strength training forms the basis of muscle power and also forms the basis of most sporting abilities to a large extent. The early training focus during the off- and early preseason is to progressively develop this component. Thereafter the training focus shifts towards maintenance of muscle strength in combination with the development of functional muscle power. One cannot sustain high-level strength and power training for long periods of time, because of the risk of overtraining and injury, and therefore programs need to be structured and planned accordingly. To optimize an athlete's strength and power development and to gain the maximum advantage from this form of training one needs to follow a periodized training approach, which allows for maximizing strength and power at the appropriate times for peak performance capabilities.

TRAINING TO IMPROVE ENDURANCE

This section aims to provide information on the practical application of the theoretical information already covered on training, with particular reference to endurance training. The goal is to provide sufficient information to the clinician or sports medicine practitioner for an understanding of the contribution that the training regimen may have in influencing various clinical conditions. Specifically, this section should aid in determining whether the reason for the problem or concern of the athlete presenting to the clinician has its source in errors in training, or whether some other cause for the problem needs to be sought and investigated. Thus, this section does not provide specific information for training prescription as might be used by a coach, but rather sufficient information to identify errors in an existing training program as used by someone participating in an endurance sport such as running, cycling, swimming, or canoeing. Running has been used for most of the specific examples, as this is a major mass participation sport and is also the endurance sport that is least forgiving when training errors are committed, with a concomitant high incidence of injury.

Goal setting

Initially, no training program is easy, and indeed, seldom pleasurable because of the state of relative unfitness when the training commences. It takes time for someone to gain sufficient fitness for the activity to be truly enjoyable, be it running, cycling, or one of the other endurance sports. It may therefore help a beginner with motivation problems to set an achievable short-term goal, as well as long-term goals. A short-term goal may simply be to train a certain minimum number of times per week, whereas a long-term goal may be to complete a particular running or cycling race. To help with motivation it is often useful to keep a logbook of training progress. It could be suggested to write down the training that has been completed each day and to keep a weekly total of training distance or time. In this way the beginner can easily see the progress being made as fitness improves.

Limitations to training

Genetic ability

It is important to realize that everybody has some genetically determined limit that will ultimately dictate how well they will perform in their chosen sport, be that performance at an elite level of competition to win races and break world records, at a level of simply achieving one's own individual best possible performance or, at the other end of the spectrum, completing a specific event within a given time to simply be classified as an official finisher of an event. By training according to a scientifically designed and constructed training program that incorporates the various features necessary for optimal physiologic adaptation, it is possible for someone to achieve the best that they are capable of within the limitations imposed by their individual genetic capabilities. This is achieved by finding the right blend of volume of training undertaken, intensity of that training, and mix of specific types of training sessions that comprise a physiologically balanced training program. To achieve this requires a combination of both sound scientific principles and the "art" of coaching.

The significant part played by genetics in determining how much someone will improve once a training program is started has already been alluded to. Particularly, there are "adaptors" and "non-adaptors" to a training stimulus. In essence, even elite athletes have a genetically determined "ceiling" as to how much adaptation can occur in response to training. Similarly, some people possess a naturally high aerobic capacity without having participated in a training program, while others have to train very scientifically to elicit as much training adaptation as possible. Thus, we sometimes hear of athletes who appear to train very hard in order to excel, and at other times we find someone who has performed at a very high level on surprisingly little training. For example, if an elite athlete had to train very little, that individual will quite likely out-perform the genetically non-gifted person who has trained very hard according to systematic program. It is important to understand that not everyone can become an Olympic champion by hard training and adhering to a good training regimen. Thus, it is important to set goals based on improving individual performance.

Effect of gender

Gender differences exist only in the maximal volume and intensity of training that can be sustained. Specifically, women generally cannot tolerate as much training as men. Even at the elite level, top male athletes can tolerate a greater training load in terms of both volume and intensity than the top females. This can probably be attributed primarily to the fact that, generally, women do not have as much muscle mass and muscle cross-sectional area as men. Thus, men can generate more force and power. However, if normalized for cross-sectional area (i.e., if a male and female are matched for exactly the same amount of muscle) then gender differences are reduced. Therefore, in terms of the intrinsic ability of the muscle to generate force and power, there are few gender-related differences. However, the elite female athlete will have a higher percentage of body fat than an elite male athlete. Thus, in two elite athletes of similar body size and mass, the female will have more fat mass and less muscle mass than her male counterpart. This is probably one of the primary reasons that the performance of female endurance athletes is approximately 10% slower than that of men for most events. This is particularly so in sports in which the upper body is involved, because men have relatively more muscle in the upper body. It is interesting to note that when male and female runners with equal 10 km or marathon times are compared over a much longer race distance of 90 km, the female runners have been found to outperform their male counterparts (Bam *et al*. 1997). This is accomplished physiologically by the female runners maintaining a relatively higher percentage of $\dot{V}O_{2max}$ and for longer, without slowing their pace as much as the men. Thus, in the sample of "average" runners in this particular analysis, females appear to be more "fatigue resistant" than men. However, it is likely that at the extremes of the population from which the very best performers come, these differences become much less. Noakes (2001) theorized that while the average male marathon runners are likely to be taller and heavier with less body fat than the average female marathon runners, these differences are likely to be much less when the world's best male and female runners are compared. Noakes postulates that the world's best male and female marathon and ultramarathon runners are all equally small and light with a low percentage of body fat, although the percentage of body fat would be marginally greater in the female runners. When considering average runners, the generally smaller women are at an advantage which becomes increasingly apparent as the race distance increases, hence their apparent greater fatigue resistance. However, because the size differences are much smaller in the world's best marathon and ultramarathon runners of both genders, it is expected that the relative advantage of the average female runner over the average male runner will disappear when the performances of the elite athletes of both genders (whose body sizes are more similar) are compared. Noakes (2001) concludes that the fatigue resistance of the very best male and female ultramarathon runners is probably not different.

Although the absolute training load that can be tolerated is less in females than males, the physiologic response to training does not differ between males and females. This is true for all the different elements of training that comprise a balanced endurance training program, such as long duration training performed at a moderate percentage of $\dot{V}O_{2max}$, high intensity interval training of short duration, longer duration intervals at lower intensity, "tempo" and "threshold" training sessions, and other specific types of training. Thus, females and males respond in the same way from a physiologic perspective to both endurance and interval training, although the upper limits of training load will be reached at a lower overall level in females.

Specificity

In all types of training a number of established physiologic principles apply. Most important of these is specificity. A swimmer will not gain much benefit by cycling or running. Similarly, a long distance runner should spend almost all training time running to gain the most benefit. Although impossible to run a marathon every day in training, the distance runner will maintain a high weekly training distance and in different training sessions include runs at slower than marathon speed, runs at marathon speed but over a shorter distance, and even shorter runs at a speed faster than marathon race speed. This is true also for other disciplines such as cycling, canoeing, and swimming. It is important to appreciate that training is absolutely specific and that the athlete is only fit for the sport for which they train. Thus, while runners may be capable of running effortlessly for hours, they are often unable to swim comfortably even for a few minutes. The reason is that running and swimming train different muscle groups. When a runner exercises the untrained upper body in swimming, for example, the body responds as if it were essentially untrained. Whereas running principally exercises the legs, leaving the upper body musculature relatively untrained, canoeing and swimming mainly train the upper body, leaving the legs untrained or less trained. This distinction becomes even more subtle: runners who do little running on hills will find hill running difficult. This is because uphill running stresses, in particular, the quadriceps – a muscle that is much less important during running on the flat and is therefore undertrained in people who run exclusively on flat terrain.

Training specificity also includes speed training, hot weather training, and altitude acclimatization. Because the speed of training determines which muscle fibers will be active in the particular muscle groups being exercised, training slowly and then racing at a faster pace utilizes muscle fibers that are relatively untrained. Similarly, to race effectively in the heat or at altitude, it is necessary to train under these conditions to allow the body to adapt. Therefore, the more closely the training simulates the specific demands of the sport for which one is training, and the environment in which competition will occur, the better the performance will be.

Start easily

When someone has decided to begin a training program, it is probably only human nature that they want to do as much as they possibly can within the first weeks of training. While this enthusiasm is laudable, it is definitely not the best way to start a new training program. The reason for this is that it takes time for the bones, tendons, muscles, and cardiovascular system to adapt to the cumulative stress of regular training. This is particularly so in the case of running where the stress on bone and tendon is high. With non-weight-bearing sports such as cycling and canoeing, the problem is somewhat reduced, but nevertheless progress should be at a slow, consistent rate. Typically, when someone embarks on a new training program, the tendency is to try and train a little bit faster or harder than in the previous training session. This approach is not sustainable.

Training intensity

It is only ever necessary and possible to train at a high intensity for 5–10% of the total training time (Daniels 1998). For example, most of the best marathon runners do most of their training at a speed of 30–50 $s \cdot km^{-1}$ slower than their race pace. While training, the effort should be perceived as "comfortable." A good way of testing this is the "talk test." It should be possible to maintain a conversation with training companions. If it is not possible to talk, then the training intensity is too high and the session should be continued at an easier pace. Training intensity will be addressed in more detail subsequently.

Training structure

All training should follow some well-established principles. The first principle is to train initially to increase weekly training duration. Once the appropriate weekly training duration has been reached, then specific training sessions of high intensity can be introduced.

An athlete should gradually and systematically increase training distance until the maximum training load that the athlete can tolerate has been reached. Signs that the maximum training load has been reached is a failure to adapt to a new, higher training load, an increase in muscle fatigue, a feeling of "tired, heavy legs," an increase in the time taken to complete a given training session (i.e., getting slower, rather than faster), or the appearance of a mild injury or illness (Noakes 2001). The total training load that can be tolerated depends on genetic factors and careful increase in the training distance, and takes years to develop fully. Ignoring signs that the body is failing to adapt to the training load can result in overtraining.

The first step in increasing the total training load is to increase the duration of all the training sessions, followed by the frequency of those sessions (i.e., the number sessions per week). All of this training should be at an intensity that is significantly slower than race speed, correlating to an intensity of 60–70% of maximum oxygen uptake ($\dot{V}o_{2max}$). Closely coupled to the increase in weekly training distance is the introduction of one or two single, long duration training sessions; the so-called "long weekend" run or training run. This prepares the muscles of the athlete to resist fatigue during races of long duration. However, this training session should only be included in the training program after the muscles have adapted to the initial stress of the training program.

Regularity of training

Training regularly through the season is an important concept that has been emphasized by many of the great coaches of endurance sportsmen and women. While this concept may have been derived from experience gained over many years of prescribing training, there is now supporting physiologic evidence. Therefore, even if the training load is modest, such as when an athlete starts a training program for the first time, the training sessions should be undertaken regularly to achieve the best possible increase in fitness. In the case of the elite performer, training regularly is an obvious element of the training schedule, and in this case regularity of training is synonymous with consistency. Specifically, the training schedule should be consistent in terms of the nature of the various training sessions undertaken. Thus, in any given 1–2 week cycle of training, a similar training structure should be followed, including the nature of the high intensity sessions. The "pattern" and the type of workouts should be retained for some time before any change is made to the fundamental components of the sessions. It is inappropriate to have an inconsistent approach as this will produce unpredictable results and also increase the risk of injury.

Although training should be consistent, it should not be followed blindly based on the assumption that any program will guarantee success. Rather, the effects of the program on the individual's performance must be constantly assessed and appropriate modifications made where necessary. Such an approach allows for varying rate of change and adaptations which are attributed to the genetic variance between athletes. Therefore, every training program must be tailored and continuously adjusted to the individual who will be following it.

Frequency of training

When someone starts a training program for the first time, training should only be on every second day. In high impact sports such as running, this ensures adequate time for adaptation and repair between training sessions, specifically to the load-bearing bones of the legs. Bone adaptation is particularly slow. In fact, for approximately 3 months after the start of a weight-bearing training program, bone loses strength. Thereafter, the osteoblasts become very active and new bone is laid down (Scully & Besterman 1982). Thus, until this time, the risk of developing a bone stress injury if the training load becomes too high, too rapidly, is greatly increased. The number of training sessions each week should be increased only once the duration of each training session performed every second day has reached an appropriate time. This depends on the sport type and training time available. For example, in the case of a running program in which weight-bearing stress is high, a more cautious increase in training frequency should be followed than in a sport such as cycling. In cycling, limitations are more likely to be related to the rate of muscle adaptation, which occurs more rapidly than bone adaptation (Margulies *et al*. 1986). The progression from training every second day to more frequent training should proceed systematically. Training every second day should be increased to training for two successive days followed by a recovery day of no training. This should be followed by three successive days, then four successive days, etc., with an appropriate amount of time at each successive "step" before proceeding to the next. On the extreme end of high training load, it is quite common for elite athletes to train every day, with twice daily training sessions 5 or 6 days each week.

Training duration

Initially, it is more useful to prescribe training duration based on the time spent training each week, rather than the distance covered. The concept of time taken to complete a single training session needs to be considered even in the case of someone who has been training for many years. Consider an elite versus a slow "club" runner. The elite runner will cover a distance of approximately 16 km in 60 min in training, whereas the average club runner may cover approximately 12 km in the same time. Alternatively, to complete 16 km would take the same club runner approximately 1 hour 20 min. Yet 1 hour 20 min of running probably imposes more biomechanical stress to the slower runner than that experienced by the fast elite runner whose training session of 16 km is complete after just 60 min in this example. Thus, at least initially, measuring training load based on time rather than distance is preferable.

Regardless of whether the training prescription is time or distance based, as with training frequency, increases should be progressive and systematic. Initially, the beginner would train for only a short time in any given training session. For someone beginning a running program, this may include a period spent walking, developing later into walking alternating with running, and finally only running. Initial progress may appear to be slow. In the case of a non-weight-bearing sport such as cycling, the rate of progression in training duration can be substantially quicker.

Initially, the duration of each training session should be increased every week, while the frequency remains at every second day, as previously described. Once the duration reaches 30–40 min in the case of a running program, or approximately 60 min in the case of cycling or swimming, the switch can be made to increasing the training frequency.

While 30–40 min of training five times weekly is adequate for health benefits, many people will want to train more than this, with a goal of completing a specific running or cycling race. For these individuals, it will be necessary to increase the duration of specific training sessions to prepare for the particular physiologic requirements of the race. To complete a marathon, for example, will require increasing the duration of one training session each week until the duration of that specific session is approximately 75% of the anticipated finishing time for the marathon. Thus, someone training with the anticipation of completing a marathon race in 4 h will systematically increase the time spent on a single run each week until 3 h of running can be completed comfortably in a single training run. These long duration training sessions are at substantially slower speed than "race" speed. The speed, or percentage of $\dot{V}O_{2max}$ at which training sessions are carried out are unimportant when a training program is started.

Initially, a week of training may consist of a training session every second day of 15 min duration each. Subsequently, the time will be increased systematically to 20, 25, 30, 40 min, etc. This will be followed by more frequent training sessions, and finally one of those sessions will become much longer in duration. Ultimately, the duration of a specific training session will be sports-specific. For example, a runner may build up training duration until capable of running for an hour each training session. On the other hand, a cyclist could build up to more than an hour in a single session on a regular basis.

Throughout this period of increasing training duration, it is not too important that much attention is given to the speed at which the training is done. While it is acceptable that the training speed gradually increases naturally during this time, no direct emphasis should be placed on speed or speed work, or trying to make each training session faster than the one before. This approach is not sustainable. Thus, the key to successful training, at least for the first 12 months or so, is the amount of time spent training each week, rather than the distance covered, or the speed at which the training sessions are done. As fitness improves, speed will increase naturally, and therefore more distance will be covered for the same time spent training. After 12 months or more of training in this way, a plateau in performance will be reached. To improve beyond this, some training will have to be carried out at a faster pace, which will require the introduction of faster paced sessions and speed work into the training program. Speed work should always be approached with caution, preferably with the help of a knowledgeable coach, or after reading widely on the topic, as this type of training is high risk for inducing injury or symptoms of overtraining.

To improve further, elite athletes can also train greater distances. However, the risk of injury and overtraining increases precipitously when, specifically with running, training is increased beyond 120–160 km per week for average and elite runners respectively. However, for someone wanting to perform at the elite or optimal individual level it is necessary to identify the maximum volume of training to achieve their best possible performance. This can be by first finding the training volume that produces the best results. This training threshold can really only be identified by a systematic increase in training until more than the optimum amount is shown by a decline in performance. Accordingly, training volume needs to be increased gradually and progressively until the individual failure threshold is identified. This corresponds to the training volume that produces a deteriorating, not an improved, racing performance. For the elite performer, identification of this training threshold is a crucial exercise in determining optimal training volume. Training beyond this threshold will result in poor performances and training less rather than more will lead to success. Gradually increasing the intensity of some of that training (speed work) will then optimize the entire training program. Thus, a scientific measure of training load that incorporates both duration of training, as well as the quality of the training, is a useful adjunct to monitoring training.

Foster *et al*. (1996) have proposed a method in which training load is calculated as the duration of the session (in minutes) multiplied by the average rating of perceived exertion during the session (a score between 0 and 10, where 0 is perceived as no effort at all and 10 is a very, very strong, almost maximal perception of effort). The total training load for the week is then plotted on a graph depicting the calculated training load against a measure of performance, such as a time trial. Such a graph will show how performance improves as training load per week is increased, until a point is reached in training load where further increases results in no further performance increase, or even a decline in performance. This type of monitoring soon shows that there is a logarithmic relationship between training load and performance. Thus, a given training increase (e.g., 1000 units per week) produces progressively smaller improvements in performance.

An important point to emphasize is that the individual who wishes to be consistently successful, at whatever level, must learn early on in his or her training career to treat everything performed in training as part of an experiment. The athlete who understands the specific effects that each manipulation of training has on his or her body and performance will be the most successful on a regular basis and have a better chance of reaching his or her full potential.

High intensity training

All the training that has been discussed to this point has been considered to be training performed at a relatively low intensity. As the athlete progresses, additional training at a higher intensity must be included at the appropriate phase of development. These training sessions are performed at 80–100% of $\dot{V}O_{2max}$, and are commonly referred to as speed work or interval sessions.

Speed work or high intensity training is not without risk. The common errors are performing the sessions too often and too fast, using an inappropriate distance, inappropriate progression, or recovery between the fast components that is insufficient for the level of fitness of the athlete. Another error is to have the mind-set that each fast training session must be performed at a faster speed than the previous one. This is neither desirable nor possible. For example, an improvement in time trial performance may only be possible every few weeks. The most positive sign that improvement is occurring is if it is possible to perform the same or better times in successive sessions, but with less effort. Conversely, if the sessions become increasingly difficult and time trial or interval times start to become slower rather than faster, then this is a clear indicator that the athlete is trying to progress too rapidly and a period of recovery is required instead of more and harder training. Typically, however, someone in the position of finding that their speed work appears to be getting slower, suspects that they are not training hard enough and compounds their error by trying to train even harder. This will likely lead to development of symptoms of overreaching (Meeusen *et al*. 2006).

Initially one but later two high intensity (speed work) sessions should be introduced into the training regimen once the total weekly training distance has been reached. One of these sessions should be of short duration but of high intensity, corresponding to approximately 60–90 s performed at a fast speed with an equal rest interval before starting the next 60–90 s rest. "Rest" refers to running at a markedly reduced speed. A second high intensity session each week should be of longer duration, of around 3–5 min but somewhat slower. Again, the rest interval will initially be of equal duration. Both types of high intensity sessions must be introduced gradually into the program, progressively building on the number included in each session until 10–12 repeats of the shorter duration speed work can be completed and around 20 min of the longer speed workout. When this is achieved, the next step is a systematic reduction in the rest period. When the athlete has achieved this level a race can be entered. Low profile races can also serve as a type of speed session.

A series of studies in the UCT/MRC Research Unit for Exercise Science and Sports Medicine at the University of Cape Town and the Sports Science Institute of South Africa have attempted to evaluate the effects of specific speed work sessions on performance. One such study showed that replacing 15% of a group of cyclists' usual training with two speed sessions per week for 3 weeks improved cycling time trial performance by 3.6% (Lindsay *et al*. 1996). Doubling the total number of training sessions by increasing the high intensity training program from 3 to 6 weeks produced no additional benefit (Westgarth-Taylor *et al*. 1997). In another study, different groups of subjects performed high intensity training from 30 s duration to longer (8 min) duration from 175% to 80% of $\dot{V}O_{2max}$ (Stepto *et al*. 1999). Interestingly, only speed work at race pace (4 min at 85% of $\dot{V}O_{2max}$) or very high intensity (30 s at 175% of $\dot{V}O_{2max}$) improved cycling performance in a 40 km cycling time trial. These findings demonstrate two important points: (i) certain types of speed work may be more effective than others; and (ii) large changes in performance can be achieved in a relatively short period of time.

The finding of measurable changes in performance was found also by Smith *et al*. (1999) who measured the effects of high intensity training using two interval sessions per week for 4 weeks. Subjects trained at the maximal treadmill speed achieved during a $\dot{V}O_{2max}$ test, with the duration of each interval being 60–75% of the maximum time that each subject could run at their individual peak speed. Each training session involved the repetition of either five or six of these intervals. In this way subjects maintained heart rates of approximately 90–95% of maximum heart rate during the fast repetitions. However, if exercise duration was extended to more than 70–75% of maximum time capable of running at the velocity of $\dot{V}O_{2max}$, then the heart rate would rise to 100% of maximum after the second or third repetition, suggesting that the intervals were too long and too stressful. Second, if the heart rate did not decrease below 125 beats·min^{-1} by the end of the recovery intervals, the next interval would always elicit a maximum heart rate. This supports the principle that more is not necessarily always better. However, the main finding was that this period of high intensity training significantly increased peak treadmill running speed, the time for which this speed could be maintained, and 3000 m time trial performance, the latter by 2.8%. The authors suggested that using the peak speed obtained in the $\dot{V}O_{2max}$ test and 60–75% of the time for which the peak speed could be maintained, might be particularly useful in exercise prescription. This suggestion is appealing for a number of reasons. First, the variables are easily measurable for a number of sports and do not require any sophisticated equipment. Second, this method does not require the measurement of blood lactate concentrations and the use of the so-called "anaerobic" or "lactate threshold," the physiologic basis of which is in doubt (Swart & Jennings 2004). Third, the incorporation of heart rate monitoring provides a tool to determine when the fast component has been too long, or the number too many (Achten & Jeukendrup 2003).

Experience has shown that high intensity speed training cannot be continued indefinitely without risk of injury, overreaching, or overtraining. It is therefore important that after 4–6 weeks of progressive increase in speed work, there is a recovery period of a week of reduced training before the next period of speed work commences.

Additional training sessions that could be added later include resistance training (use of hills for runners and cyclists) and training sessions of 90–120 min at close to race speed (often called "tempo" training). Like the speed work already discussed, these specialized training sessions also require the input of a sports scientist or experienced coach to reduce the risk of injury or overtraining. It should be stressed that these sessions, as with the other high intensity sessions, need to be introduced into the training schedule progressively, but only much later in the development of the training regimen.

Short races are an excellent form of speed training. These sessions can be carried out as hard efforts with the intensity controlled by perceived effort or heart rate. Provided that these sessions are not at all-out racing intensity, it is a perfectly acceptable addition to a structured training program and should not necessarily be viewed as a training error.

In essence, the introduction of speed work into the training regimen should not be a random event. Rather, the introduction of speed work must be carefully planned, particularly with regard to the distance of the speed work sessions, intensity of the sessions, number of sessions per week, recovery between hard intervals, and overall progression of the speed work component of the training regimen. Failure to pay attention to these factors can lead to an increased risk of injury or the manifestation of the symptoms of overtraining. Therefore, the sports medical practitioner should carefully analyze the nature of any speed work carried out by anyone presenting with injury or symptoms of chronic fatigue.

Hard day, easy day principle

Bill Bowermann and Bill Dellinger, coaches who have trained a dynasty of great runners from the University of Eugene, Oregon, were the first coaches to teach that training should not always be at the same intensity and duration every day. They observed that progression was best when the athlete was allowed a suitable recovery period after each hard training session. This period of recovery ranged from as little as 24 h for some athletes to 48 h for others. This became known as the "hard day/easy day" training principle and incorporates the physiologic principle that a recovery period is needed for physiologic adaptation to take place after a training load that has caused a significant physiologic stress (Busso *et al*. 2002).

For experienced competitors training to improve performance, all training should follow a "hard day/easy day" principle. The training session on one day should be "hard" in intensity rating, followed the next day by a session that is "easy." For those athletes training twice daily, only one session would be a "hard" session on a "hard" training day. Some athletes find it difficult to train easily when they should be on the "easy day," and for these athletes the use of a heart rate monitor to prevent training too hard is a useful tool. All athletes must establish for themselves how frequently they can train hard. Success will, to a large extent, depend on whether or not they achieve this balance.

Tapering

To achieve a best possible performance, at some point every athlete should reduce their overall training load. Typically, this is primarily a reduction in training volume, with a smaller reduction in the high intensity sessions. Many athletes fear that they will lose their fitness by reducing their training load. Contrary to this opinion, however, an appropriate reduction in training load at the right time before a major competition will enhance performance (Bosch *et al*. 1999). In the third week before competition, training load can be reduced to approximately 80% of the normal training load in terms of weekly duration or distance; 2 weeks before competition the training load can be further reduced to 60–70% of the normal training load. In the final week training should be maintained, but at the reduced, or even more reduced, level. By maintaining the high intensity workouts (at the same speed, but reduced in overall volume) performance will be improved. It is important to note that the high intensity workouts must not be removed from the training regimen.

Many athletes who are training to improve their performances, rather than for health benefits, fail to either engage in speed training or in tapering and get locked into a regimen in which all attention is focused on weekly training distance. These athletes will only perform their best when they understand the importance of speed work in improving performance and the beneficial effects of tapering before important competition. Scientific evidence has confirmed that tapering produces a dramatic improvement in performance (Mujika *et al*. 2004). The effect is greatest if there is a rapid reduction in training volume in the first few days of the taper, but maintenance of the high intensity workouts, although somewhat reduced in total volume. It has not been clearly established how long the optimal tapering period before a competition should be. The shortest period is probably 10 days, to the 3-week period already discussed. It is quite likely that this may be an individual response, also influenced by the preceding training load. The heavier the preceding training, the more likely it is that a longer tapering period will be required for the body to recover fully in order to achieve optimal performance. As with the optimum volume of training that needs to be determined for each individual, so each individual must experiment with different tapering programs to determine which program produces the best results.

Peaking and subsequent decline in competitive performance

After reaching a peak in competitive performance, many athletes do not accept the fact that it is impossible to perform well for more than 3–6 weeks before their performances start to decline. Performance may improve steadily for as long as 10 weeks, but beyond this period the athletes will often become easily tired, sleep badly, become prone to injury, illness and symptoms of overtraining (Meeusen *et al*. 2006). The decline in performance can occur very rapidly. It may take only 3 weeks to go from a best performance to the point at which the athlete is physically incapacitated. These athletes often present to the medical practitioner for help because they are convinced that there is something medically wrong with them. While this may well be the case in some instances, it is important for the sports medicine practitioner to realize that it is quite normal for performances to decline after a period of peaking, tapering, and racing. A period of reduced training should be planned at this phase of training before the next build-up to another peak begins, otherwise overtraining can result. Once in the overtrained state it may take the athlete many weeks to recover and be able to resume normal training (Noakes 2001).

Recovery

Whether the training regimen is one that requires two training sessions each day (e.g., the elite athlete aiming to win races and championship medals), or four training sessions per week (e.g., the person training for health and fitness reasons), the rule discussed previously in this chapter pertaining to regularity of training applies. However, even though regularity is an important principle of training, there should also be periods of rest built into the training program. Indeed, no matter what the level of training, there should be periods during which the training load is strategically reduced. Thus, in a given year, even the elite endurance athlete will have a number of periods during which little training is carried out. Typically, this will be after an important race or after a continuous build-up in the training load. Similarly, the non-elite participant will benefit from the occasional rest period consisting of a significant reduction in the normal training load. These recovery periods, usually consisting of a training week of reduced distance and intensity, can themselves be considered to be a part of the "consistency" rule by virtue of the fact that they appear regularly, about every 6–8 weeks, in the training schedule.

Heart rate monitoring

A popular trend in recent times has been to use heart rate and a heart rate monitor to control training intensity. While scientific in many respects, training entirely on heart rate has many drawbacks, as the so-called heart rate training zone often fails to predict adequately the correct intensity for training (Lambert *et al*. 1998). Reasons for this include the fact that heart rate while exercising is very dependent on factors other than just the work rate. These include temperature, diurnal variation, and prior sleep. Heart rate also does not adequately account for muscular fatigue which may occur from a prior training session incurred on the previous day. Thus, heart rate may indicate that the training intensity is too low, whereas a low intensity may be appropriate for tired muscles resulting from a previous speed workout for example. Therefore it may be better to use a perception rating of intensity to control training speed. Specifically, does the session feel easy, somewhat hard, hard, or very hard? Where heart rate monitoring may be used to advantage is to monitor trends of either an increase or decrease in heart rate for a given controlled training session.

Often, those who wish to use heart rate during exercise as a monitor of training effort will use an equation based on a predicted maximum heart rate using a simple formula of 220 minus age in years. Therefore, the predicted maximum heart rate of a 40-year-old is (220 – 40) beats·min^{-1}, which equals 180 beats·min^{-1}. However, there is little or no scientific basis for this calculation (Edwards 1997). Therefore, should someone wish to use this method to determine the appropriate exercise intensity, true maximum heart rate should first be established, because all younger, highly trained athletes have maximum heart rates that are lower than expected for their ages. In contrast, highly trained athletes older than 50 years have higher maximal heart rates than predicted by this equation.

Maximum heart rate can be established accurately in one of two ways: an exercise scientist can perform a maximum exercise test or an individual can perform their own test while wearing a heart rate monitor while exercising as hard as possible for 4–10 min. This test should not be undertaken in an unsupervised setting by people whose heart conditions are not known. The popular training dogma is that maximum benefit from training is achieved by training at 60–90% of maximum heart rate. Various exercise training prescriptions can be found that are based on different training heart rate zones. However, for the reasons already described, it is not the best method of monitoring training. For certain people, it may be better than no monitoring whatsoever. This may be particularly true for those individuals who tend to train too hard, too often. For these people, a coach could prescribe a training session (particularly the "easy" day) in which a particular heart rate should not be exceeded. More useful in general terms, however, is that as fitness increases, at any particular exercise intensity or speed, the heart rate will be less. Another benefit from heart rate monitoring is that, performed regularly, the heart rate after exercise will return more quickly towards resting values. Conversely, an increased heart rate at a given speed may indicate the onset of overreaching or overtraining. When this is observed, the individual needs to rest from training, or train less, until recovery has occurred.

Weight training

Weight training performed two or three times weekly has a positive effect on endurance performance if it does not replace training sessions in the endurance training program. In contrast, adding endurance training to a strength training program in which the main expected outcome is a gain in muscle strength and power causes reduced adaptation with a resultant compromised gain in strength (Fleck & Kraemer 1997). There are some specific advantages of strength training for "downhill" races because of the damaging effect of eccentric muscle contraction that occurs when running downhill, which can be reduced by the increased strength from a carefully planned weight-training program. Typically, for those athletes who wish to include weight training into their program, there should be no more than two to three sessions per week. When the training load is increased, the supplementary weight training sessions should be reduced to two sessions per week. Weight training is best performed on the "easy" training days of the sports specific training schedule.

Stretching

Training strengthens the active muscles and reduces their flexibility. To maintain flexibility of the muscles, specific stretching exercises can be performed. However, the exact benefit of stretching, particularly to prevent injuries, has not been proven conclusively (Shrier & Gossel 2000). This has not prevented the popular belief that stretching helps in this regard. There is also no published evidence to suggest that regular stretching improves endurance performance. The one condition that may well be prevented by regular stretching is exercise-associated muscle cramping (Schwellnus 1999). When all the evidence is considered, the pragmatic recommendations are that a stretching program should be carried out in moderation and that the stretching exercises should be performed correctly. Importantly, the stretch must always be applied gradually. Ballistic stretching, which involves bouncing up and down, is considered to be an ineffective method as it simply activates the stretch reflex, causing the stretched muscle to contract rapidly. The tension inside the muscle during this type of stretching is much higher than in a static stretch. Although it is often said that this form of stretching increases the risk of injury, there is no convincing published evidence to confirm this.

Static stretching is a specific type of stretching exercise. During static stretching, the stretch position is assumed slowly and held for 30–60 s. The build-up of tension in the muscle is slow, and so the stretch reflex which causes the muscle to contract is not activated. This type of stretching invokes the inverse stretch reflex which causes muscle tension to fall, enabling the muscle to be stretched a little further. More sophisticated techniques include the contract–relax and contract–relax–antagonist contract techniques. The static stretch technique has been shown to be highly effective for increasing the range of motion while being relatively low risk for inducing injury (Hughes 1996).

Overtraining

Overtraining is discussed in detail in Chapter 3. From a practical perspective relating to endurance training, one way to help prevent overtraining is to ensure application of the "hard day, easy day" training principle. A heart rate monitor can be useful to prevent hard training on a day when only light training should be carried out, by prescribing a heart rate that must not be exceeded during training. However, if one day of easy training is insufficient for the athlete to feel adequately recovered, then an extra day of "easy" training should be carried out before the next strenuous workout. Applying this diligently will reduce the risk of developing symptoms of overtraining.

Symptoms of overtraining include one or more of the following: painful muscles, muscle fatigue, general feeling of fatigue, depression, irritability, disturbed sleep patterns, and increased POMS score, weight loss, raised resting pulse rate, an increased susceptibility to upper respiratory tract infections, gastrointestinal disturbances, and a decrease in running performance (Lehmann *et al*. 1993; Meeusen *et al*. 2006).

There is no magical cure for overtraining other than a reduction in training load until the symptoms have passed. Complete rest from training may be necessary. Reducing training or resting is not something that a sportsperson training seriously wants to do, and it is often difficult to convince someone that these are the only options to recover from the overtraining syndrome. The training at which the onset of symptoms commenced should be noted (Foster 1998). This represents somewhat more than the maximum training load that can be tolerated. Subsequently, as that particular training load is reached, the volume and speed should be increased only very gradually as the physiologic adaptations are given every chance to occur. However, it should be recognized that everyone has a genetically determined ceiling in training load above which adaptation will not occur.

TRAINING FOR SKILL ACQUISITION

To be successful in sport athletes must possess great physical attributes such as strength, power, stamina, and flexibility, as well as demonstrate expert motor skill abilities. Indeed, at the elite level the difference between athletes often relates more to the ability to perform skills with high levels of consistency, precision, and smoothness than it does to issues of speed, power, and strength. However, despite the importance of effective skill execution in determining sporting performance, research into the areas of motor learning and skills training have often brought conflicting results, leaving coaches confused about the best training methods to use.

One of the difficulties facing researchers concerns the definitions of skill and skill acquisition. For example, the concept of skill itself is much more difficult to define than the physical capacities such as strength or stamina, as it is more a construct than a physical capacity. Leonard (1998) summarized this issue when he indicated that skill is not a term than represents a singular entity, but rather involves sensory processing, motor learning and control, coordination of muscles, adaptability of control during various conditions, and retention of the acquired skills. Importantly, skill acquisition is also multidisciplinary and involves areas such as neuromuscular physiology, biomechanics, and psychology.

Despite the complexities in defining and categorizing skill acquisition, the goal in training for skill acquisition is to allow the athlete to perform skills with quality, certainty, and with economy of movement, thereby conserving energy and reducing potential injury. In order to do this, the coach must be aware of how the neuromuscular system works, the mechanical principles underpinning movement, and the environments that may facilitate or inhibit skill acquisition. This part of this chapter is divided into two sections: the underpinning physiology that contributes to skill acquisition and theories of skill acquisition, followed by evidence-based concepts influencing motor skill acquisition.

Physiologic basis of motor skill acquisition

Skilled performance is purposeful movement and is reliant on the coordination of agonist, synergist, and antagonist skeletal muscles. Motorneurons innervating skeletal muscles are found in both the central nervous system (CNS) and peripheral nervous system (PNS) and excite or inhibit muscles to produce coordinated movements. The synchronized and coordinated means by which the nervous system varies the amount of force required to produce meaningful movement is one of the fundamental aspects of motor skill acquisition. Performance with too little or too much muscular force can mean the difference between success and failure. To produce skilful movement, there must be an interaction between the number of motor units recruited, the muscular fibre types involved, and the synchronization and firing rate of motorneurons. For reviews on motor unit recruitment the reader is referred to Binder and Mendell (1990), Enoka and Stuart (1984), and Noth (1992). In addition to the amount of motor unit recruitment, the nervous system must also control agonist–antagonist muscle activity. When an individual performs a goal-directed motor skill of moderate to fast speed, a three burst pattern of agonist–antagonist–agonist muscle is observed allowing for smooth controlled movement from initiation to completion (Enoka 1994).

Skilled movement also requires sensory feedback to the nervous system, particularly from the internal environment. There are two receptors that provide sensory feedback to the CNS: muscle spindles and Golgi tendon organs (GTOs). Muscle spindles, found within each muscle fiber, provide information about the length of a muscle and the rate in change of the length during movement. If a muscle is stretched, these receptors will send impulses to the CNS, which in turn sends a motor command to the muscle to contract, thereby stopping the muscle from overstretching. GTOs, found in the musculotendinous junction, responds to muscle tension either from the muscle being stretched or generated by muscular contraction. Unlike spindles that monitor individual muscle fiber length, GTOs receives information from 10–15 motor units, thereby monitoring whole muscle tension rather than individual muscle fiber tension (Hullinger *et al*. 1995). For more extensive discussion on sensory feedback the reader is referred to Rothwell (1994).

Central nervous system and motor control systems

The coordination and management of muscle groups during skilled movement is the responsibility of

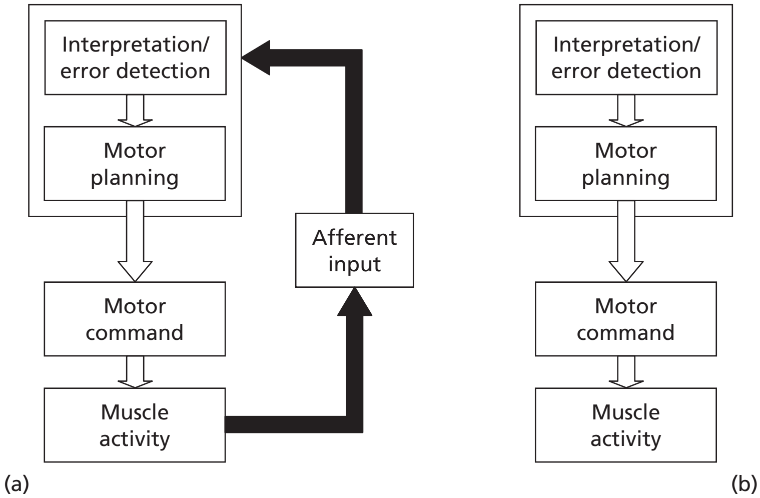

Fig. 1.1 (a) Closed-loop control system. (b) Open-loop control system (Schmidt & Lee 1999, after Hodges, 2003).

higher CNS brain centers, such as the cerebellum, basal ganglia, and cerebral cortex. Unlike reflexes, which are stereotypical responses to a stimulus and controlled primarily at the spinal level, higher brain centers have the ability for modification with voluntary movements. Schmidt and Lee (1999) have suggested two basic systems of motor control. One is via the closed-loop system where movement is continually updated and modified on the basis of feedback through muscle spindles, GTOs, joint, skin vestibular and visual receptors (Fig. 1.1a). The alternative is through open-loop control systems where movement is controlled by means of higher CNS centers independent of sensory feedback (Fig. 1.1b). Movements are preplanned and performed without deliberation of sensory feedback, which may be too slow to make adjustments to the movement, or are just not needed. Despite continuing debate regarding these two theories, Hodges (2003) has suggested that motor control maybe a hybrid of these two theories.

Physiologic mechanisms underpinning motor skill acquisition: Cortical plasticity

The acquisition of skills is associated with changes in the brain's neural networks, otherwise known as plasticity, or functional reorganization (Donoghue 1995; Kaas 1991). Cowan *et al*. (1985) have suggested that in early life, plasticity occurs through regression of neuronal networks, with up to 50% loss in neurons in brain structure studies. By approximately 3 years, this regression is almost complete with children having a basic ability to modify or control grips and load forces, which by 6–8 years becomes much more adult-like (Forssberg *et al*. 1995). Importantly, neurophysiologic research has demonstrated CNS plasticity in healthy (Pascual-Leone *et al*. 1994, 1995) and diseased adults (Byrnes *et al*. 1999), showing that acquisition or reacquisition of motor skills is possible throughout the life cycle. These findings are contrary to the earlier neuropsychologic learning theories of Freud and Piaget, which viewed neural growth and development as virtually complete by mid to end of adolescence. CNS plasticity is achieved through the process of long-term potentiation (LTP) where changes are activity dependent; synapses will strengthen (or weaken in the case of long-term depression) depending on the strength of the stimuli from practice. For more information on LTP the reader is directed to Leonard (1998) and Perkins and Teyler (1988).

Mechanisms to suggest plastic changes from skill acquisition include the establishment of new connections and/or alterations of the effectiveness of previously existing connections (Donoghue 1995; Kaas 1991; Pascual-Leone & Torres 1993). However, cortical plasticity seen with older children and adults suggests that it is likely changes occur in pre-existing connections that are normally present but physiologically silent (Leonard 1998). Neuro-imaging studies have demonstrated plasticity in the motor cortex in highly skilled adult athletes and musicians who have undertaken structured motor skill acquisition and reinforcement (Elbert *et al*. 1995; Pearce *et al*. 2000). Elbert *et al*. (1995) demonstrated changes in the motor cortex representation in the fingering hand but not the bow hand of skilled violin players. Similar findings have also been identified by Pearce *et al*. (2000) who found differences in the motor cortex (plasticity) and increased neural excitability to the playing hand in elite, but not recreational badminton players. These researchers suggested that the presence of structured practice was the stimulus for the observed changes in both the elite athlete group and in highly skilled musicians.

Physiology of motor learning

A number of sequential models, such as Gentile's (1972, 1987, 2000) two-phase model and the popular Fitts and Posner (1967) three-phase model, are outlined below describing the stages of an individual learning a motor task. More recently, these stages of learning have been used to demonstrate changes in the individual's neural strategy (muscle activation patterns and motor commands) reflecting cortical plasticity. For example, changes in whole muscle activation patterns (reflecting motor learning) using electromyography (EMG) have been demonstrated in a number of sports and activities (Kamon & Gormley 1968; Vorro *et al*. 1978; Jaegers *et al*. 1989; Williams & Walmsley 2000). These studies have shown that during initial stages of skill acquisition (*cognitive* stage) the individual uses muscles inappropriately by both activating excessive or redundant muscle groups, and activating muscle groups with incorrect timing. However, as practice continued (*associative* to *autonomous* stages) the number of muscles activated decreases to a minimal (or optimal) number required to perform the skill effectively, and the timing of muscle activation became appropriate (Magill 2003). Similar findings have been demonstrated in motor unit recruitment where variability in motor unit recruitment decreases with the acquisition and improvement of a motor skill (Moritani 1993). These authors have also shown changes in motor unit firing frequency following specific practice of skills requiring fast movements.

TIME COURSE OF MOTOR LEARNING

From a practical point of view an area of great interest for coaches concerns the time it takes to learn skills (Baker *et al*. 2003). Ericsson *et al*. (1993) have suggested that it takes approximately 10,000 h (or 10 years) of deliberate practice for a high performance athlete to be developed. However, this view has been questioned recently, with researchers suggesting that approximately 69% of all senior national level athletes had 4 years of experience or less in that sport (Oldenziel *et al*. 2003, 2004). However, these authors noted that these "*quick learners*" had played at least three sports (3.3 ± 1.6) before settling on their main sport, a fact in stark contrast to the limited prior sporting experiences (0.9 ± 1.3) of those athletes who had taken 10 or more years to achieve a similar level of performance.

Theories of motor skill acquisition

Plasticity of the neuromuscular system allows for the acquisition of skills throughout the life cycle. Plasticity is dependent on activity, providing stimulation to strengthen neural pathways to facilitate LTP. Although the old saying "practice makes perfect" holds true to a certain extent, when training for skill acquisition, practice and repetition are not the only variables to consider. To optimize training for skill acquisition, a number of authors have suggested that it is important to understand the conditions that athletes practice under. For example, the type and amount of feedback presented, the grouping and sequencing of practice, and the type of sensory feedback provided all influence the acquisition and retention of motor skills (Leonard 1998; Magill 2003; Schmidt & Lee 1999).

Grouping of practice sessions

BLOCK VERSUS RANDOM PRACTICE

A common question among the coaching fraternity is whether it is better to practice a skill repetitively within a practice session, or whether it is preferential to mix up skills during the session. The former is often referred to as blocked (or massed) practice, while the latter is described as random practice. A typical blocked practice session involves athletes practicing one skill (more skills may be involved but they are practiced independently of each other) in a session with relatively low contextual interference (Battig 1979). Conversely, random practice sessions involve a multiple number of skills practiced simultaneously (or under tactical conditions) and present athletes with higher contextual interference (Battig 1979). Table 1.2 provides an example of the differences between these two types of practices for a racquet sport.

Research has shown that blocked practice sessions result in faster skill acquisition of complex motor skills (Shea *et al*. 1990), most likely as a result of strengthening of the effectiveness of an existing (but singular) neural pathway (Leonard 1998). However, a large number of studies have shown that random practice results in greater skill retention and adaptation to the sporting environment than blocked practice (Shea & Morgan 1979; Goode & Magill 1986; Hall *et al*. 1994; Landin & Herbert 1997). Leonard (1998) has suggested that this is due to LTP of the skill among a number of neural pathways rather than a singular circuit. In recognizing the value of random practice studies, Rose and Christina (2006) noted that practice sessions should be sport-specific and practice conditions should reflect *real-world* sports

Table 1.2 Example differences between blocked and random practice styles in tennis. The emphasis is on technical development; however, the practice environment differs greatly between the two practice styles. Under random practice, the coach will facilitate skill learning with questions and addressing technical problems within a tactical framework.

Blocked practice	Random practice
Forehand crosscourt Ball racquet feed* from coach to player's forehand side Player to return ball to predesignated area (marked by cones)	*Zone rally* Rally started with courtesy feed (underarm) from player (or coach) to opponent Rally progresses with a point awarded to the player who can hit a winning or unreturnable forehand. No points given for errors
Service practice Classic service practice into open service box No return from an opponent or coach	*Service rally* (3 shot rally) Player practices service but under realistic conditions (i.e. with return of serve) Three shot rally includes service (shot #1), return (shot #2), and first shot after return (shot #3) Player is instructed to create serves to force weak return from opponent (from good placement of serve) and to set up aggressive third shot after return (ground stroke or volley)
Closed rally drill Players will hit only one shot (e.g., backhand cross-court) and instructed to keep the cross-court rally going for as long as possible	*Open rally game* Player gives courtesy feed (underarm) with both players rallying full court to create winning situations. Points awarded for tactical awareness One point: Winning point when opponent makes unforced error Two points: Forcing opponent into error Three points: Hitting outright winning shot

* Also known as "*dead-ball*" drill training.

settings in order to reinforce the skill in a relevant context.

PRACTICE VARIABILITY

Closely linked with random practice is the issue of practice *variability*. Practice variability refers to providing and structuring a practice environment for the learner to apply different parameters, or variations of a motor skill (e.g., in tennis, adapting different swing patterns for low or high bouncing on-coming balls). A number of studies conducted in the 1970s and 1980s (Catalano & Kleiner 1984; Margolis & Christina 1981; McCracken & Stelmach 1977) have demonstrated that variability in the acquisition of a new motor task facilitates transfer of that learning to a similar but novel task. Sports-specific training is important in this regard as studies have shown that practicing variable movement patterns must relate to the performance of that skill (Leonard 1998).

From a practical point of view, the issue of whether to *block* a practice session or to use a *random* style creates a considerable problem for coaches. For example, blocked practice sessions are themed, sequenced smoothly, and athletes tend to improve skill execution during the course of training. Many coaches prefer these sessions because training *looks good*, and sessions are *easier* to plan. In addition, coaches can provide repetitious models, based on their own experiences from which their athletes copy, despite the limited skill retention that tends to occur (Roetert *et al*. 2003). Similarly, some players have been so conditioned by the blocked practice approach that they almost require drills to be performed in a routine order before they can produce a certain skill. This is an obvious problem for performance situations. Typically, excessive use of blocked style training results in the "*We can do it at training, so why can't we do it in the game*" syndrome, which is frustrating for both coaches and athletes alike.

Random style training sessions provide a different set of problems for coaches. While there is little question that random style training results in better skill retention, some coaches, especially those conditioned to using blocked training, are still reluctant to implement it. Even coaches who profess to using both forms of practices generally demonstrate a reliance on repeated closed environments and progress to open environments slowly. Clearly, some coaches need to have the courage to forgo the *perfect looking* training session, in favor of training that may not look as good, but results in genuine skill acquisition.

PART VERSUS WHOLE PRACTICE

Whole practice describes situations where the learner practices the entire skill (movement pattern) from the outset, while *part* practice occurs when the various components of the skill are learned thoroughly first. Considerable debate continues regarding the effectiveness of one over the other. A complicating factor in much of this research has been the choice of skills examined, as it is generally agreed that the type of skill required will dictate whether it is learned best using part or whole methods (Naylor & Briggs 1961; Wightman & Lintern 1985). Rose and Christina (2006) have recommended that complex movement patterns, involving the combination of many individual skills (e.g., gymnastics floor routine), should be taught using the *part* method. Conversely, less complex but highly organized skills (e.g., hitting a baseball) are better suited to the *whole* method.

The *whole–part–whole* practice model is an extension from both the *whole* and *part* practice methods (Swanson & Law 1993). In the *whole–part–whole* model, the subject is provided with the skill in its entirety before having it broken down into parts and taught using the segmentation, simplification, or fractionization methods (Wightman & Lintern 1985). The skill is then taught as a whole a second time to complete the understanding process (Swanson & Law 1993).

Many successful skills coaches prefer to use *whole* or *whole–part–whole* style training, with very few selecting *part* style training during complex technique or skills sessions. One of the key advantages of *whole* and *whole–part–whole* style training over *part* training is the fact that it enables skills to be expressed in the context in which they are to be performed. Whether from an individual or team skill perspective, focusing on just one of the components of a skill ignores the important interaction effects. A traditional approach in some sports has been to focus excessively on the movements of each of the individual segments before "*putting the skill together*" (*part* training). That is, many skills (e.g., kicks, hits, or throws) involve movement of multiple body segments where the coordination, sequencing, timing, and forces produced at each segment must all be optimized for the skill to be executed successfully. For example, the knee extension velocities achieved at ball contact in kicking (approximately 25 rad · s^{-1}) occur primarily through the actions of the preceding segments (e.g., pelvic tilt and rotation, hip flexion) and not through a forceful knee extension via the quadriceps (Davids *et al*. 2000; Lees & Nolan 2002; Lees *et al*. 2005; Robertson & Mosher 1985). Therefore, training drills that isolate the knee extension action and focus on the use of a forceful contraction of the quadriceps actually bear little resemblance to the kicking action. Several coaches still persist with the latter, but their athletes often have problems such as "*My athlete has performed this kicking drill well, but how come he can kick only 30 m?*" A similar argument can be developed for the use of *whole* or *whole–part–whole* style training for game moves practice sessions (i.e., moves from set pieces in football, rugby, basketball, etc.). That is, while each move involves several players all executing individual tasks, it is the coordination of these actions into the whole that determines the game move's overall effectiveness.

Role of feedback

While practice and repetition are integral components of the skill acquisition process (Newell & Rosenbloom 1981), it is important to realize that practice itself does not guarantee that learning will be either maximized, or occur at all. For example, in a classic study by Bilodeau *et al*. (1959) it was shown that the absence, or removal of feedback during a simple movement task had a direct effect on the execution of that task with practice (Fig. 1.2). While providing somewhat of a simplistic view, this study highlights the important role that feedback has in the skill acquisition process. However, this research did not address other key issues such as "*What sort of feedback should be provided?*" and "*What is the optimal time to provide feedback?*"

There are two basic types of feedback: knowledge of performance, where feedback provides information

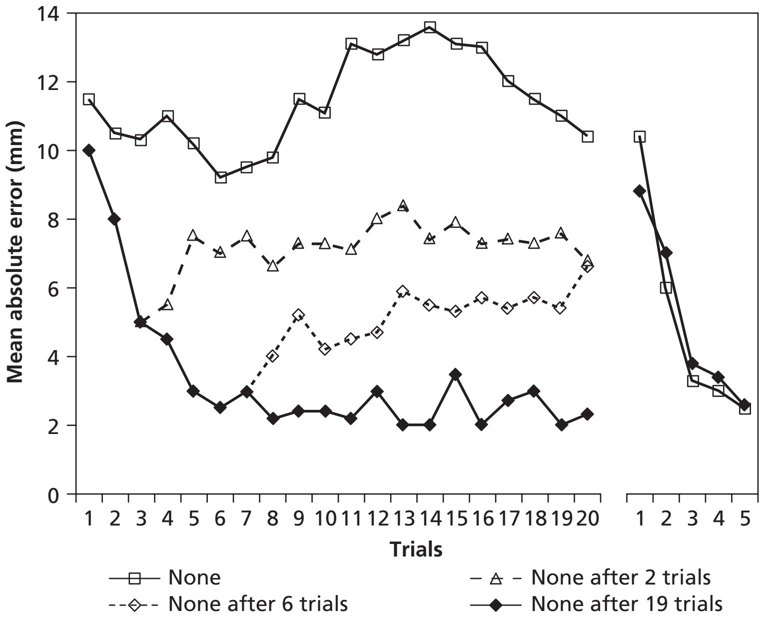

Fig. 1.2 Error in reproducing a simple movement as a function of the amount and type of feedback provided. Following a pause, subjects from the *None* and *None after 19 trials* groups were retested over five trials, but with both groups being given feedback after each trial. (After Bilodeau *et al*. 1959.)

regarding the ongoing sensory or perceptual information provided during the movement, and knowledge of results, providing feedback on the outcome of the movement. Feedback is also obtained *intrinsically* through visual, auditory, or kinaesthetic processes and/or *extrinsically* from the coach or an observer. However, these two processes are not interdependent.

Coaches may often provide excessive feedback or feedback that lacks specificity. The level of feedback needs to be congruent with the skill level of the performer, as less skilled performers are likely to experience overload if too much, or too precise levels of feedback are provided (Magill & Wood 1986; Smoll 1972). It is important here to note that simple praise (e.g. "good shot") is not a true form of feedback, and has been shown to be largely ineffective (Kulhavy & Wager 1993). Research findings have demonstrated that feedback was more effective when provided from the learner's perspective (Magill 1993; Schmidt 1991) because the acquisition of motor skills relies on both internal and external sensory feedback. The *amount* and *timing* of extrinsic feedback is also important (Ho & Shea 1978; Reeve & Magill 1981). Williams and Hodges (2005) have suggested that disproportionate amounts of extrinsic feedback, stemming from the timing of the feedback (almost immediately after the skill has been executed), may incur an overreliance by the player on the coach and impair the learner's problem-solving processes. Table 1.3 illustrates some feedback examples that coaches can use to facilitate independent thinking.

Instruction versus demonstration

A fundamental issue in coaching is to provide verbal instruction or visual demonstrations (or a combination of both). There is considerable inconsistency regarding the effectiveness of verbal feedback versus visual demonstration. For example, Magill and Schoenfelder-Zohdi (1996) have suggested that visual information is superior to verbal instruction, while other researchers have indicated that the combination of verbal instruction and visual demonstration is far superior to the use of verbal feedback alone (McCullagh *et al*. 1990; Weiss & Klint 1987). Moreover, other researchers have suggested that verbal instructions do not have a positive influence on the learning process (Hodges

Table 1.3 The use of questioning as a form of feedback in comparison to traditional instructions. In order to reduce the potential for overreliance, coaches can pose questions rather than prescriptive feedback to assist learning from the player's perspective. The examples below pertain to racquet sports such as tennis and badminton, but can be adapted for other sports.

Coach's questions	Traditional instructions
When is the best time to go for a winning shot?	When the opponent is out of position I want you to go for it, and put the ball away
In this game, were more points won on outright winners or opponent's errors?	In that game most of your points were won due to your opponent's errors
On a scale of 1–5 (5 being great and 1 being poor), how would you rate your balance during those last couple of forehands?	Your balance was a little off in that last rally, next time keep your weight on the balls of your feet, widen your stance slightly, and stay low
On a scale of 1–5 (5 being great and 1 being poor), how would you rate your weight transfer in those last serves	You are transferring your weight really well. However, make sure that you keep finishing here though (coach points to a position on court)
What are some ways to make it easier for you to play angled cross-court shots?	For all your cross-court shots make sure that you take the ball early and hit it out in front of the body
If your opponent hits short cross-court and is out of position, what would be the best choice of shot?	Hit the ball down the line when your opponent hits his or her cross-court shot short

& Lee 1999; Masters 1992; Wulf & Weigelt 1997). Williams and Hodges (2005) noted that for precise replication of a technique, demonstrations were preferred, as these played a significant part in aiding motor learning (Haguenauer *et al*. 2005; Magill & Schoenfelder-Zohdi 1996). Hodges and Franks (2002) also indicated that demonstrations were effective particularly when the activity being taught was based on combining movements for which the athlete had a prior degree of proficiency. However, in situations involving novice learners it was important to provide some verbal instruction to avoid either overload, or the learner may attend to inappropriate cues during the demonstration (McCullagh *et al*. 1990; Weiss & Klint 1987). Further, demonstrations may be less effective when used to try and refine an existing movement pattern (Horn & Williams 2004). From a coaching perspective, the combination of verbal instruction and demonstration is desirable for most sports, but it does depend on the type of skills being taught, and the level and motivation of the athletes being trained.

Implicit versus explicit perceptual learning

Perceptual skill learning is a relatively new area in the motor skill acquisition literature and has become fashionable in many coaching circles. Underpinning the issue of perceptual learning is the concept that expert performers have an enhanced cognitive knowledge of their sport. This is based on their ability to recognize cues of relevance and patterns of play, superiority in anticipating opponent's actions, and greater accuracy in expectations of what is likely to happen given a particular set of circumstances (Williams & Grant 1999). This expertise is developed primarily as a result of long-term sport-specific experience. However, Abernethy (1993) explored the concepts of whether there were any potential training methods that could be employed to enhance the development of perceptual skill in sport as an alternative to years of task-specific practice.

A key issue within the perceptual skill acquisition domain is the importance of implicit versus explicit learning processes (Magill 1998; Williams & Grant 1999). The arguments surrounding this issue center on whether skill learning is superior when training is based on the learner's internal *feel* and experience (implicit), rather than sessions based on instruction and external feedback (explicit; Gentile 1998; Jackson 2003). The relative merits of each of these training methods have been the subject of considerable debate, with some researchers heavily in favor of implicit training (Masters 1992, 2000), while others emphasize that explicit knowledge has an important role in the learning process (Beek 2000).

The issues surrounding the implicit versus explicit debate have resulted in a great deal of confusion. Apart from the difficulty in conducting interference-free research in this area (Jackson 2003), there is also conflict regarding study design and the applicability of these findings to the training environment (Farrow & Abernethy 2002, 2003; Jackson 2003). From a practical point of view, a major failing of this research is that it tends to promote a bias towards either the implicit or explicit concepts, with many researchers even suggesting the explicit instruction is counterproductive to the skill learning process (Horn & Williams 2005). Such a bias can lead to confusion in skills coaches who must operate in an environment more flexible than that used to meet research methodologic constraints (e.g., coaches must deal with athletes at vary stages of skill development, and over a wide range of contexts).

Regardless of the arguments for and against implicit versus explicit practice, many successful skills coaches lean towards an implicit model in their coaching, while selectively using explicit methods to great success. One important constraint of research in this area relates to the fact that few implicit training studies have been conducted on highly experienced or elite level athletes (i.e., groups with high explicit knowledge of their sport). In particular, an interesting problem arises when coaching a high level athlete who develops a technical problem that interferes with performance (e.g., a golfer who develops the "*yips*" when putting, a rugby goal kicker who starts to push the ball to the right of the posts). It is not uncommon for these athletes to have a great deal of difficulty "feeling" this technical flaw (especially if they have had the error for a long time), negating the effectiveness of using a purely implicit approach during technique correction. In this case, some explicit instruction can often result in very rapid improvements. It appears that both methods sit along a continuum that although favoring the use of implicit practices, must also acknowledge the role of explicit instruction in skill development.

Mental imagery

The bridge between neuropsychology and neurophysiology is demonstrated through the relationship of mental rehearsal, or imagery, and their affect on motor skill acquisition. For example, a number of studies have shown that similar neural circuits and cerebral cortex activation patterns are involved during both mental rehearsal and the performance of the motor skill (Decety 1996; Grafton *et al*. 1996; Jeannerod 1995; Sirigu *et al*. 1996). This provides a possible explanation as to why mental practice using imagery can result in athletic motor performance improvements (Feltz & Landers 1983). However, some differences exist between mental imagery and actual performance, in particular when an individual is performing simple or complex motor skills. Bennet (1997), in research using non-invasive neuroimaging techniques, suggested that during the performance of a simple motor skill an area within the sensorimotor cortex becomes active. However, when a more complex motor skill was required, a secondary motor area (the supplementary motor area [SMA]) becomes active at the same time. During mental imagery performance of the same complex motor skill (without muscular activity) only the SMA is active. This may have implications for coaches to reinforce the value of mental imagery to their athletes in training complex skills pertinent to their sport, as well as to injured athletes who maybe unable to perform the skills physically. For more information regarding the link between mental imagery and the neuromuscular system the reader is referred to Lotze and Halsband (2006).

Physical fatigue and muscle damage

Despite studies dating back to the 1970s suggesting otherwise (Carron 1972; Thomas *et al*. 1975) it is relatively common to observe athletes practicing motor skills while in a state of physical fatigue, or for coaches to follow up heavy or intense training sessions by programing "light" training based around skill acquisition. Research has demonstrated that motor skill acquisition and performance is affected following fatiguing exercise. Arnett *et al*. (2000) showed that anaerobically induced fatigue had a detrimental effect on gross motor skill acquisition. Similarly, although Lyons *et al*. (2006) demonstrated significant detriments in passing performance following fatiguing exercise in both novice and elite basketball players, the decrements in the elite players were not as great as those of the novices. Other studies measuring motor skill decrements have used fatiguing exercise involving eccentric exercise, which produces muscle damage (Pearce *et al*. 1998; Saxton *et al*. 1995), and concentric exercise that fatigues muscle but does not cause as much damage (Bottas *et al*. 2005; Walsh *et al*. 2004). Saxton *et al*. (1995) and Walsh *et al*. (2004) showed position errors in a subject's arm when matched to their non-exercised arm. Despite different time course measures, similar results were found in both eccentric exercise and concentric exercise. Pearce *et al*. (1998) demonstrated that following eccentric exercise subjects exhibited both greater error in a subsequent visuomotor tracking task and reduced motor skill proficiency than control subjects (Fig. 1.3). Further studies correlated these errors with a drop in muscular force (Pearce *et al*. 1998; Walsh *et al*.

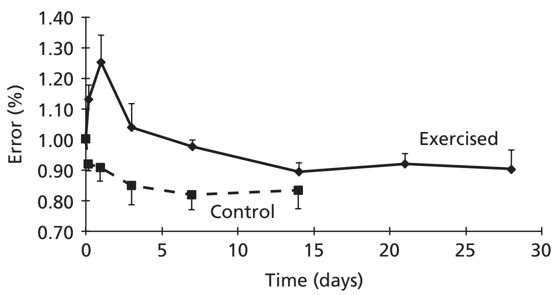

Fig. 1.3 Comparison of change in tracking error in exercised (solid line) and control subjects (dashed line) normalized to initial values. A score lower than 1 shows improvement, whereas values greater than 1 shows greater error (Pearce *et al*. 1998).

2004). Using EMG, Bottas *et al*. (2005) found that reduced force from fatigued muscles impaired activation patterns of agonist and antagonist muscle groups, as well as reduced position sense from muscle damage, contributing to decline in the motor skill task.

Although further research needs to be conducted in the area of fatigue and motor skill training, the coaching implications of this research indicate that undertaking developmental skill-based training sessions with fatigued athletes is contraindicated. Therefore, developmental skills training should precede voluminous or intense training sessions. Contrary to this view, many high performance coaches use light skills-based sessions as a means of active recovery (e.g., the day after an international football match). While this practice should probably be avoided in novice athletes it does not appear to interfere with the skill levels of high performance athletes.

Conclusions

This section has provided a brief overview of the physiologic, biomechanical, and psychologic components underpinning motor skill acquisition. Recent advances in neurophysiology have shown that skill acquisition can occur at any stage of the life cycle, rather than occurring only when athletes are young. For the coach, the main issue is to understand the processes underpinning motor learning and motor control, as well as creating the optimal environment to improve and maintain the athlete's technical skill base. The areas of motor learning, skill acquisition, and motor control are complex and challenging areas which are continually expanding. Results from future studies will provide coaches with more information enabling them to program training practices more effectively and enhance the skill level of their athletes, regardless of chronologic or training age.

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